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LIST OF CONTRIBUTORS

J. L. BENNETT, Manager, Chemical Operations, Explosives Department, Hercules Powder Company. *Plant Operation and Control.*

O. F. BENZ, Sales Consultant, E. I. du Pont de Nemours & Company. *Consumer Marketing.*

HARDING BLISS, Ph.D., Professor of Chemical Engineering, Yale University. *Data for Cost Estimation.*

R. P. GENEREAUX, Ch.E., Assistant Manager, Design Division, Engineering Department, E. I. du Pont de Nemours & Company. *Plant Design.*

R. A. KINCKINER, Ch.E., Assistant Director, Engineering Research Laboratory, Engineering Department, E. I. du Pont de Nemours & Company. *Operative Investment.*

ROBERT V. KLEINSCHMIDT, Sc.D., Consulting Engineer. Professor, Harvard Graduate School of Engineering. *Heat and Power.*

RICHARD M. LAWRENCE, M.S., Development Department, Monsanto Chemical Company. *Market Research.*

PAUL D. V. MANNING, Ph.D., Vice-President in Charge of Research, International Minerals and Chemical Corporation. *Research.*

W. H. MCADAMS, S.M., Professor of Chemical Engineering at the Massachusetts Institute of Technology. *Economic Balance.*

A. R. PLUMLEY, LL.B., Manager, Patents Section, Ammonia Department, E. I. du Pont de Nemours & Company. *Patents.*

ELMER F. SCHUMACHER, Director of Sales, Ammonia Department, E. I. du Pont de Nemours & Company. *Industrial Marketing.*

CHAS. R. SCHWARTZ, Manager, Control Division, Ammonia Department, E. I. du Pont de Nemours & Company. *Cost Accounting.*

CHAPLIN TYLER, S.M., Member, Development Department, E. I. du Pont de Nemours & Company. *Characteristics of the Chemical and Allied Industries; Development; Market Development; Organization; Management.*

J. L. WARNER, C.E., Retired Executive, E. I. du Pont de Nemours & Company. *Plant Location.*

ROGER WILLIAMS, JR., B.A., Assistant Editor, *Chemical Engineering, Standardizing Cost Data on Process Equipment.*

CHEMICAL ENGINEERING ECONOMICS

by CHAPLIN TYLER, S.M.

Member, Development Department
E. I. du Pont de Nemours & Company
Lecturer in Chemical Engineering Economics
University of Delaware

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PREFACE

To the practitioner of chemical engineering the question, "Will it pay?" is as vital as the question, "Will it work?" Economic as well as technical factors are present in every phase of the chemical engineer's work, whether the task be concerned with research, process development, plant design, production, marketing, or general management.

The third edition is directed toward assisting the chemical engineer in dealing with the economic aspects of his work, as were the first and second edition. Particular emphasis is put on topics that readers of previous editions have stressed over the past twenty-two years; for example, the objectives, organization, and administration of research and development; the evaluation of new products and processes in terms of cost, price, investment, and financial return; the fundamentals of plant design and the achievement of low-cost plant facilities; the role of the chemical engineer in production; the evaluation of markets and the mechanism of industrial and consumer-products marketing; the principle of economic balance in design and operation; the essentials of cost accounting; pertinent aspects of patent law; and certain aspects of management relating to the chemical engineer's work. Virtually the entire text has been rewritten and is, therefore, practically speaking, a new book.

This new material and fresh point of view have been made possible largely through the painstaking effort of the fourteen contributing authors to whom the editor wishes to express his thanks.

CHAPLIN TYLER

WILMINGTON, DEL.
February, 1946

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CHAPTER I

CHARACTERISTICS OF THE CHEMICAL AND ALLIED INDUSTRIES

By Chaplin Tyler

Production may be classified into the following groups:

1. Agricultural production (products of the soil and of animal husbandry).
2. Extractive production (products of the mine, forest, and sea; as for example, coal, metallic minerals, petroleum, natural gas, sulphur; timber; fish).
3. Factory production.

There is, of course, much integration within these groups. For example, many producers of petroleum refine part or all of their primary crude production. Similarly, many producers of metallic minerals operate smelters and mills for winning and fabricating metals. Forestry already is becoming an agricultural pursuit, as, for example, the growth of pulpwood in the South.

Factory Production Classified.—Factory production in turn may be classified into two groups:

1. Production based essentially on change in physical form.
2. Production based essentially on change in chemical form.

Examples of the first group are such manufactures as automobiles, furniture, machinery, shoes, and textiles. Thus, the automobile is an assemblage of hundreds of materials and fabricated parts—metals, wood, glass, fabric, plastics, rubber, finishes—all of which can be identified in the ultimate product. There has been no change of substance, only a change in physical form.

Examples of the second group are such manufactures as synthetic ammonia, dyestuffs, plastics, soda ash, and sulphuric acid. Thus, nitrogen from the atmosphere and hydrogen from water are combined to form a third substance, ammonia.

Such distinctions are perfectly clear. Some industries, however, are not so easy to classify. Thus, in the tanning industry, the hide, though coagulated, does not undergo a complete transformation. The leather "molecule," if one might use such designation, is an addition product of the protein hide substance and the tanning agent. In the petroleum industry, some processes are physical—for example, dewaxing, filtration, and solvent refining. These are separation processes and involve little or no chemical change. In the cracking process, however, higher hydrocarbons are broken down chemically into lower liquid hydrocarbons, gas, and coke. Polymerization, the reverse of cracking, is a more recently applied chemical process for producing liquid hydrocarbons from gaseous hydrocarbons. Likewise, the treating processes based on such reagents as sulphuric acid, caustic soda, and sodium plumbite are chemical processes.

Ordinarily, the metallurgical industries are not classed as chemical industries, yet they depend upon chemical reactions. Examples are the smelting of copper, iron, lead, zinc, and other metallic ores. The electrolytic winning of aluminum is just as much a chemical process as the electrolysis of aqueous salt to chlorine, caustic soda, and hydrogen.

Sugar refining is largely a physical process industry, yet chemistry plays an important part in various steps, as in purifying the sirup and in sugar recovery from beet molasses. A similar condition is found in the corn products industry. The recovery of starch from the corn is a physical process, assisted by chemical treatment. However, the conversion of corn starch to corn sugar is a chemical process.

In the cotton textile industry, the basic processes of spinning, knitting, and weaving are physical, although such finishing processes as bleaching and mercerizing are chemical. In the rayon branch of the textile industry, the processes of fiber manufacture are chemical as well as physical.

Scope of Chemical and Allied Industries.—If one were to classify as "chemical" all manufacturing industries in which chemical change rather than physical change is predominant, the list would include not only chemicals as such—that is, distinct chemical entities such as acids, alkalies, salts, gases, oxides, synthetic organic compounds, and solvents—but the following branches as well:

Carbon black.
Cement and plaster.
Ceramics and glass.
Coal distillation.
Corn sugar.
Explosives.
Fermentation industries.
Fertilizer compounds.
Fuel gas generation.
Glue and gelatin.
Leather.
Lime.
Metals smelting and alloys—ferrous and nonferrous.
Oil hardening (hydrogenation).
Petroleum refining.

Pigments.
Rubber.
Soap and glycerin.
Synthetic fibers.
Synthetic resins.
Wood distillation.

These industries comprise approximately 20 per cent of the value of product of all manufactures.

In addition, there are industries in which chemical change plays an essential but not predominant part:

Animal and vegetable oils.
Coated fabrics.
Cosmetics and perfumes.
Paint, varnish, and lacquer.
Pulp and paper.
Sugar and starch.
Natural dyestuffs and tanning agents.
Wood naval stores and gum naval stores.

These two lists approximate the industries covered by standard works on industrial chemistry, as for example, "Read," "Rogers," and "Shreve."

As pointed out in Chap. XII, the U.S. Census of Manufactures is one of four major statistical sources of interest to the chemical economist. The 1939 Census covered approximately 250,000 manufacturing establishments classified into 20 major groups and 470 subgroups. One of these major groups is "Group 9—Chemicals and Allied Products," which in 1939 comprised the subgroups shown in Table I.

The reader will note immediately that the industries comprising Group 9 are considerably less inclusive than the classification outlined in this chapter. There are several reasons for this disparity: In general when a well-defined industry becomes large, it is accorded individual characterization as a census group. Thus, paper and allied products, products of petroleum and coal, rubber products, leather and leather products, stone, clay and glass products, iron and steel, and nonferrous metals are treated as major groups and as such are not included in Group 9.

The cement and lime industries are subgroups of "Group 13—Stone, Clay, and Glass Products." Coated fabrics, which the Census characterizes as "Artificial Leather and Oilcloth" is a subgroup of "Group 3—Textile Mill Products and Other Fiber Manufactures." Beet sugar, cane sugar refining, distilled liquors, baking powders, yeast and other leavening compounds, cooking and other edible fats and oils, not elsewhere classified, and corn sugar, corn oil and starch are in "Group 1—Food and Kindred Products."

Statistical Aspects of the Group.—Despite these differences in scope, the fact remains that Group 9 is an official classification which is particularly convenient as a basis for statistical studies. As indicated by Table I, the most recent comprehensive Census of Manufactures was for the calendar year 1939, prior to which biennial reports had been issued for 20 years. The Census undoubtedly will be resumed on a considerably expanded basis, that is, a "bench-mark" census of the old biennial type supplemented by annual reports based on a simplified schedule showing employment and value of product.

Although the Census of Manufactures has been suspended since 1939, industry has not been altogether without statistics. Data have been published by the Department of Commerce[1] showing the value of

Table I.—Census of Manufactures—1939
Group 9.—Chemicals and Allied Products

	Value of Product (Millions of Dollars)	
Total for Group		3,733.6
Paints, varnishes, and colors		518.8
Paints, varnishes, and lacquers	434.9	
Colors and pigments	83.9	
Animal and vegetable oils (not including lubricants or cooking and salad oils)		337.3
Cottonseed oil, cake, meal and linters	171.5	
Linseed oil, cake, and meal	68.0	
Soybean oil, cake, and meal	43.9	
Essential oils	9.8	
Fish and other marine oils, cake and meal	13.6	
Vegetable and animal oils, not elsewhere classified	30.5	
Drugs, medicines, toilet preparations, insecticides, and related products		605.9
Drugs and medicines (including drug grinding)	365.0	
Perfumes, cosmetics, and other toilet preparations	147.5	
Insecticides, fungicides, and related industrial and household chemical compounds	93.4	
Soap and glycerin		302.6
Rayon and allied products		247.1
Hardwood distillation, charcoal, and naval stores		38.3
Hardwood distillation and charcoal manufacture	6.8	
Wood naval stores	14.1	
Gum naval stores (processing but not gathering or warehousing)	17.4	
Fertilizers		185.7

[1] *Domestic Commerce*, August, 1946, p. 52.

TABLE I.—CENSUS OF MANUFACTURES—1939.—(*Continued*)
Group 9.—Chemicals and Allied Products

		Value of Product (Millions of Dollars)
Industrial chemicals		1,169.1
Tanning materials, natural dyestuffs, mordants, assistants, and sizes	42.2	
Coal-tar products, crude and intermediate	42.9	
Plastic materials	77.6	
Explosives	71.1	
Salt	27.5	
Compressed and liquefied gases—not made in petroleum refineries or in natural gas plants	53.4	
Bone black, carbon black, and lampblack	14.6	
Chemicals not elsewhere classified	839.8	
Miscellaneous chemical products		328.8
Printing ink	49.1	
Ammunition	29.1	
Cleaning and polishing preparations, blackings, and dressings	89.8	
Glue and gelatin	34.3	
Grease and tallow (except lubricating greases)	58.2	
Lubricating oils and greases—not made in petroleum refineries	49.1	
Fireworks	4.6	
Candles	6.3	
Bluing	1.1	
Mucilage, paste, and other adhesives, except glue and rubber cement	4.2	
Writing ink	3.0	

TABLE II.—VALUE OF PRODUCT OF BASIC CHEMICALS, ALLIED PRODUCTS AND RELATED COMMODITIES*
(Millions of Dollars)

Year	1939	1943†	1944†	1945
Basic chemicals	790.4	2,235.7	2,710.1	2,505.0
Allied products	2,507.4	4,662.9	5,074.9	5,556.3
Related commodities‡	411.4	667.6	667.2	625.2
Total	3,709.2	7,566.2	8,452.2	8,686.5
Estimated physical volume, 1939 = 100	100	174	195	200

* Value of products produced for sale or transfer from producing plant; no value is assigned to chemicals consumed where made.

† Revisions which were made in the previously published estimates for 1943 and 1944 are included in this table.

‡ These commodities were included with "Allied Products" in previous studies but are segregated here in order to conform more closely with the Census of Manufactures grouping for "Chemicals and Allied Products"; included in these commodities are lime, phosphate rock, potash, crude sulphur, candles, chemical cotton pulp, coated fabrics, flat glass and glass tableware, matches, and molasses.

TABLE III.—FINANCIAL STATISTICS OF 35 COMPANIES IN "CHEMICAL AND ALLIED INDUSTRIES"
(Thousands of Dollars)

	Net sales	Operating profit	Per cent of net sales	Net worth	Net income	Per cent of net worth	Fiscal year ended
Abbott Laboratories	$ 37,930	$ 9,873	26.1	$ 26,055	$ 3,157	12.1	Dec. 31, 1945
Air Reduction Co., Inc.	80,689	10,477	13.0	46,482	8,278	17.8	Dec. 31, 1945
Allied Chemical & Dye Corp.	275,003	39,210	14.3	191,303	18,025	9.4	Dec. 31, 1944
The American Agricultural Chemical Co.	34,885	4,434	12.7	22,726	1,741	7.7	June 30, 1945
American Cyanamid Co.	100,000*	14,456	14.5	77,304	6,213	8.0	Dec. 31, 1945
American Viscose Corp.	119,376	17,774	14.9	86,389	5,192	6.0	Dec. 31, 1945
Atlas Powder Co.	44,381	4,372	9.9	23,584	1,415	6.0	Dec. 31, 1945
Celanese Corp. of America	104,197	20,889	20.0	88,380	7,613	8.6	Dec. 31, 1945
Columbian Carbon Co.	27,244	5,452	20.0	32,669	3,352	10.3	Dec. 31, 1945
Commercial Solvents Corp.	40,285	6,550	16.2	23,618	2,033	8.6	Dec. 31, 1945
Davison Chemical Corp.	33,399	4,086	12.2	13,558	1,471	10.9	June 30, 1945
Diamond Alkali Co.	29,949	3,395	11.3	35,389	2,897	8.2	Dec. 31, 1945
Dow Chemical Co.	124,570	22,155	17.8	104,017	8,739	8.4	May 31, 1945
E. I. du Pont de Nemours & Co.	631,575	122,374	19.4	521,521	49,491	9.5	Dec. 31, 1945
Eastman Kodak Co.	301,502	52,752	17.5	207,203	32,716	15.8	Dec. 29, 1945
General Aniline & Film Corp.	68,659	10,374	15.1	54,720	3,901	7.1	Dec. 31, 1945
The Glidden Co.	111,616	6,998	6.3	35,116	2,348	6.7	Oct. 31, 1945
Hercules Powder Co.	100,556	16,301	16.2	44,624	4,926	11.0	Dec. 31, 1945
Heyden Chemical Corp.	17,156	4,276	25.0	12,018	1,403	11.7	Dec. 31, 1945
Hooker Electrochemical Co.	19,075	3,989	20.9	11,267	1,078	9.6	Nov. 30, 1945
Industrial Rayon Corp.	32,872	7,181	21.8	31,363	2,438	7.8	Dec. 31, 1945
Interchemical Corp.	44,100	2,177	4.9	20,510	1,036	5.1	Dec. 31, 1945
International Minerals & Chemical Corp.	30,301	3,124	10.3	27,576	2,038	7.4	June 30, 1945
Mathieson Alkali Works (Inc.)	19,590	2,271	11.6	24,300	1,149	4.7	Dec. 31, 1945
Merck & Co., Inc.	55,602	8,070	14.5	25,219	2,284	9.1	Dec. 31, 1945
Monsanto Chemical Co.	95,339	14,977	15.7	64,794	5,318	8.2	Dec. 31, 1945
Parke, Davis & Co.	54,665	16,137	29.5	33,418	7,763	23.2	Dec. 31, 1945
Pennsylvania Salt Manufacturing Co.	21,210	2,974	14.0	19,111	1,441	7.5	June 30, 1945
Pfizer (Chas.) & Co., Inc.	27,538	8,838	32.1	12,045	1,853	15.4	Dec. 31, 1945
The Procter & Gamble Co.	342,512	33,680	9.8	154,510	19,512	12.6	June 30, 1945
The Sherwin-Williams Co.	150,000*	13,257	8.8	60,200	5,065	8.4	Aug. 31, 1945
Union Carbide & Carbon Corp.	481,521	92,880	19.3	308,848	37,890	12.3	Dec. 31, 1945
U.S. Industrial Chemicals, Inc.	40,537	2,852	7.0	21,257	1,691	8.0	Mar. 1, 1945
Virginia-Carolina Chemical Corp.	33,425	2,788	8.3	26,277	956	3.6	June 30, 1945
Westvaco Chlorine Products Corp.	17,973	1,557	8.7	17,505	963	5.5	Dec. 29, 1945
Results for 35 companies	$3,749,132	$592,950	15.8	$2,504,676	$257,386	10.3	

* Estimated.

product of a number of key commodities allocated by the Chemicals Branch, War Production Board. Summaries are shown in Table II.

These figures are not strictly comparable with the Census figures, as they do not cover precisely the same industry groups. However, the comparison undoubtedly is closely indicative of the true total value of product, which in 1945 was approximately two and one-third times that in 1939.

The Census, of course, does not disclose the operations of individual companies. However, a great deal of information of this kind can be obtained from company reports as abstracted by various statistical services such as "Moody's" and "Standard and Poor's." Table III, for example, shows certain results for 35 companies which operate within the field of chemicals and allied products. With one exception, the list covers results for the calendar year 1945 or for the fiscal year 1945.

The 35 companies had combined net sales of $3.75 billion, representing approximately 43 per cent of the United States total of $8.69 billion indicated by the U.S. Department of Commerce figures for 1945. Combined operating profit of the 35 companies was $0.59 billion, or 15.8 per cent on sales, before deduction of federal income taxes. The range of operating profit was 4.9 to 32.1 per cent. After deduction of federal income taxes, a combined net income of $0.26 billion was earned, representing 10.3 per cent return on net worth of $2.50 billion. The range of net return was 3.6 to 23.2 per cent.

Industrial statistics of this kind can be used to sample national output, thereby obtaining data for years in which there are no census figures. Such a study was made by Michael Pescatello for *Chemical Industries.*[1] Pescatello found that sales of 29 companies in 1945 amounted to 2.4 times sales of the same 29 companies in 1939. This it will be noted is the same ratio of value of product shown in Table II, namely $8.69 billion in 1945 vs. $3.70 billion in 1939. A summary of Pescatello's study is shown in Table IV.

TABLE IV.—SUMMARY FOR 29 CHEMICAL COMPANIES
(Millions of Dollars)

Year	Sales	Net worth	Working capital	Net income
1945	2,389.8	2,091.7	1,118.9	211.3
1939	1,009.8	1,671.5	627.0	198.5

[1] *Chem. Ind.*, May, 1946, p. 773.

TABLE V.—CHEMICALS AND ALLIED PRODUCTS
Summary of Production, 1899–1945

Census year	Number of establishments	Number of wage earners, average for year	(Thousands of dollars)							
			Wages paid		Cost of materials, supplies, fuel, and purchased energy		Value of product	Value added by manufacture		
				¶		¶			¶	**
1945*	......	....	....	....	....	....	8,686,500	....	....	6.20
1943*	......	....	....	....	....	....	7,566,200	....	....	5.09
1941†	......	....	....	....	....	....	5,790,000	....	....	6.19
1939‡	8,263	286,371	356,783	9.7	1,826,275	49.4	3,699,014	1,872,737	50.6	6.51
1937§	7,419	314,520	381,405	10.2	1,927,948	51.8	3,721,531	1,793,583	48.2	6.13
1935§	7,419	276,434	285,875	10.1	1,448,832	51.1	2,837,315	1,388,483	48.9	6.30
1933§	6,527	237,480	220,771	10.4	968,473	45.7	2,117,513	1,149,041	54.3	6.92
1931§	7,444	230,370	263,271	9.9	1,255,459	47.3	2,650,635	1,395,176	52.7	6.65
1929‡	8,224	279,198	351,984	9.5	1,935,058	52.3	3,702,672	1,767,614	47.7	5.44
1927‡	7,500	252,106	316,027	9.5	1,782,569	53.8	3,315,228	1,532,659	46.2	5.48
1925‡	7,224	243,162	294,426	9.4	1,790,263	56.8	3,150,088	1,359,827	43.2	5.17
1923‡	7,129	244,950	286,836	9.9	1,682,215	58.2	2,894,731	1,212,515	41.8	4.98
1921‡	7,243	198,040	222,289	10.1	1,328,942	60.7	2,192,371	863,429	39.3	5.27
1919‖	10,604	295,892	308,936	9.3	2,117,949	63.5	3,331,971	1,214,022	36.5	5.54
1914‖	10,683	209,304	107,006	8.3	818,166	63.6	1,285,760	467,594	36.4	5.58
1909‖	10,302	186,844	82,788	8.1	615,319	60.0	1,027,090	411,771	40.0	5.15
1904‖	8,556	169,269	70,328	9.5	437,686	58.9	743,091	305,343	41.1	5.23
1899‖	7,883	151,537	54,235	10.1	314,329	58.3	538,601	224,474	41.7	4.88

* *Domestic Commerce*, August, 1946, p. 52.
† National Income Unit, U.S. Department of Commerce.
‡ Adjusted to "base years" by adding "Baking powder, yeast, and other leavening compounds" and deducting "Gum naval stores" and "Lubricating oils and greases."
§ Base years: as reported by Census of Manufactures, without adjustment.
‖ Includes establishments under $5,000 value of product.
¶ Per cent of "Value of Product."
** Per cent of Value of Product of "Chemicals and Allied Products" relative to value of product of *all* manufactures.

The study also shows that turnover (relationship of sales to net worth) was 114 per cent in 1945 compared with 60 per cent in 1939 and that net return (relationship of net income to net worth) was 10.1 per cent in 1945 compared with 11.9 per cent in 1939. Turnover was abnormally high in the chemical industry in the war years because of the extent to which production was forced. Ordinarily a 75 per cent turnover is considered good in chemical operations, whereas in manufacturing industry as a whole a turnover of 100 per cent or more is the rule.

In the 40 years 1899–1939 the value of all manufactures increased from $11 billion to $56.8 billion, an increase of more than fivefold. At the same time, the value of "chemicals and allied products" increased from $0.54 billion to $3.7 billion, or nearly sevenfold. Thus, the chemicals and allied products industry is growing more rapidly than manufacturing as a whole, a fact which is self-evident particularly with respect to such component branches as synthetic textile fibers, synthetic organic chemicals, and synthetic resins.

As shown in Table V, the proportional value of chemicals and allied products to the value of all manufactures increased from 4.9 per cent in 1899 to 6.2 per cent in 1939. U.S. Department of Commerce reports, previously cited, place the value of basic chemicals, allied products, and related products at $8.7 billion in 1945, which likewise is 6.2 per cent of the $140 billion value of all manufactures in that year.

The outstanding characteristic of the chemicals and allied industries is, of course, the chemical transformation that occurs during manufacture: the product is chemically different from its raw material. Moreover, chemical change must be preponderant in the basic processes of manufacture, not merely incidental. The fact that a printing plate is etched with acid does not qualify a printing establishment as a chemical plant.

Product and Process Obsolescence.—Another notable characteristic of chemical industry is the rapidity of technological progress. This does not mean that products are necessarily rendered rapidly obsolete, but rather that the processes and techniques by which products are manufactured are subject to change. Pyrolysis of wood, for example, was at one time the only source of methanol, acetone, and acetic acid for technical use. The output of these chemicals has increased enormously, and costs have been substantially lowered through modern syntheses. Thus the whole complexion of manufacture was changed within a period of some 20 years. Wood pyrolysis is today only a minor source of these chemicals.

The complexion of the plastics industry likewise has changed. However, this change is due to the addition of new members to the plastics family, rather than by complete displacement of older plastics.

Up to the time of Baekeland's basic patents on phenol-formaldehyde resins in 1909, only three organic plastics of any importance had been invented. These were hard rubber in 1854, plasticized cellulose nitrate in 1869, and casein-formaldehyde in 1897. As casein plastics were not made in the United States until 1919, there were only three commercial plastics as recently as the end of the First World War. Casein plastics and coumarone-indene resins were introduced in 1919.

However, in the decade 1920–1929, four products appeared: alkyd resins in 1926, and cellulose acetate plastic, urea-formaldehyde resin, and vinyl copolymers—all about 1929. In the next decade, 1930–1939, the number of major new plastics reached eight: ethyl cellulose, cellulose acetate-butyrate, the polyacrylates and methacrylates, polystyrene, nylon, polyvinyl acetals, polyvinyl alcohol, and polyvinyl acetate.

This brief chronology shows that the number of major plastics introduced doubled in each of the four decades beginning in 1900:

1900–1909	1
1910–1919	2
1920–1929	4
1930–1939	8

Developments since 1939 indicate that this progression will be maintained in the decade 1940–1949. These include polyethylene, polybutylene, interpolymers of butadiene with acrylonitrile and styrene, "silicone" resins, and polytetrafluorethylene.

It follows that such rapidly advancing and changing technology induces rapid obsolescence. Although physical exhaustion (wear and tear) is a significant factor in production costs, this component of depreciation is largely compensated by maintenance. Thus, only the portion of wear and tear that cannot be compensated by maintenance is charged to depreciation. Obsolescence comprises the larger portion of chemical plant depreciation. For example, analysis of a specific industrial operation showed that the composite depreciation rate should be 8 per cent on plant investment of $29 million, or an annual depreciation charge of $2.3 million, of which only $0.5 million or 22 per cent was attributable to wear and tear. The remaining $1.8 million or 78 per cent was attributable to obsolescence.

Wage, Profit, and Price Relationships.—Wage costs in the chemical and allied industries are shown in Table V. The ratio of wages to value of product in the 40 years 1899–1939 has been roundly 10 per cent, with a range of 8.1 per cent in 1909 to 10.4 per cent in 1933. For all manufactures, the average has been 16.5 per cent, with a range of 16 per cent in 1919, 1929, and 1939 to 17.9 per cent in 1921. Thus, wage costs are significantly lower in chemical and allied industries than in all manufacturing industry. Large-scale continuous processes operating "around the clock" under precise scientific control enable chemical industry to achieve a low ratio of direct labor cost to value of product.

Although the wage cost per dollar of product is less for chemicals than for all manufactures, hourly wage rates and weekly take-home pay are substantially higher. The steadily increasing complexity of chemical plant operations and consequent high degree of intelligence required account in part for the higher wage earned. The strong growth trend of the industry, relative freedom from violent cyclical changes, and good working conditions also are factors favorable to high earnings. The substantial premium earned by chemical workers is shown by the following figures:

Earnings	Year, 1939	March, 1946
Hourly earnings, chemicals	\$ 0.77	\$ 1.21
Hourly earnings, all manufactures	0.64	1.03
Weekly earnings, chemicals	31	51.14
Weekly earnings, all manufactures	24	42.14

It will be noted that in March, 1946, hourly rates were 17 per cent higher for chemicals than for all manufactures, and weekly earnings were 21 per cent higher.

Despite the higher wages, high depreciation, and high research expense, chemical industry in recent years has shown consistently higher net margins on sales, as shown by Table VI which is based on Department of Commerce figures.[1] In 1939, for example, the margin on chemical sales was 12.2 per cent compared with 6.5 per cent for all

TABLE VI.—NET MARGINS ON CORPORATE SALES

Year	Chemical industry, %	All manufactures, %	Ratio of chemical sales to all sales, %	Ratio of chemical profits to all profits, %
1929	10.7	7.2	5.7	8.5
1932	4.7	(4.2)	7.0	(Indeterminate)
1939	12.2	6.5	7.4	14.0
1941	16.2	12.4	7.2	9.3
1945	9.9	7.8	6.4	9.3

manufactures. While chemical sales comprised only 7.4 per cent of all sales, chemical profits comprised 14.0 per cent of all profits.

Prices.—Chemical prices are characterized by relative stability. Since 1921, the index of average wholesale prices for chemicals and allied products has been considerably less than for all commodities,

[1] *Survey of Current Business*, April, 1946, p. 9.

and in general the fluctuations have been smaller. Based on an index of 1913 = 100, chemical prices in 1929 were 117 vs. 137 for all commodities; this compared with 92 vs. 93 in 1932; 95 vs. 110 in 1939; and 121 vs. 161 in mid-1946. Thus, even under the inflationary conditions prevailing in 1946, chemical prices were up only moderately from the 1939 level. These index relationships are tabulated below:

Year	Index of prices	
	Chemicals	All commodities
1913	100	100
1929	117	137
1932	92	93
1939	95	110
1946	121	161

The price index for chemicals and allied products includes fats and oils, which if excluded would result in even greater stability for this group.

One reason for price stability in chemical industry is the facility with which the industry can adapt itself to alternative processes and raw materials. Thus, nitric acid manufacture no longer is subject to the ups and downs of the natural nitrate market; it uses synthetic ammonia, which during the past 20 years has moved progressively lower in price and progressively more abundant in supply. Another reason is the relatively large increment of "value added by manufacture" that characterizes the chemical and allied industries. As shown by Table V, value added by manufacture (value of product minus cost of materials, supplies, fuel, and purchased energy) in 1939 was 50.6 per cent of value of product. This compares with 43.5 per cent for manufacturing industry as a whole. Thus, the wealth-creating factor in chemical industry is relatively high, a characteristic that contributes to the triple objective of good management—high wages, low prices, and high return on invested capital.

By-products.—Characteristic of chemical industry is the fact that products other than those primarily desired usually are produced. Thus, glycerin is produced with soap; hydrogen is produced with electrolytic caustic soda and chlorine; charcoal, crude methanol, tar, and oils are produced with acetic acid or acetate of lime when wood is distilled; gas, tar, oils, and ammoniacal liquor are produced with coke; calcium chloride is produced with soda in the ammonia soda process.

When there is little or no demand for one of these unavoidable products, it is called a waste product. For example, the digester liquors from the chemical pulp industry are largely run to waste. Considerable progress, however, has been made toward their utilization. Most of the carbon dioxide from fermenters and from the ammonia soda process is wasted. Some is used for making solid carbon dioxide refrigerant.

When an unavoidable product is marketable but is not a major factor in the profitable operation of the process, the term "by-product" is used though, in a general sense, the term applies to any product other than the one primarily desired. For instance, normally there is a demand for all the glycerin produced by the soap industry. Assuming, however, that the demand for glycerin should cease, the soap industry would continue to operate. In such circumstances, the price of soap would be increased to make up for the loss of revenue from glycerin.

Sometimes it is difficult to determine which of several products is the principal product. In this case, the products are called joint products. Thus, electrolytic caustic soda and chlorine are joint products. Both are essential to the profitable operation of the process.

Circumstances may alter radically the economic position of a product. Niter cake is an example. Approximately 2 tons of niter cake is produced per ton of nitric acid (calculated as 100 per cent HNO_3) when nitrate of soda reacts with sulphuric acid. Thus, in the census year 1923, the production of niter cake was 154,087 tons and the production of nitric acid was 77,633 tons. The total value of the niter cake, assuming an average value at the factory of \$4.54 per ton, was \$699,555, and the total value of the nitric acid, assuming an average value at the factory of \$126 per ton, was \$9,781,758. In 1923, therefore, the niter cake represented only 6.7 per cent of the total value at the factory of the two products.

By the census year 1935, the production of nitric acid had increased to 122,596 tons, although only 14,000 tons, or 11.5 per cent of it, was made from nitrate of soda, owing to the widespread adoption of the ammonia oxidation process. The total value of the 27,933 tons of niter cake, assuming an average value at the factory of \$18.41 per ton, was \$514,247, and the total value of the equivalent quantity of nitric acid, assuming an average value at the factory of \$87 per ton, was \$1,218,000. In 1935, therefore, the niter cake represented 29.7 per cent of the total value at the factory of the two products.

A comparison between the census years 1914 and 1935 would show an even greater contrast, as in 1914 the average value at the factory of niter cake was only $1.31 per ton. The tremendous increase in value of niter cake from $1.31 per ton in 1914 to $18.41 per ton in 1935 resulted not only from the decrease in supply, but also from the development of smelting processes which require niter cake (or the equivalent, as salt cake) in large quantities. Moreover, the demand for neutral sodium sulphate also has increased, because of the growth of the kraft pulp industry and the glass industry. As a result, sodium sulphate in all forms has assumed greater importance. Supplementing the output of the chemical industry, large quantities are recovered from the Chilean salt deposits and from various natural sources in the West and in Canada.

Emphasis on Research.—In the chemical and allied industries, emphasis on research is relatively great. This is not surprising, since many branches of the industry were created by research; as, for example, the dyestuffs, plastics, rayon, high explosives, and nitrogen fixation branches. Moreover, the industry recognizes that research is essential if continued progress is to be achieved.

Within chemical industry proper, research expenditures are between 2 and 3 per cent of sales, whereas in all manufacturing industry such expenditures are only one-fifth as much. With respect to research in the heavy chemicals branch of chemical industry, E. M. Allen[1] says:

> Emphasis put on research is one of the outstanding characteristics of the American chemical industry. No other division of industry has been more dependent upon investigation and technical developments. Any firm in the chemical business which does not support an effective research program, soon falls behind its competitors, if indeed, it does not in time suffer elimination. It is, therefore, not strange that a surprisingly large percentage of the income from the sale of chemicals has been expended for research, in order to improve existing processes, devise new and more efficient methods of manufacture, develop new products and render technical service to the consumer. In the inorganic or "heavy chemicals" branch of the chemical industry, approximately $2.25 of each $100 of sales is spent for research, and one well-known firm spends 20 per cent of its net income from sales for research.

Reliable estimates indicate that in 1946 approximately $700,000,000 was expended for industrial research and that some 57,000 scientific personnel were required for such activities. The chemical and allied industries accounted for about one-quarter of the foregoing total.

[1] *Textile Bulletin*, **53**, 18 (1938).

Research as a Factor in Change.—Considering the tremendous emphasis on research in chemical industry, one would expect a corresponding fluidity with respect to products, processes, and applications of products and processes. Such is the case. As several authorities have expressed it, the only unchanging thing in chemical industry is change itself. For instance, at the Sixteenth National Exposition of Chemical Industries, New York, December, 1937, the American Chemical Society displayed a group of more than 100 new products which had been put on the market during the preceding two years.

In the Annual Report to Stockholders for 1937, the president of the du Pont Company stated that 40 per cent of the company's sales was accounted for by twelve groups of products representing the more important developmental lines introduced in the preceding 10 years:

The twelve groups of products in question, with the year of introduction shown in each case for those not in production at the start of the 10-year period in 1928 are as follows: "Duco" finishes; "Dulux" enamels (1930); neoprene (1932); synthetic camphor (1933); "Ponsol" dyes; anhydrous ammonia; synthetic methanol; urea (1935); titanium pigments (1931); viscose rayon; acetate rayon (1929); "Cellophane" cellulose film. These twelve lines accounted for about 40 per cent of the Company's total 1937 sales volume; and their production and sale are now directly giving employment to approximately 18,000 workers, as compared with about 10,700 employees in 1928 in the same groups of products. During the same period, the Company's investment in facilities for the manufacture of these products has increased from approximately $65,000,000 to approximately $174,000,000.

The composite, or weighted average, reduction in sales prices for these twelve groups of products from 1928, or the year of introduction, if later than 1928, up to and including 1937, has been approximately 40 per cent.

Capital Investment and Employment.—Employment cannot exist until adequate facilities have been provided. A worker must have a workplace, equipment, tools, and materials. Moreover, management must provide cash working capital with which to pay wages and other current bills. These facts might be termed *the capital law of employment.*

The practical operation of this law is illustrated by reference to the financial reports of the du Pont Company. Between 1925 and 1940 that company's operative investment increased approximately $373,-000,000 or about 350 per cent, a large part of which was for relatively new products. In that same period, the number of employees increased by 38,000. Thus, to provide employment for each additional employee an average investment of nearly $10,000 was required.

The record also shows the effect of new product development on employment. At the end of 1945, approximately 27,800 employees were engaged in the manufacture and sale of products that either did not exist in 1925 or that the company did not then manufacture on a commercial scale.

CHAPTER II

RESEARCH AND DEVELOPMENT

PART 1. RESEARCH

BY PAUL D. V. MANNING, PH.D.[1]

No manufacturing organization, no matter what its size, can afford to neglect or exclude research from its corporate activities. Research should be looked upon as a form of insurance, the purpose of which is to protect the future as well as the current business of the organization. It safeguards the investment of shareholders or owners of the business by making sure that all the following functions are carried out:

1. Determination of the best and cheapest raw materials.
2. Constant investigation of alternative raw materials for emergency.
3. Development and constant maintenance of the most efficient processes for use with all possible raw materials.
4. Development of processes for production of all possible by-products.
5. Establishment of means of control of raw materials, processes, and products.
6. Constant improvement of products to reach perfection.
7. Devising of new uses for all products.
8. Building up of a patent structure around the business of the organization.
9. Developing a prestige for the technical organization.
10. Service to the production, sales, and advertising departments.
11. Constant investigation of new products and new fields.
12. Development of some personnel for management, production, sales, etc.

Place of Research in General Organization.—Because of the close relationship of research to the business, it is directly an important function and part of top management of any manufacturing enterprise. The executive responsible for the planning and execution of the research program should report directly to the president of the company.

[1] Vice-president in Charge of Research, International Minerals and Chemical Corporation, Chicago, Ill.

Most American production enterprises may be classified into one of two general types of organizations, with some differences in detail. The first is entirely functional and is shown in skeleton in Fig. 1. It lends itself to businesses of almost any size. It is preferred where the

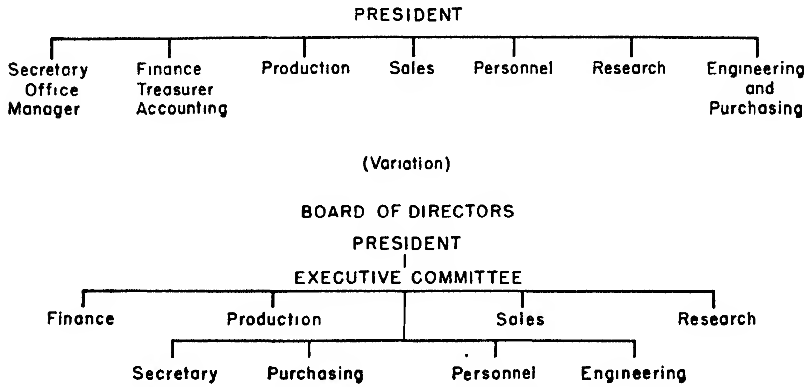

Fig. 1.—Functional organization.

products manufactured are few and closely related. The second is arranged for a large corporation operating a number of plants producing diverse commodities that are best handled by separate production and sales units. This is the "commodity" type of organization illustrated in Fig. 2.

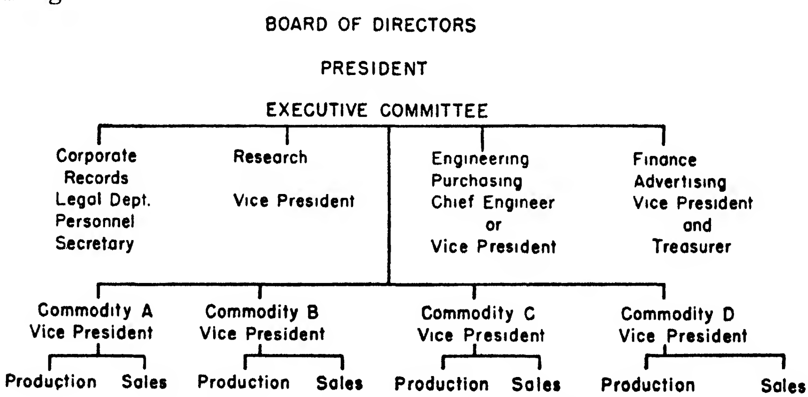

Fig. 2.—Commodity or divisional organization.

In both cases the most satisfactory arrangement is found when the research executive is a part of the top policy-making and management group. Since he is primarily concerned with not only the future planning but present operations, the need for this is obvious.

The second type of organization may be looked upon as somewhat analogous to a parent corporation with a number of subsidiaries or smaller companies, each producing and selling one or more commodities. In reality it consists of several divisions each similar to the one shown in Fig. 1, all being correlated under a general staff. Where several products are made by one division, they ordinarily bear some relationship to each other either through raw materials, processes, or by-products.

As a commodity division expands in volume of business, a point is eventually reached where its own research department is justified. In this case the head of the department reports directly to the top executive responsible for the commodity division. Research is represented and coordinated in the over-all corporate setup by a vice-president for research or general technical direction, in other words, a staff officer.

Organization of Research.—For either type of general corporation organization, the setup of a research division is similar, depending of course, upon the size of the business. In small businesses where informality governs, few general rules apply and the individual in charge of research will assume direct responsibility for the functions listed previously, as well as for direct control of production and laboratory testing and analysis. He should not, however, be asked to be responsible for production or manufacturing operations.

Even the smallest organization should have on its staff a technical man of good ability with training of the type indicated by the kind of business. It may appear initially that the enterprise cannot afford such a man, but once started, he will demonstrate his worth in a short time. In a smaller business where a good technical man of satisfactory personal characteristics has been found, the owner can usually profit by making an arrangement whereby the technical man may become a partner or at least share in the proceeds of the business.

Because chemistry and chemical engineering together make up an exceedingly broad field and because scientific progress in this field is so rapid, training beyond fundamentals is a matter of specialization. Therefore even a smaller business can profit by a technical staff—the minimum satisfactory number of which is about five.

As the business grows, a more formal organization of the research department is required. The general outline shown in Fig. 3 can be modified to suit any special local conditions and can be expanded or contracted to take care of the requirements of a business of practically any size.

If the business is not concerned with one of the main divisions of the chemical field, then that may be omitted, but sooner or later no matter what the major products, it will be found advantageous to have the

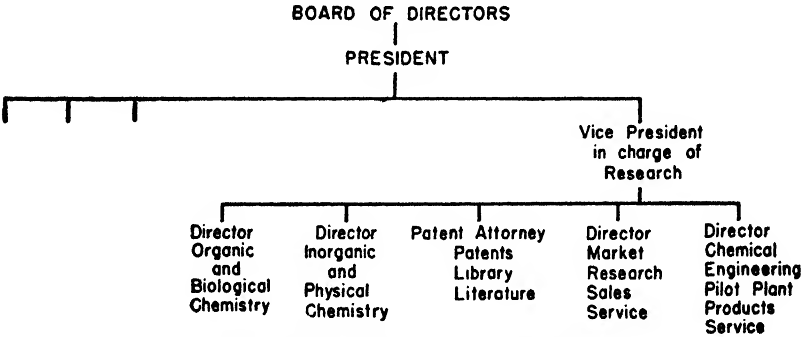

FIG. 3.—Expanded functional organization.

general organization outlined in Fig. 3. The research executive should be on the same level of responsibility and authority in the type of corporate organization shown in Fig. 1, as the executives in charge of

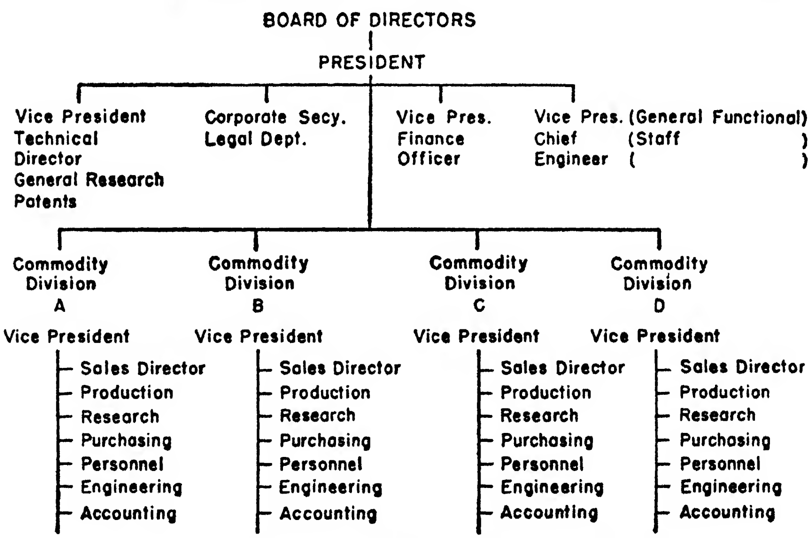

FIG. 4.—Expanded commodity or divisional organization.

sales and production. In that type shown in Fig. 2, he should be a vice-president.

As the business of a particular commodity division continues to grow, a point is reached where it may be advantageous for the division to have its own research department. In that case, modification of the organization of Fig. 2 may be used. This is shown in Fig. 4. The executive in charge of the commodity division functions in reality as the president of a subsidiary company. He may carry the title of vice-president in charge of the division or general manager of the division. It is important, however, to note that in the case under consideration the executive in charge of research reports to the executive in charge of the division and that all research of the corporation is coordinated and functionally directed by the general staff vice-president and technical director. Patents are also handled by his division.

As growth continues, some organizations—notably some oil companies—have found it advantageous to make all research the business of an entirely separate but subsidiary corporation.

Size of Research Organization and Expenditure for Research.—No general rule can be established to govern the relationship between the size of the research organization, the expenditure for research, and the amount of business done by a corporation. It depends on the type of business and the general corporate policy relative to expansion. But the expenditure for research should amount to a higher percentage of the total dollar volume of business in the smaller organization.

Corporation policy is more important than is generally realized. Research is an expensive activity, and its costs are constantly increasing. Therefore, unless the corporation desires to use the results of research, it is wasteful to carry it out. The expenditure of $500,000 per year by a good research organization, after it has been established several years, may be expected to return processes and improvements which will justify capital expenditures of from $2,000,000 to $6,000,000 per year in new plants and modernizing older ones. Therefore, the top policy-making group of the corporation must be willing and able to secure the new capital required for this growth, to justify large expenditures for research.

Progress in all fields of science is so great that a process once developed and not used becomes obsolete within a short time. Results of research "placed on the shelf" cease to be assets. In fact, if not used, they become liabilities because of the discouraging effect on the research staff that produced them.

The size of a properly administered research organization and its expenditure for research should be regulated by the ability and willingness of the board of directors and top management to secure capital for utilization of the results of the research. Although there is always the possibility of discovering something revolutionary such as nylon, the corporation should not carry on research with the idea of using only those results of occasional revolutionary character.

Financing Research.—The most satisfactory method of handling research expense is by means of a general annual appropriation not charged directly to production costs. If research is charged as a part of production, the production manager tends to become the deciding factor in determining what research is to be carried out. To him immediate production costs are always most important.

One of the difficulties faced by research departments is the tendency on the part of the top management to cut down on research when business is poor and to be somewhat extravagant with such expenditures when business is good. These tendencies can be counteracted and minimized if the executive in charge of research is part of the policy-making group of management and keeps his associates well informed as to his activities and the work of the research group.

By evaluation of research results to show what the work has done for the corporation and the financial advantage accruing, the expenditures can usually be easily justified.

Personnel for Research.—As is true with all types of human activities, the development of an organization is of first importance. The research executive must be first of all, a good organizer and a good manager. He need not necessarily be a top-flight research man, but it is important that he have demonstrated his ability to do research well. Relatively few humans have the ability and training to be good administrators, and this is just as true in the field of research as in other lines. Any business has only a few administrative positions. Therefore it is wise to so arrange a research organization that good research men who may not be good administrators can be allowed to stay in research and can be compensated commensurate with their abilities without need of becoming administrators. The compensation received by a research worker should be regulated not by his ability to administer but by his ability to produce results in research.

In selecting research workers, the qualities most needed are a thorough fundamental knowledge of the science that is the worker's speciality, imagination, ability to reason and to think, an insatiable curiosity, good health, and finally, a good personality and willingness to cooperate with others. Although mentioned last, the ability and willingness to get along with others is of such importance that only in exceptional cases should anyone be employed without it. Few worthwhile inventions or discoveries have been made by one man without the help of others, and the ability and willingness on the part of research men to work with each other will produce more and better results than the same men working individually.

Considerable work is being done on the development of aptitude and other tests as aids in selecting research personnel. Most of these are of value but of course constitute only a means of making a rough preliminary screening and cannot supplant the personal interview. The latter is of such great importance that in almost all cases the research executive should meet and talk with the prospective worker.

Compensation and Working Conditions.—As a rule, a research man does not select his vocation because of the attraction of money but primarily because he likes this type of work. With him the thrill of discovery and the satisfaction and freedom that is part of his work count for more than the financial remuneration. In the past this has often resulted in his being imposed upon and being paid a low salary. During the Second World War and in the present period following, this condition has been corrected by the recognition of the value of research and the great increase in demand for good technical men.

It is wise to establish classifications for technical personnel with qualifications as to education, experience, and salary ranges. The latter should be set up with due regard to standards in use by other reputable industrial research organizations and with consideration for local differences in living costs. It must always be remembered that best results in morale and productivity will come from well-paid workers. Good pay and good working conditions will attract the best men even in times when good men are scarce. The cost of research is at a level where the difference in salaries needed to attract the best workers over that of poorer workers is relatively small. The following classification of research positions is suggested:

Title	Minimum scholastic training	Minimum experience
Laboratory technician	Graduation from high school	None
Laboratory assistant	Graduation from high school	2 years
Junior research chemist	A.B., B.S., or equivalent	None
Assistant research chemist	A.B., B.S., or equivalent	2 years
Research chemist	M.S., M.A., or equivalent	None
Senior research chemist	Ph.D. or equivalent	None
Principal research chemist	Ph.D. or equivalent	2 years

In the case of chemical engineers, metallurgists, etc., the appropriate word may be substituted for the word "chemist." This classification is flexible enough to permit variation for individual merit and also makes it possible for exceptional men to qualify for higher classifications even without advanced college work.

All research workers above the rank of laboratory assistant should be given the opportunity of attending professional society meetings. As a worker advances, he should be given such opportunities more frequently. In all cases, his expenses should be paid, and the time required should not count as vacation.

Publication of research results by workers should be encouraged whenever the interests of the corporation are not harmed by such publication and the quality of the work justifies it. The patent attorney should give final approval to manuscripts.

The executive in charge of research should endeaver to better working conditions, salaries, and scope for advancement but in addition to these interests, his vision and ability to inspire must stimulate the research men to highest productivity. Workers who early indicate a lack of response to such treatment should be dropped.

Administration of Research.—Administration of research is just as much of a science as is the research itself. The background of a research worker, coupled with business judgment, an understanding of the personal problems of workers, the ability to judge the worthwhileness of research results, a cooperative attitude with his fellow executives, a desire and faculty for selling research and its results to the organization, and finally, an enthusiasm that enables him to inspire his staff are some of the qualities most needed by the top research executive. He must have the ability to transmit to his staff the attitude of believing that all things are possible.

Through his assistants and department heads, the research executive must keep himself well informed as to the progress of each research project without at the same time becoming burdened with the details. He must have faith in the abilities of the workers in his organization and must remember that he can easily take away the joy of accomplishment from the worker by too much attention to the details of each problem. As an executive, his job is to inspire, to help set up policies, and to direct the work of execution but not of the details of each individual research project. One of his most important functions is to constantly evaluate results and to "sell" them to his fellow executives.

Selection of Research Projects.—Selection of research projects is best carried out by a committee made up of the top executives of the corporation in the case of the organization of the type shown in Fig. 1. In the type of organization illustrated in Fig. 2, the research program affecting each commodity division should be set up by a committee composed of the president, the vice-president in charge of the division and the vice-president in charge of research. General research projects should be discussed with the president and the executive committee. Unless care is used, the general tendency is always to set up too many projects.

Once programmed, a budget of estimated cost of the project should be made. It is recognized, of course, that no exact estimate of research costs can be developed in advance, but an estimate can be made of the cost of carrying out a certain program for a period of time. The actual cost of each project should be worked out at the end of each month and should be reported to the executive in charge of the research division, the appropriate department head, and the workers on the project.

At least every month, and preferably every two weeks, the research committee, consisting of the research executive and department heads of the research division should meet and discuss progress on each project. At these meetings all workers assigned to a project under discussion should be invited to participate in the discussion at the appropriate time. This gives every worker a chance to discuss his ideas with the research executive. Great care should be exercised to keep criticisms constructive and the discussions entirely objective. Every worker on any project should be made to feel that he is an important part of the work, and all questions for information regarding the project should be answered as fully as possible.

Every industrial research organization should carry out continuously some fundamental or abstract research. Regarding research, Tyler[1] says:

> It is safe to say, however, that there is no other activity of modern business that yields as much of permanent worth for every dollar as does continuous, well-directed technical effort. Whatever the problem or its outcome, something worthwhile is certain to be gained, and in a surprising proportion of instances financial success rewards the research that is begun solely in the interest of fundamental theory. Steinmetz once remarked that the whole character of the transmission-equipment business was changed as a result of an apparently abstract investigation that was started by the General Electric Company on the properties of the electric corona. This is by no means an isolated example, and for that reason the nontechnical executive should be slow to scorn an effort from which there is no apparent immediate benefit.

[1] "Chemical Engineering Economics," 1st ed., p. 191, McGraw-Hill Book Company, Inc., New York, 1926.

The regular conferences at which each research project is discussed give the research executive an opportunity to revaluate the project, and this must be continuously studied. Research is expensive, and talent and money must always be applied where it will bring the best returns.

Function of the Patent Department.—One of the most important phases of work of the research division is to develop a patent structure surrounding the entire business of the corporation. To this end, the patent department staff must be familiar with all research under way and must work constantly with the members of the research staff. The head of the patent department should be a well-trained patent attorney. He should develop a staff to aid in preparing and filing patent applications. He should not be a member of the corporation legal staff but a department head in the research division. The patent department may well have supervision of the research library, prepare literature for research workers, and also care for the files and disposition of reports.

Function of Market Research Department.—Market research is a necessary step in the determination of the value of a research project designed to produce a new product or to bring the corporation into a new business. It requires the services of a well-trained specialist.

In addition to market research surveys, this department has also the function of working with the sales managers in developing markets, new uses for products, and customer service.

Function of the Chemical Engineering Department.—This department not only carries on fundamental research in chemical engineering but is also responsible for pilot plant work on new processes, development of cost estimates, and cooperation with the engineering department of the corporation in the design of new plants and with the production department in the initial operation of a new plant and in trouble shooting and development work.

When a new process developed by research is ready for pilot plant tests, sufficient data should be available from fundamental research, market research, and chemical engineering research to assure that the new process will be a satisfactory enterprise *if* the pilot plant work is satisfactory.

Members of the corporation production and engineering departments should then come into the pilot plant and work with the research chemical engineering staff in the final development work on the process.

Final Evaluation of a New Process.—To make possible a decision as to whether to put capital into a new process developed by research, data on the following essential elements must be prepared:

1. Raw materials, including fuel and water, supply and cost.
2. A satisfactory process with costs worked out.
3. Market for products and by-products.
4. Data on products and by-products.
5. Satisfactory methods for disposal of waste products and fumes.
6. Patent situation and advantages which the corporation may have over its prospective competitors.

Complete data on these points facilitate the decision as to the business potentialities of the results of a research project.

PART 2. DEVELOPMENT

By Chaplin Tyler

Between the discoveries of the research laboratory and the realization of commercial operation lies the field of process development. Neglect to recognize factors in technical development work is such a common cause of failure that there is little danger of being too conservative when considering the commercial possibilities of new processes. Although this discussion contains much that is repetition, research and operating men alike should continually be impressed by the necessity for sound, step-by-step progress from the first laboratory experiment to ultimate factory production.

Research and Development Contrasted.—As pointed out by Mees[1] the work of the development department is an extension of laboratory research. The development of commercial processes calls for different personal characteristics than those needed for laboratory research; consequently, it is usually carried on by a separate staff if the size of the laboratory permits. Since there must be coordination between the two, general supervision should be unified. Mees says:

> The commonest mistake is to transfer laboratory work to the manufacturing department too soon; experimenting in a manufacturing department is a costly matter, and the experimental work should be done on a small scale under control of the laboratory before any attempt is made to transfer it to a full-scale manufacturing department.
>
> The development department itself should have an organization separate from the research laboratory, though under the same general direction. It will study all proposals for new methods, processes or products which may be

[1] "Organization of Industrial Scientific Research," McGraw-Hill Book Company, Inc., New York, 1920.

submitted to the company, and will report on them, these reports bearing at their conclusion definite recommendations on which the executives of the company can act.

Importance of Intermediate Experimentation.—Chemical engineers agree generally that only in a few exceptional cases is the direct transfer of a process from laboratory to plant permissible. Cooper[1] has summarized a symposium on factory experimental procedure contributed by technologists in widely varying industries:

Direct transfer is a hazardous undertaking and is disliked by the ordinary chemical engineer. Risk is lessened by extending the period of preliminary study. If it were possible to anticipate every variable that will be involved, there would be little to fear, but the average engineer prefers to admit the possibility of overlooking something and likes to proceed cautiously. An example was cited where every variable in the extraction of a vegetable oil was supposed to be known, and a 3-ton extractor was ordered, but the operation worked differently on a large scale. A filter press should have been used to remove much of the oil. The difficulties of operating on a large scale are sometimes less than those encountered in the laboratory, but more often they are much greater.

Except in the most elementary examples, the process should at least go from the laboratory to a unit plant, including the largest single piece of apparatus that is to be used. This plan has the merit of giving actual factory production at once, though not on the full ultimate scale. If standard equipment is employed, the unit plant will not cost much more than an intermediate plant and will make a strong appeal to the confident promoter.

One company spent $15,000 on a small-scale plant and found out that the process was not profitable, thus saving most of the $100,000, the estimated cost of the full-sized equipment. If a maximum of caution is desired, a combination of semifactory scale equipment and unit plant should be employed, especially when profit is more important than speed, and competition is keen. When a well-known oil refining process was being installed, the deposition of carbon was overlooked or overestimated, even in the intermediate study; but the full-sized unit brought it out. The Standard Oil Company of Indiana, in developing the Burton process, had to prepare for more than a threefold increase of pressure. They started with a 1-qt. bomb and the stills were increased from 13 to 50 gal. and then to a unit plant of 8,500 gal. costing $100,000. This was later multiplied into a battery according to requirements.

Whiting's Concept of Process Development.—Although it was published in 1912, one of the clearest expositions of chemical develop-

[1] *Chem. Met. Eng.*, **32**, 426 (1925).

ment is that by Whiting.[1] He divides process evolution into five distinct stages:

1. Beaker or laboratory stage.
2. Small-sized model.
3. Large-sized unit.
4. Semicommercial plant.
5. Commercial plant.

Beaker or Laboratory Stage.—The function of the first stage is to test the correctness of the technical principle of the process, the novelty, and the commercial soundness.

Common sense dictates such a preliminary investigation as a safeguard against wastage of money and effort. Quoting Whiting:

The first step in this direction is to conduct such experiments as may be necessary for a full preliminary study of the technical side of the problem in hand. It is not the function of the laboratory to produce accurately the condition of practical work, but rather to enable the experimenter to test out the fundamental principles on a small scale with a correspondingly small outlay of time and money. The aim should be, therefore, to isolate the idea, to divorce it from any conditions which may be misleading in their effect, and also to subject it to severe strains to determine its pluck and endurance. Moreover, the experiments should include a study of the underlying causes of the defects in existing competing processes, and their extent and importance. This study of the technical side of the problem is necessary as an insurance against useless work.

But the function of the first stage is not ended here. The novelty of the process must likewise be investigated by a thorough study of the state of the art in textbooks, periodicals and patent office records, an undertaking which requires time and patience and not a little self-control. In the investigations of the Whiting cell, more than a thousand references were found, classified, and catalogued. And just as important as the search covering the novelty of the process is a study to determine whether the basic commercial conditions surrounding this process are sound, that is, whether the raw materials required are to be obtained at a reasonable price and in sufficient quantities; whether the operation is likely to involve any extra-hazardous conditions, and whether there is a permanent market of sufficient size and stability for the product. From a practical standpoint it is useless to spend time and money on a process not commercially sound, but this is being done constantly by investors all over the world. I have personally known of several cases where men have spent years developing a secret process, only to find in the end that the market conditions were unsound, a fact easily ascertainable in the beginning.

[1] "The Commercial Development of Chemical Processes," Eighth International Congress of Applied Chemistry, New York, 1912.

Small-sized Model.—Assuming that the laboratory stage yields favorable results, development passes to the small-sized model, the purpose of which is to determine the optimum operating conditions. In order to facilitate the study of each variable, the design of the model should be as simple as possible, and flexible enough to meet the wide range of conditions that should be investigated in a preliminary way. Again quoting Whiting:

The model should be as flexible as possible. For instance, in the original design of the model of the Whiting cell, the compartments in which the salt is decomposed and the amalgam oxidized were made independent of one another, and in such a way that the dimensions of each and the relationship of one to another could be varied independently within wide limits. By this means, with a single model, we were able to determine the proper size and shape of each compartment, their relationship and the most effective method of operation. It is interesting to note that in this instance the results obtained with the first model have had permanent value. This is not always true. By operating the apparatus under a great variety of conditions, the best procedure can be ascertained and the scope of the invention determined within the limits of the experiments performed.

The small-sized model, moreover, should be big enough to permit the manufacture of a sufficient quantity of the product to enable the experimenter to determine its quality. In the laboratory one experiments generally with pure chemicals. In the small model it is well to use commercial materials, the impurities in which often are disturbing factors in the success of the process. As regards the final efficiency of the process under actual conditions of plant operation, very little of value can be learned from this model, but much knowledge may be obtained which will aid in the design of the final apparatus and in determining the choice of materials to be used therein.

Large-sized Unit.—The effects of the operating variables having been determined, the elementary design should be worked out. To do this is the function of the large-sized unit. At this stage a broad knowledge of engineering materials and of other practical aspects of design is especially helpful. That is one of the reasons for the rapid progress characteristic of large technical organizations, in which each major problem of design is assigned to a specialist.

With increased size, the optimum operating conditions as determined for the small-sized model may not hold. Consequently, flexibility in design remains desirable in the large-sized unit. According to Whiting, this is the most critical stage in the entire development program:

The tendency to hurry over the third stage in the evolution of a process is often almost overpowering. After a few weeks or a few months, as the case may be, the operation of so small a plant becomes tedious, and the inventor is apt to chafe at not being able to make more rapid progress. It is evident, however, that defects are much more easily remedied on a single unit than on a great number of units, and the more perfect a process emerges from this stage, the shorter and easier will be the subseqnent stages, and more complete the success. Moreover, many chemical processes which work well on a small scale are failures on a large scale. Thus, in the development of the (Whiting) electrolytic cell, the provision made for decomposing the amalgam in the oxidizing compartment, though perfectly satisfactory when applied to the small-sized model, proved inefficient and unreliable in the life-sized unit, necessitating much research work and a redesign of the apparatus before the defect was overcome. Likewise, many processes have defects that may be called accumulative. I have known a piece of apparatus to work well for a period of 7 months, and at the end of that time develop a defect which made it practically useless.

Semicommercial Plant.—At the termination of the third stage, operating conditions and the elements of design will have been determined, and the next step—the semicommercial plant—has for a purpose the determination of efficiency, simulating in design and operating conditions the final plant in every respect except capacity. Compared with previous stages, experimental work of this sort requires a generous financial backing, and this brings up the problem of financing the enterprise prior to commercial production. Whiting says:

At the beginning of this stage it is necessary to consider a new and very necessary element for success—money. The first three stages consume large amounts of time and energy, but comparatively little hard cash. Now, however, a considerable sum will be needed to carry the process through the fourth stage. Of course, there are many ways of proceeding to get this money, and conditions must govern the final analysis, but I would suggest that there are advantages in the erection of this semi-commercial plant in connection with some going concern, giving certain limited rights to use the process, if successful, in consideration of the opportunities and equipment furnished. Generally this is a safer and more economical arrangement at this stage than to attempt to form a company for the exploitation of the process and the erection of a small independent plant. The well-oiled machinery of the allied concern, its purchasing department, its engineers, its laboratory and workmen will all be available for the new work, leaving the experimenter free to concentrate on his own special problems.

The proper size of this plant depends, of course, upon individual conditions. It should be as small as possible, and still be able to produce enough of its product to permit the testing of its quality under the conditions of actual use. It should be large enough to indicate something of the cost and quality of the labor required for the commercial operation of the process.

The life-sized unit was looked after by skilled men. It is now necessary to prove that the process may be operated by ordinary cheap labor. Moreover, the plant should contain a sufficient number of units to enable the experimenter to determine their efficiency under the average conditions of plant operation. A single unit may do very good work when petted and pampered by constant adjustments, but give it its place in a series of units all subject to the grueling test of average conditions and it often falls down. Much can be learned from this little plant, especially as regards the general arrangement of the large plant and the relation of one piece of apparatus to another. These are important points, which affect not only the first cost of building the final plant, but also the cost of its operation over an extended period of time, and both factors will aid greatly in obtaining the full measure of benefits to be derived from the development work.

Commercial Plant.—If the process survives the exacting tests of semicommercial operation, and estimates indicate that the production cost will be sufficiently low, the last and final stage of development, the full-sized commercial plant, may be designed with the assurance that all risks, both technical and economic, have been minimized.

Lewis and Radasch[1] recommend a procedure for process development similar to Whiting's and with particular reference to stoichiometric methods of calculating plant-scale capacities and requirements, based on laboratory or small-scale data.

Importance of Cost Estimates.—A large proportion of wasted research effort is caused either by a complete disregard of cost estimates or by gross inaccuracies therein. The least that might be done in every instance is to assume theoretical yields and the most optimistic results generally. Then, if the proposed process fails to meet such extremely favorable conditions, it must be hopeless.

As pointed out by Becket,[2] in those instances in which cost estimates have been made, but in which the ultimate result has been failure, serious errors of omission usually can be demonstrated. Poor judgment also may be a contributing factor. Quoting Becket:

Now, it is deserving of special emphasis that in a large proportion of the hopeless cases that have come to my attention, the great error, the cause of the wasted effort, has been found either in complete omission of any attempt to estimate the cost of manufacture, or more often to predetermine it with reasonable accuracy. In all of these cases a revealing estimate could have been made by assuming theoretical yields from the chemical reactions and

[1] "Industrial Stoichiometry," McGraw-Hill Book Company, Inc., New York, 1926.

[2] *Chem. Met. Eng.*, **33**, 283 (1926).

excellent results in connection with all other factors. The last thought is worthy of a little elaboration in that it provides a method of precluding these extremely wasteful procedures. By assuming theoretical yields from the chemical or electrochemical reactions, which are oftentimes interestingly clever, and by further taking the most optimistic view of all other factors that an experienced, reasonably intelligent engineer would dare to assume, it has been possible by cost estimating in this way to convince many who have experimented diligently that they have been seeking a worthless goal. The saddest instances revealed by this method are those in which mental energy and capital have been wasted to a much greater extent, in which the technology of a process has been carried to successful demonstration on a minor scale and for which great economy has been forecast in the operation of a plant of commercial size. In cases of the latter class cost estimates had been prepared by the proponents. Then, wherein lies the difficulty? The most serious errors are those of complete omission of important cost factors rather than the application of poor judgment to the factor considered, although, frequently, both errors are combined.

That a stronger impression may be left of the type of pitfalls that have brought keen disappointment to many sanguine and in some cases obstinate persons, it may be well to depart from broad generalizations and mention a very few specific cases drawn from actual experience. For obvious reasons, the citations will avoid identification of processes or persons.

Within the past decade a process for the extraction of potash from an abundant domestic mineral was devised, considerable preliminary work was performed, the technology of the novel steps was developed in semi-commercial apparatus and the process was offered to one of the companies with which I am connected. In common with other processes of the kind the transition from potash-bearing rock to a soluble potash salt offered the major problem, the solution of which presented the chief novelty. Hence, most of the money and effort were expended on the design, development and operation of the furnace in which the rock was decomposed at a moderate temperature through ingenious reactions. Good thermal economy and a high recovery of soluble potash were attained and were accepted as criteria of commercial success. The steps subsequent to leaching of the furnaced product, which were principally washing and evaporating operations, fretted the chief technologist and his associates not at all and had never been carried out quantitatively, on the ground that they represented "perfectly simple chemical engineering." Early in our investigation an estimate was made of the cost of operating this complete process, based on the assumption that substantially theoretical yields would result from the furnace reactions, and it brought to light that the cost of evaporating the necessarily dilute solutions, even by the most efficient means, precluded the commercial success of the project, if the average selling prices of the potassium salt and the by-products were duly considered. Neglect to estimate the cost of "perfectly simple chemical engineering" processes explains the failure of this enterprise.

An example of a different class is represented by a high-temperature electrolytic process for the reduction of a metal having a melting point over 1500°C., which was offered after considerable work had been conducted on a moderate scale. Samples of the product were presented with the claims for predicted commercial success. In this instance, quite apart from glaring practical difficulties that had not been solved and speculation concerning the quality of the product, the estimated cost of the three items, raw materials, power and labor, assuming 100 per cent current (ampere-hour) efficiency and a large-scale operation, slightly exceeded the highest selling price of the product over the several years preceding. The market price of this product is today 40 per cent less than at the time of the investigation. Later, this process met with a reception enthusiastic enough to be optioned by another group who continued experimentation for a few months, but it was soon thereafter abandoned.

Before attempting to predetermine costs, it is a logical procedure to select an appropriate scale of operation and then to visualize the complete plant and organization required or the desired end. However clearly a process may have been conceived as a succession of chemical reactions and unit processes, cost estimating each material and operation develops a clearer picture of the producing and economic structures; and the mental courage requisite to develop a thorough cost estimate will find its reward in an enhanced understanding of the project. In every case the estimate deserves careful analysis. An estimate which reflects favorably on the process will show points of strength and of relative weakness, so that further work can be directed toward factors in which further economies should be sought or can most easily be secured. The autopsy on an unfortunate process will usually reveal the principal cause of failure and will at least dictate the need of a new line of attack. If the product is already being made by another method, an estimate of the corresponding cost may wisely be attempted, since, however ingenious a new process, its competitive utility will be slight, if the cost is relatively high. Clearly, a cost estimate is the logical nucleus around which to gather data for the complete engineering report which the critical executive desires.

The importance of constructing a flow sheet before proceeding with the cost estimate cannot be overemphasized. The flow sheet, which should depict as completely as possible the process in its technical aspects, will minimize errors of omission and will serve to organize the whole project. Assumptions as to location of plant, yields, power and fuel consumption, labor requirements, and plant cost may be difficult to make, but someone must assume the responsibility before too much money is expended on what ultimately map be an uninteresting project.

In order that essential factors in project analysis may not be overlooked, a fairly comprehensive procedure is outlined in the following section of this chapter. Naturally, the exact composition of such an outline will vary with the type of industry. However, a simple standard guide is a constant aid, even to the experienced investigator.

OUTLINE FOR PROCESS DEVELOPMENT[1]

I. Derivation of flow sheet.

1. Statement of reactions upon which process is based: A full explanation of the chemistry of the process.
2. Description of process: A general statement of the process, including each of the various steps.
3. Block-form flow sheet: An elementary flow sheet of the process as outlined in the preceding paragraph.
4. Calculation of flow-sheet quantities:

   a. Selection of unit basis for calculation.

   In treating gas volumes it is convenient to use a volume unit of 100 cu. ft., based on the raw gas entering the process. In treating solids it is convenient to use either 100 lb. or 100 mols of the raw material. In certain cases it may be advisable to use a unit based on an intermediate product or on a finished product.

   b. Application of necessary assumptions.

   The various assumptions which are necessary for calculating the flow sheet should be tabulated, in order that the assumed conditions may be clearly understood.

   c. Application of experimental data.

   All experimental data not included in the statement of reactions should be reviewed with reference to the practicability of the process.

   d. Calculation of flow sheet.

   Any calculation relating to the flow-sheet derivation should be fully explained.
5. Tabulation of flow-sheet quantities: A complete tabulation of quantities and compositions based on the steps outlined in the description of the process.

II. Design of plant.

1. Factors in choice of plant capacity:

   a. Quantity of raw material available.

   b. Quantity of finished product to be manufactured.

   c. Capacity of process units.

   For example, in treating gas volumes it is convenient to use the capacity of a single compressor unit as a basis. It is not advisable to use a fraction of a compressor unit, but the use of multiple units may be desirable. In general, the use of standard unit capacities will result in considerable savings in cost of plant.
2. Derivation of a multiplier for quantities in the unit flow sheets in order to transform them to plant quantities: Since the unit flow sheet is based on 100 cubic feet, 100 mols, or a similar unit at some stage in the process, the deriva-

[1] Adapted from an outline developed by R. L. Dodge, Manager, Planning Division, Ammonia Department, E. I. du Pont de Nemours & Company, Wilmington 98, Del.

tion of the flow sheet for the plant is readily accomplished by using an appropriate multiplier based on the ratio of the units used in the flow sheet to the plant capacity at the same stage of the process.

3. Study of individual steps in process:
   a. Determination of conditions necessary to effect desired results.
      (1) Thermal considerations.
      (2) Equilibria, or yields.
      (3) Solubilities.
      (4) Auxiliary requirements.
      (5) By-products.

Each of the steps in the process should be considered in the light of the foregoing factors. It may be found convenient to subdivide each of the steps mentioned in the description of the process into smaller unit steps in order to illustrate the calculations more clearly.

   b. Design of equipment.
   c. Pressure losses.
   d. Heat losses.
   e. Material losses.
   f. Power requirements.
      (1) Electric.
      (2) Steam.

In considering equipment design it is necessary to strike a balance between detailed design and rough estimates. Since most paper studies are preliminary, it is not usually advisable to make a detailed design. It is, however, necessary to obtain sufficient data to estimate costs of the various pieces of equipment. This distinction may be illustrated by stating that it is necessary to calculate the area of heating surface in preheaters, but is not necessary to design the pipe lines leading to and from the preheaters. It is neither appropriate nor desirable to design involved mechanical devices for accomplishing well-defined objectives.

   g. Summary of all quantities for each step.
      This is a tabulation of the quantities for each step, including a list of the equipment required.

4. Block flow sheet showing all quantities and temperatures: This flow sheet should illustrate the entire plant. It should show the entrance and exit temperatures for each step of the process, and the heat quantities.

III. Derivation of cost estimate.

1. Investment for equipment required in each step, including 20 per cent for contingencies and 10 per cent for engineering and design: The investment should be summarized from the equipment list. It should show the equipment at present installed and the estimated cost of any new equipment which is required.

   For wholly new and untried operations, 20 per cent should be taken for contingencies; for operations duplicating or similar to present operations, 10 per cent is ample.

The investment should include working capital, as follows:
   a. Cash equivalent to 30 days' mill cost.
   b. Accounts receivable equivalent to 30 days' sales.

   c. Inventory of finished product carried at cost. This should be the average inventory required for 12 months' operation.

2. Summary of investment:
   a. Land, including such improvements as roads, fences, railroad sidings, docks, and parking space.
   b. Buildings complete with such necessary services as heat and ventilation, and connections for water, power, steam, sewer. Also investment in buildings for finished-product storage, raw-material storage, and fuel storage.
   c. Process equipment, including auxiliary equipment, as for example, water-purification plant.
3. Operating cost:
   a. Ingredients.
   b. Services.
      (1) Electric power.
      (2) Steam.
      (3) Water.
   c. Direct supervision.
   d. Direct labor.
   e. Repair labor and materials.
   f. Supplies.
   g. Work expense.
   h. Fixed charges.
      (1) Taxes and insurance.
      (2) Depreciation.

In each case where the item is a percentage of the investment or of the direct labor, the percentage should be shown. This applies to repairs, works expense, and fixed charges.

4. Determination of unit-process cost of product: This cost applies to the product as issued from the process and includes no storage, handling, packing, or other charges.
5. Determination of unit-process cost of product f.o.b. plant:
   a. Packages.
   b. Packing.
   c. Loading.

   It is usually necessary to make some assumption regarding the packages in which the product is to be marketed and the stock which is to be maintained. If market surveys are at hand, the type of container can be specified. The amount of stock which must be carried will be determined by the capacity of the plant and the buying habits of the trade.
6. Determination of the price to yield a given return on investment, or the return on investment yielded at various prices: Ordinarily, a return of 20 per cent on the full investment should be used in this calculation.
7. Determination of the effect of varying the cost of one or more ingredients on the final product cost: This need be shown only for important ingredients.

IV. Market survey.

1. Description of product:
   a. Physical and chemical properties.

   b. Physiological action.
   c. Shipping classification.
2. Standard specifications:
   a. Definition of grades.
   b. Limits of impurities and of physical properties, for example, specific gravity, color.
   c. Packing specifications.
   d. Possibility of improving quality.
3. Consuming industries:
   a. Total consumption and value.
   b. Distribution of consumption by industries and by geographical areas.
   c. Distribution of consumption by important individual consumers, when information available.
   d. Exports.
   e. Possibility of developing new uses.
4. Buying habits of consuming industries:
   a. Contracts, and basis of quotations.
   b. Sales methods now in use.
   c. Possible substitutes and market conditions governing choice.
   d. Seasonal or fluctuating demand.
   e. Wide market or restricted to few consumers.
5. Production statistics:
   a. Domestic production and trend of production.
   b. World production, and production by specified countries.
   c. Production by principal individual producers, when available.
   d. Imports for consumption.
   e. Stocks on hand.
6. Competitive situation:
   a. Principal competitors, their location, and capacity.
   b. Near-by markets.
   c. Imports, and dependence of domestic industry on tariff protection.
   d. Trends and possibility of new processes.
7. Freight tariffs from principal producing centers to principal consuming centers.
8. Comparison of manufacturing processes:
   a. Raw materials: sources, reserves, availability.
   b. Fuels and power.
   c. Labor.
   d. Capital investment.
   e. Yields.
   f. Costs of production.
   g. Importance of by-products.
   h. Health hazards.
9. Probable future markets:
   a. Trend of consumption.
   b. Trend of prices.
10. Patent situation and other legal restrictions on manufacture, sale and use.

Effect of Delays in Development Work.—Once a development project is undertaken, a conclusive result should be achieved with all possible speed. One danger to which delays expose development work is, of course, excessive expenditure. Considering that even laboratory-scale development work costs $1,000 or more per technical man-month, expenditures of $25,000 to $100,000 accrue quickly when group attack is employed. Delays result in shifts of personnel from one project to another thereby causing lost momentum and waning enthusiasm. Delays also have a competitive aspect in that the potential results of a development are more likely to be anticipated by others, causing loss of patent coverage, loss of profits incident to being the first to exploit a process or product, and loss of prestige that would otherwise be gained.

Capital Requirements.—The amount of capital needed at various stages of a chemical development is a highly variable figure. That

TABLE I.—RELATIONSHIP OF RESEARCH, DEVELOPMENT, ENGINEERING, AND CONSTRUCTION COSTS

Item	Case *A* (New product; large volume)	Case *B* (Improved product; small volume)	Case *C* (New product; small volume)
Research (including all laboratory research but excluding pilot plant construction and operation)	4	7	33
Development (pilot plant construction and operation)	4	16	30
Engineering (plant design, including all necessary supporting studies)	4	12	4
Construction (inclusive cost of plant and starting up)	88	65	33
Total cost (basis = 100)	100	100	100

generalization concerning the subject is dangerous is illustrated by Table I which shows, on a ratio basis, the expenditure for small-scale research, development, engineering, and construction for three projects which are in operation on a commercial scale.

A number of comments might be of interest regarding these cases. For example, other cases might be cited in which the development (pilot plant) cost is many times, ten times or more, as great as the research cost. In some cases at least, such high ratio is caused by premature transfer of the work out of the laboratory. Impatience on the part of those immediately connected with the development, or on the part of top management may contribute to such forced action. However, more frequently unforeseen difficulties arise which cause delays with attendant additional expense. Naturally, when experimentation which should be done in the laboratory is carried on in a pilot plant, cost is incurred at an inordinate rate.

Obviously, there is no fixed relation between the cost of research and development work and plant cost. A scientific problem may be exceedingly complex and may require, for example, an expenditure of $500,000 for satisfactory solution. A plant might cost $500,000 or $5,000,000 depending upon the volume of sales forecast. In such cases, it is management's job to decide whether the price of admission to a new field is reasonable.

The ideal case, of course, is the one in which the potential is exceedingly large, as for example, the dyestuffs market at the time of the First World War. Many millions of dollars were spent in research and development work, but the market was measured in terms of tens of millions.

Project Financial Ratios.—Projected ratios between sales revenue, costs, earnings, and investment are shown in Table II. The figures depict estimates covering an actual new process development.

TABLE II.—FINANCIAL SUMMARY OF A CHEMICAL PROJECT

			Per Cent of Sales
Sales and intercompany transfers		$3,621,900	100.0
Less:			
Mill cost	$1,846,700		51.0
Freight, delivery, and selling expense	362,200		10.0
Administrative and all other expense	148,800		4.1
Cost of Sales		2,357,700	65.1
Net earnings before federal tax on income		1,264,200	34.9
Less:			
Federal tax on income @ 35%		442,500	12.2
Net earnings		821,700	22.7
Fixed investment in plant and facilities		3,168,000	87.4
Working capital		1,036,000	28.6
Total investment (basis: operation at 90% of theoretical capacity)		$4,204,000	116.0
Net return on investment = 19.6%			

Growth of Industrial Research.—Research and development has become a huge activity in its own right. As reported by the National Research Council, the number of industrial research laboratories has increased as follows:

Year	Number of laboratories	Total personnel	Estimated research expenditure, millions of dollars
1920	300	9,300	30
1930	1,625	34,200	135
1940	2,350	70,000	300
1946	2,443	133,500	700

Continued large increases in research and development expenditures are in prospect. Such expenditures in the chemical industry proper are approximately 5 per cent of the value added by manufacture and may soon reach 6 per cent. These figures are equivalent to 2½ to 3 per cent of value of product. However, manufacturing industry as a whole probably spends less than one-fifth as much for research as does chemical industry, which is a rough measure of the research potential in manufacturing alone. Thus in the next quarter century, should only half this potential be realized, expenditures for industrial research readily could reach $2 billion per year.

CHAPTER III

PLANT LOCATION

By J. L. Warner[1]

Before the advent of steam power, mills and factories necessarily were located alongside a waterfall on a swift-flowing stream capable of turning the mill wheel. Small mills driven by wind wheels were the exception to this practice.

With the development of the steam engine, the choice of sites for factory location was greatly broadened. A mill or factory no longer was confined to a riverside or below the breast of a dam. From the viewpoint of power, a location needed only access by railroad siding. Even this requirement can be obviated by utilizing electricity for power. Certain types of plants may now be located anywhere that an electric cable can be installed.

Just as steam removed the limits that confined power to waterways, so electricity further extended the area of power distribution. The growth of industry to the point where water power became inadequate and the demand for more power encouraged the development of abundant and economical steam power, followed later by the development of electric power and high-tension distribution systems. Cheap power thus became available in increasingly larger areas thereby decreasing the relative importance of power as a factor in factory location.

Likewise the progressive development of transportation has had a distinct influence upon industrial location. Before the coming of the railroad, transportation was slow and difficult. Trading areas were limited in extent and number. Because freight was for most part water-borne, industrial growth developed along the seacoasts and rivers. With the construction of railroads, locations near waterways no longer were essential. Automobiles and motor trucks and the network of modern highways have provided additional transportation facilities for better distribution of merchandise particularly to areas distant from railways. Hence transportation is not so critical in selecting manufacturing sites as it was 20 years ago.

[1] Retired executive, E. I. du Pont de Nemours & Company, Wilmington 98, Del.

Changes taking place within industry itself affect the importance of the various factors that control plant location. Inventions, improved processes, and new products have wrought many changes in location practice, particularly in the chemical industry where development of synthetic products and utilization of new and cheaper raw materials have revolutionized industrial production.

At one time plentiful cheap labor or highly skilled labor might have been an essential requirement, but now the invention of high-speed, automatic machines may permit a plant to operate with only a few skilled employees, thereby greatly lessening the importance of labor as a location factor.

General business conditions also have a bearing on plant location. The depression of the 1930's established the habit of purchasing in small quantities to meet immediate trade needs. This policy prompted many manufacturers to build branch factories from which local markets could be quickly and economically served.

Although the importance of various factors affecting plant location change from time to time due to industrial progress and to changes in the way of life of the population, these effects may be foreseen and evaluated. Notwithstanding continual changes in trade and business conditions, definite conclusions can be reached, and by systematic study unmistakable indications may be discovered to show the superiority of one site over other locations.

The location of a manufacturing plant bears a vital relation to management's ability to reduce production costs. The cost of raw materials delivered at a plant, also the cost of labor, or fuel, power, and the cost of distribution of finished product are all more or less affected by location. Accordingly, the selection of an economical location depends upon the resolution of several major factors and may be influenced by other factors of lesser importance.

After a location is selected and plant built, any inherent faults of location are forever carried as a financial burden. Whereas operating defects may often be corrected at comparatively low cost, compensation for a poor location may necessitate enormous expenditure. Such defects may be sufficiently serious to cause abandonment of the plant.

Importance of Location Study.—The location of a manufacturing plant should not be selected at random, or by mere whim of some official who arbitrarily decides to build a new factory or move his plant to another location because of some personal preference. The determination should be based upon a detailed and comprehensive study of all factors affecting production costs.

As a rule, a manufacturer prefers to add to an existing plant thereby increasing its output instead of establishing a branch factory in another location. He prefers to continue operating where he is acquainted with all the conditions affecting his business rather than to venture into unknown territory. In spite of this natural resistance to change, failure to thoroughly analyze the existing plant location as it affects production costs and failure to recognize inherent defects may neglect economies which vitally affect the success of the enterprise.

The following are good reasons for relocating:

1. Changes in business conditions may necessitate a move in self-defense, when a plant can no longer produce economically at the original location.

2. Continued expansion of existing plant capacity eventually reaches a point where economies resulting from further increase in capacity diminish. Increased overhead, rearrangement of facilities, purchase of expensive adjoining land, and other items in the aggregate may increase production costs much more than if a new plant were built at another location.

3. With growth and shifting of markets, a new location may make possible more economical distribution of finished products and quicker and better service to customers.

4. If new products or by-products are used or produced in large quantities, it may be economical to locate near an industry that produces or uses such commodities.

Location Procedure.—The same procedure used in selecting a location for a new factory may be applied in measuring the efficiency of an existing plant, or in determining which of two or more plants should be shut down when necessity arises to rearrange production capacity due to changing conditions. The procedure may be outlined as follows:

Assume that the sales manager and the operating manager from forecasts decide that existing capacity is inadequate to meet future demand. From tabulated sales sheets a sales distribution map is constructed indicating where the goods were sold the past year. Comparison with previous years will show in what sections of the country the market is growing most rapidly. If this map alone were considered, the factory would be located in the best market area. Such location would permit the quickest delivery of goods and the shortest haul for freight.

The operating manager estimates the number of new units and also the tonnage of raw materials required to meet the contemplated demand. The purchasing agent tabulates the origin and cost of each item of raw material. With these data another map is prepared indicating the best location with respect to raw materials. This map may be complicated by variations in the cost of the same material in different sections of the country, so that it is not merely a transportation map. Similar maps would be prepared showing advantageous locations as indicated by other influencing factors.

Knowing the number of machines, units, and other equipment that must be provided, the amount of power, boiler capacity, and fuel required to operate the plant is calculated.

A tentative plan for an ideal layout is made in which sufficient space is allotted for future expansion. The allowance for expansion is based on sales data and business forecasts. The layout will show how much land is needed, the most suitable dimensions, and what portions of the area must be level.

From maps indicating the effect of factors controlling the location, the undesirable territory is blocked out, thus by elimination reducing the field to a limited area. The most advantageous site in this limited area is selected for the proposed factory. The procedure followed in selecting the site consists of several definite steps, each step following in logical sequence and working toward the final goal—the actual determination of the most economical location.

Factors Controlling Location.—The following factors are generally considered significant, particularly for chemical plants:

1. Sources of raw materials.
2. Market for finished products.
3. Transportation facilities.
4. Labor supply.
5. Power and fuel.
6. Water supply and waste disposal.
7. Special factors influencing location.
8. Costs (capital requirements and unit production cost).

In no two industries are the foregoing factors likely to have equal weight. Their relative importance varies widely. Therefore, each problem requires that all factors be carefully evaluated. How this is done is described in the following sections.

Raw Materials.—The extent to which raw materials procurement influences the determination of an economic location depends primarily on the nature and source of the materials required.

Certain raw materials are known as basic or primary. This classification includes clays, coal, oil, minerals, and products of farm and forest. The main characteristics of such materials are large bulk and low unit value.

Industries using basic materials require large quantities and are usually located near the source of supply. Thus, potteries are located at the clay pits, smelters and refineries near mines, and wood-pulp mills and box factories near the forests.

Except by water or pipeline, it is not economical to ship low-cost bulky materials in quantity any great distance. Furthermore, it is important to be assured of a continuous and plentiful supply in order to avoid the expense of maintaining large stocks. Excessive inventories not only tie up capital but require additional storage and handling facilities.

Industries that must import basic raw materials from overseas carry large stocks to insure an ample supply. For such industries a seaport location provides the lowest delivery costs.

If the raw materials have a speculative price range, such as rubber, cotton, and hides, a manufacturer may be compelled to buy when the market is favorable and to buy in large quantity in anticipation of advance in price. In such circumstances, the expense of storage is necessary regardless of location; and savings in shipping costs may be relatively unimportant as compared with the weight of other factors, consequently nearness to source of raw material may not be a controlling factor. For example, the rubber industry prospers at Akron, Ohio—an inland location. Rubber, moreover is not a cheap material, the normal value being $300 or more per ton.

With perishable raw materials, a location near the source of supply is desirable in order to eliminate excessive losses from spoilage in transit and to avoid the expense of special storage and handling facilities.

Certain industries use the by-products or waste products of other industries as their essential raw materials, such as the manufacture of casein from skim milk, wallboard from bagasse, and gelatine from hide scrap. Such materials usually are bulky and inexpensive, and the cost of shipping over any great distance may be greater than the value of the material itself, so that a location near the source of supply is imperative.

Many industries use the finished products of other industries as raw materials. For example, shoe factories use leather from the tanneries. Printers and publishers purchase products of the paper mills. Paint manufacturers use pigments, synthetic resins, vegetable oils, and thinners. In fact, most of the products of the chemical industry are used as raw materials by other manufacturers. In such industries the determination of the economic location depends importantly on the cost of assembling the manufactured articles and materials at the plant.

When acids and other heavy chemicals are the raw materials, there is often a large number of sources of supply, so that the manufacturer has the choice of a number of reasonably satisfactory locations from the standpoint of the cost of securing such materials. On the other hand, when the supply of a particular manufactured product is limited to the production from one or two plants, the location of the source of supply has a definite effect on the cost of securing that material.

In studying the effect of proximity to raw materials on economic plant location, certain general methods of analysis should be observed. The proportion of value of each material to the value of the finished product should be determined. Materials representing a large percentage of the cost of the finished product indicate a location near the source of supply or at least a location which is competitive with other producers. If the material represents a small part of the production cost, the distance of the plant from the source of supply is not a controlling factor.

When large quantities of two or more bulk materials are drawn from different sources, a compromise location must be found to effect the lowest composite cost for these materials. The steel mills near Pittsburgh and Chicago are located where coal, iron ore, and limestone are easily accessible. Where several sources of the same material are available, analysis should be made of the cost of obtaining necessary quantities from each source, giving consideration to price and shipping costs and to the ability of the supplier to deliver the material promptly in the required quantities. In fact, to insure permanency of supply, it is important not to depend on only one source, as this puts the manufacturer in a vulnerable position. Permanency of supply must be assured or else satisfactory alternative raw materials must be developed.

It is also important to consider the quality and uniformity of the material from each source, since the use of inferior raw materials directly affects the cost of production. Excessive processing cost, substandard merchandise, and dissatisfied customers may all result from failure to obtain raw material of proper quality and uniformity. Calcium carbide manufacture, for example, requires limestone of exceptional purity and high calcium content.

Markets.—In analyzing the market for a particular product it is essential, first, to determine the geographical distribution and the density of sales in the various market areas and, second, to study the probable growth of the market in order to determine which areas show the greatest prospective demand.

After making a general market survey, the next step is to study methods whereby the product may be distributed from the point of production to the consumers at lowest possible cost. The location of an industrial plant with respect to its markets largely controls the cost of distribution.

Nearness to markets means accessibility, and accessibility is generally governed by transportation facilities and freight costs. This does not mean that the geographical center of the market area invariably is the logical location for the plant, although this usually is the case. For example, because Oklahoma City is nearer to Fort Worth, Tex. than to St. Louis, Mo. does not necessarily mean that customers, for any and all products, located in Oklahoma City can be served more economically from Fort Worth than from St. Louis. Under certain circumstances analysis of transportation facilities and costs may show that the reverse is true in spite of much longer haul. Cities that are junction points for a number of railroads and cities offering both rail and water transportation are good manufacturing locations as far as accessibility to the markets is concerned.

A manufacturer distributing a product over a large area may find, after studying transportation costs, that it is more economical to divide production among a number of plants rather than to attempt to serve too large a territory from a single plant. Sulphuric acid is accordingly produced in regional plants.

With such products as bottled acetylene gas which are shipped in heavy and expensive containers, the cost of distribution over large areas from one plant may be prohibitive.

The problem of distribution of finished products not only involves keeping transportation costs at a minimum but also includes giving prompt delivery service. If prompt deliveries cannot be made, the customer is inclined to purchase elsewhere. Thus, it may be necessary to use more expensive forms of transportation rather than lose business as a result of inability to give satisfactory service, or carry unduly large warehouse stocks in various territories where it is impossible to make prompt shipments direct from the plant.

In considering location due regard also must be accorded the amount of competition already in the distribution area. Study should be made of the existing plants of other companies producing the same product, and if their capacities are ample to supply the territory, an additional factory may increase the output beyond a reasonable limit of probable consumption. If a market is already oversupplied, it is poor judgment to locate another plant in that area. In many industries postwar production capacity is much greater than before the Second World War.

Transportation.—The study of plant location with respect to transportation involves consideration of all kinds of carriers—those that sail on water, travel on land over rails or highways, or fly the airways. The sea, rivers, and canals were the early routes of transportation; then the railroads exerted a powerful influence in directing industrial growth; and now with improved highways motor trucking has widened the distribution area and has brought manufacturers into closer touch with surrounding markets. Express delivery, parcel post, and air freight assist in providing quick and convenient distribution of compact, high-value products.

Transportation charges include freight costs on all raw materials and containers to the plant and on finished products to the market. These charges in relation to location have a decided bearing on production costs and the ultimate manufacturing profit.

Transportation by ocean, coastal, and inland waterway has the advantage of low cost but often has the disadvantage of low speed and infrequent service. Also, ship or barge cargoes usually require handling or reshipping from port or terminal to the destination, with the risk of breakage and delay, whereas railroads can make deliveries over sidings to factory or warehouse, and motor trucks can deliver direct to consumer's door without rehandling.

When a plant receives or ships large volumes of low-value commodities it should, whenever possible, be located on or adjacent to deep water, so that full advantage may be taken of the cheaper water transportation. Such transportation usually is distinctly advantageous, even though it may require an intermediate movement by railroad or motor truck between plant and ship-side. Industries in the Great Lakes region can ship by rail to the Atlantic Coast, then by boat via Panama Canal to the Pacific Coast, at less cost than by direct rail. Economically, the Pacific Coast is closer to New York than some cities in the Middle West. In some instances, inland waterways may provide dependable service at lower cost than railroads or motor trucks. In other instances, a railroad which parallels an inland waterway may equalize its rates with the waterway. Thus, processing industries that perform some operation on the product at various places en route to final assembly can, by taking advantage of "milling-in-transit" rates, often obtain freight concessions that give one site a decided benefit over other locations between the various sources of raw materials and the market for finished products.

The railroad freight rate structure within the United States is far too complicated for ready understanding in all its phases in this discussion. Every kind of material and every phase has its own problems and schedules. Identical materials have widely different rates in different parts of the country, and often are subject to gross inconsistencies within limited geographical areas. Class rates, distance scales, and blanket rates further complicate matters. Before a decision is made as to the location of a plant, a detailed transportation analysis should be made by a competent traffic manager in order to develop in full all pertinent factors.

Other questions to be investigated are: How many railroad lines serve the location under consideration? Do they directly tap the raw material and fuel sources? Do they adequately serve the markets? Do railroad companies cooperate with one another and with manufacturers? What are the demurrage charges and switching charges? Sometimes heavy charges are made for these services, burdensome rules imposed, and aggravating delays occur in switching freight. A belt-line railroad with uniform charge per car and efficient service is a decided advantage to any location.

The main highways throughout the United States parallel many of the principal railroads, and motor trucking has developed to the point where it is not only economical, but highly dependable. One of the main reasons for increasing use of the motor truck is the flexibility of this method of shipping. Railroads operate over definite routes and on definite schedules, whereas motor trucks can travel at any time to any point reached by highways. A shipment by truck usually can be sent to its destination by direct route, whereas the same shipment by railroad might require routing over a number of connecting systems with intermediate switching and delays in transit.

For short hauls the motor truck is practically without competition. For long hauls and carload quantities rail shipments are usually more economical and provide the most satisfactory service. However, through improved equipment, increased load capacity, and use of trailers motor trucks are giving good service over long distances. The cost of handling by rail LCL shipments is usually increased by cost of trucking between freight station and the plant unless the railroad can make store-door deliveries without an additional charge.

Passenger transportation for employees must be given consideration because where cost of fares to and from the plant is high, higher wages possibly would have to be paid than if plant were located where fares are low. The plant should be located where street cars, buses, or railroads provide good service, suitable schedules, and reasonable commutation fares and where the flow of traffic during shift hours will not result in overcrowded cars, causing discomfort and discontent. Another transportation matter that must not be neglected is the provision of ample areas for convenient parking of automobiles of employees.

Labor.—The importance of labor as affecting the economic value of a location depends upon the nature of the product manufactured and the relationship of labor cost to the total cost of the finished product. Although the average ratio of labor cost to value of all products in 1939 was approximately 16 per cent, labor in the chemical industries averaged only 11 per cent. In some lines of industry, however, labor may account for 24 to 50 per cent of the cost of the finished product, as in making of machinery, precision instruments, novelty goods, rayon, and some textiles. The substantial increases in labor rates since the Second World War make these percentages no doubt out of line, but the comparison between the different industries probably remains approximately the same.

Wage rates and labor costs are affected by supply and demand, quality of labor, local laws and customs, living costs and living conditions. These influences vary at different locations and affect the cost of labor.

In industries, such as some chemical lines where labor cost is relatively small, other factors assume major importance, and labor seldom exerts a controlling influence on the value of the plant location. Where a small proportion of skilled help is required, such labor may be brought to the new location or local labor may be trained for that particular work.

In other lines, large numbers of semiskilled laborers are needed. Skilled and semiskilled workers are found in concentrated groups in cities where existing plants have created a steady demand for a particular type of labor. Thus there are large numbers of automobile workers in Detroit, Mich.; tire makers in Akron, Ohio; silk spinners and weavers in Paterson, N. J.; and metal workers and machinists in Bridgeport, Conn. Such concentrations of labor often present serious problems affecting production costs and the ability of the manufacturer to meet his trade requirements.

Most important is the factor of supply and demand for labor. In some cities the demand for a particular class of labor may be sufficient to absorb the entire available supply. An increased demand will result in competition for this class of worker, with resulting increases in wage rates and labor turnover. Centers of labor concentration are likely to become fertile fields for labor unrest, resulting in strikes and shutdowns, thus increasing manufacturing costs.

If a plant is so located as to be unable to conveniently attract the proper type of labor, a manufacturer is generally forced to spend a considerable amount of time and money in training workers. Incompetent help increases manufacturing costs through high turnover, excessive spoilage, and reduced rate of production. A few years ago many textile companies migrated to the South to be near the source of raw materials and to take advantage of the large supply of cheap labor. Many such concerns found that they could not realize the savings anticipated. They were forced to spend large sums training workers and were still unable to attain the rate of production that they had achieved at their former locations where highly skilled, competent help was obtainable.

Sometimes the cost of available skilled labor is so high that a manufacturer can afford to train unskilled workers, thus meeting his needs at lower cost. The success of such a program depends primarily on careful selection of employees to be trained.

Cost of living also exerts an influence on wage rates. Wages in large cities are higher for the same class of labor than in smaller communities because the worker needs more money to obtain the necessities of life.

Prevailing living conditions have an important bearing on the ability to secure competent help. If the locality from which labor is drawn does not provide convenient and satisfactory living accommodations, a manufacturer may be forced to offer higher wages to compensate for increased cost for commutation or to actually provide living accommodations. Industrial villages, together with accompanying churches, schools, shops, and recreational improvements are expensive to construct and maintain. Such projects are seldom self-sustaining and usually result in an indirect subsidy to the worker, which must be considered a part of total labor costs.

Power and Fuel.—The statement has been made that industry follows coal. Although this is not literally true, coal is the prime basic commodity of industry, and the operation of factories, railroads, and public utilities depends largely upon it.

The construction of long pipelines and water shipments in large tank steamers have made oil increasingly available almost everywhere, permitting its use for producing power and heat for many industries. Natural gas and by-product gas also are used in manufacturing but not to great extent relative to other fuels.

The development of high-voltage electric systems has made economical distribution possible over hundreds of miles of network, thus lessening the influence of power as a deciding factor in plant location. However, in air-reduction plants, in the making of aluminum, and in synthetic ammonia, low-cost power is still a major factor.

The kind of power used has a direct bearing on the cost of operating a plant. The kind and amount of power required and the extent to which power affects the cost of the finished product may be the one controlling factor in deciding upon a plant location. Where abundant water power is available, electric power will be relatively cheap. For the same reason where steam coal is cheap both steam and electric power at low cost may be anticipated. Even so, it costs money to transport power, whether in form of electricity over cables, or coal in railroad cars.

Hydroelectric power for a single manufacturing plant may be more costly than steam power, when return on the investment is taken into consideration. The cost of a hydroelectric station with dam and water rights is estimated to be at least twice that of a steam plant of the same capacity. Unless there is sufficient natural water flow, or an ample reservoir, the water supply may diminish in dry seasons to such an extent that the capacity of the power station is seriously reduced, or even at times completely shut down.

A large steam power plant requires an unfailing supply of good-quality water for its boilers and a large quantity for condensers; hence a location with an abundant supply of good water, near coal deposits, is ideal for steam production.

In a large plant where power is important, dependence should not be placed on only one source of power or fuel. When there is little demand for process steam, it may be preferable to buy power rather than build a power plant, in order to save investment costs. However, plans should always contemplate building a power plant at a future date, if necessary. Therefore the cost and grades of fuel available at site must be investigated. Some coal is cheap because of low heat content, whereas higher priced coal may be far cheaper when considered in terms of its heat producing value. Freight on coal is paid on tonnage, not on heat units. Steam is used not only for making power and for general heating purposes, but also for evaporating, distilling, condensing, ventilating, drying, and to produce compressed air, vacuum, and refrigeration. It is also used as a reactant in numerous processes, as, for example, in water-gas generation. High-pressure and superheated steam is used in many operating processes. Often by study of power and steam requirements, it may be found cheaper to generate power even when low-priced power may be purchased. Where the plant processes require a large amount of low-pressure steam, as in a pulp mill or sugar refinery, generation of power may effect large savings. In this way electric power is a by-product of steam generation and may be had at less cost than the best purchase price obtainable.

Where there is a fluctuating daily demand for electric power in a community, off-peak power may be purchased at lower rates there by affording decided savings in power costs to a manufacturer having heavy power requirements during the off-peak period.

Water Supply and Waste Disposal.—Water is often an important item in deciding upon a location for an industrial plant, particularly for a chemical plant that uses large quantities of process water.

Bacteriological and chemical analysis as well as the available quantities from lakes, streams, and wells may be deciding factors. The presence of some mineral in the water may discolor or ruin the product. Of course, water may be filtered, softened, and purified, but all forms of treatment add to water costs and therefore to operating costs.

Sometimes low-temperature well or spring water may be utilized, thereby saving the cost of installing and operating refrigerating equipment. As an illustration, a rayon plant in Virginia realized a saving of $200,000 per year by locating where low-temperature spring water was obtained.

The minimum flow of water must be accurately known. Some plants operate on a 24-hr. schedule and cannot permit even a 1-hr. shutdown, as lack of water would cause considerable damage and expense. Accordingly, a river that in some seasons flows ten times as much as needed is of no use if at other times it is dry. Such a location will not meet requirements unless an impounding reservoir is constructed to take care of the dry seasons.

A knowledge of geology, and reference to hydrographic maps will often reveal underground water supplies that may be utilized to great advantage in locating industrial plants. The location for a smokeless powder plant in Tennessee was selected where the site was underlaid by a deep stratum of gravel, which it was believed would yield a plentiful supply of satisfactory water because of infiltration from the nearby Mississippi River. This proved to be true and saved building a filter plant and expensive intake and pipeline from the river, which would be costly to construct and operate.

Likewise at Louisville, Ky., the same thing was accomplished. Good-quality water of sufficient quantity to meet needs of plant was obtained from wells thereby avoiding use of river water that, because of frequent freshets and floods, would require a settlement basin and filtration plant. Underground conditions should not be guessed—test wells should be drilled to prove both the quality and quantity of the supply. The various depths that reliable information indicates as probable sources of water supply should be investigated. Experienced well drillers who have drilled in the neighborhood also can give helpful data.

The disposal of waste from a chemical plant is a subject that must not be overlooked in selecting a site, since it may be of such importance as to eliminate from consideration an otherwise desirable location.

Disposal of industrial waste is constantly becoming more and more difficult. A few years ago factories could dump almost any waste into a stream, but an ever-increasing population demands unpolluted water and an unpolluted atmosphere. Health authorities throughout the country are requiring industries to treat their wastes before discharging them into public water courses. A natural depression or low land on the site can be used as a dump for cheap disposal of useless waste sludges or solids.

Although some localities are without restrictions, such conditions will not always prevail. Therefore, an industry must provide means for immediate or future treatment of plant wastes, and the cost of such installation and maintenance must be regarded as a part of necessary investment and operating cost. Likewise, the effect of fumes and smoke in connection with prevailing direction of wind must be considered. A city location is not suitable for a plant producing obnoxious fumes and odors, as lawsuits may result in heavy damages. A city ordinance or an injunction may require either a costly remedy or shutdown of the plant.

Special Factors Influencing Location.—The selection of an industrial site may depend upon factors other than those previously noted. Under this heading are special requirements relating to the particular type of manufacturing operation under consideration and its operating methods and processes. For instance, a location that would be satisfactory for a single-shift plant might not do for three-shift or continuous process plant; and a part-time or seasonal operation might make out very well at a place that would be entirely inadequate for a full-time operation.

The size of the industry, the scope of business, and the specific plant requirements may have a decided effect upon location. This is particularly true of a small plant intended to serve a localized market.

When the plant to be located is small and a single building or small lot of land is all that is needed, then almost any site may be selected if the plant itself is not objectionable. Conversely, a large area is imperative as in dynamite manufacture where the law demands, and safety dictates, long distances between buildings containing explosives and from public highways, railroads, and neighboring dwellings. Obviously such a plant cannot be located in a populated area. Where very large areas are required, proximity to centers of population is prohibitive because of high cost of land and high taxes.

The nature of the business, and the kind and size of the buildings to be constructed will generally determine the topography desired. Some plants require large level tracts of land, as for example, where long buildings are to be provided. Rough and irregular land will necessitate increased construction costs due to excessive grading to accommodate large buildings. Thus, it may be cheaper to buy level land at a higher price, instead of moving much earth. On the other hand, as for instance the explosives industry, hilly terrain may not only be desired but may be demanded to afford natural barriers, which would otherwise have to be constructed at considerable expense. Sloping ground can be utilized to provide necessary fall for grades in the direction of load travel, for gutter lines, wheeling walks, and tramways, and to aid in transporting materials in process of manufacture.

In general hilly land is less expensive than more level land. Level land is as a rule used for high-grade farms or is held for real estate developments. If the proposed plant is small and the operations do not require that all buildings be on the same level, then the cheaper rolling land may be selected.

Meadow or lowlands may be bought at a low cost per acre, but such land may have a bearing value entirely inadequate for support of the proposed buildings unless expensive piling is provided. Furthermore, meadow land may be subject to flooding which seriously handicaps if not totally destroys the value as an industrial site.

A small area will involve only a slight initial investment in cost of land, and the real estate taxes may be comparatively insignificant. As land values increase with proximity to the heavily populated districts, a site in the heart of a large city will be unjustifiably expensive, if the plant can be just as well located outside city limits. If, however, the proposed plant will have a large payroll, and especially if many women are employed, then nearness to centers of population is a decided advantage and has a distinct valuation.

With development of air cargo transportation and extensive highway construction, industry will in the future tend to migrate into country districts, avoiding congestion and high costs of city locations.

Relation to other industries may be a ruling factor in selecting a location. Where a plant will utilize waste, by-product, or surplus material produced by another industry, or where the proposed plant will produce a waste or surplus by-product, which it is desirable to dispose advantageously, then the closer the plants are together, the better. A few examples of technical interrelations that have affected choice of location may be cited:

A plant to manufacture synthetic ethyl alcohol was located adjacent to an oil refinery, in order to be assured of an ample supply of low-cost gas, rich in olefins. Several plants to make synthetic ammonia have been located adjacent to electrolytic caustic-chlorine plants in order to utilize the by-product hydrogen. A plant to manufacture solid carbon dioxide was located adjacent to a soda-ash plant. In this case, the low-cost gas offset the relatively high freight to centers of consumption. A gelatin plant in New England was located centrally with respect to a number of tanneries from which it purchased hide trimmings. A plant to make synthetic ammonia and synthetic nitrate of soda was located on tidewater and in such position that it could (1) receive soda ash by water; (2) ship nitrate of soda by water to coastal points as well as abroad; (3) ship liquid ammonia by rail to the fertilizer and industrial centers of the East, at reasonably low average freight.

A plant that emits objectionable fumes, bad odors, large quantities of smoke, obnoxious industrial wastes, or creates loud noise will not be welcomed near populated areas and must of necessity be located where complaints will be a minimum. Even if wastes are not objectionable, a location should be selected where such wastes can be disposed of at a low cost and not create a nuisance. A cellophane, rayon, or food plant should not be placed where air is contaminated by soot, smoke, or dust.

Climatic conditions may have a bearing on plant location. Cotton and wool work requires humid air, and rayon requires rigid control of both temperature and humidity. Accordingly, weather requiring the least change to adapt it to ideal conditions is conducive to economy. Seasonal changes promote health and vigor, whereas hot and humid climates are blamed for low efficiency. Northern and temperate climates are therefore favorable to industrial activity.

The heating of factory buildings in cold climates where the cost of fuel is high may be an item of considerable expense, while on the other hand a warm location may require air cooling and refrigeration, thereby offsetting the saving on the expense of heating in a cooler climate.

Regions subject to frequent severe windstorms and to disastrous floods should be avoided. Building construction in tornado belts must be designed to resist hurricanes and to minimize delays in production occasioned by storms. Careful review of all local weather records is therefore recommended. Driftwood, deformed trees, and erosion of river banks indicate the extent of high water that may be expected. Broken tree tops indicate the severity of wind storms.

In order to provide for future expansion, a site should have sufficient adjoining unimproved land, or the necessary land should be included in the original purchase. This precaution is often neglected, whereupon high prices are paid for adjoining land that has been improved or has appreciated in value because of the construction of the plant.

City planning, zoning, local ordinances, restrictions, and building codes will have a bearing on selection of a site. Sound comprehensive planning will prove advantageous in locating a plant, effecting a saving in construction costs by providing adequate public utilities, highways, railroad sidings, and convenient villages for employees. On the other hand, regulations may be so stringent as to discourage industrial development.

Taxation and Regulatory Laws.—Fifty years ago industrial operations were only slightly restricted by law, and even 25 years ago only moderate limitations were imposed. Now, however, thorough investigation must be made for every location considered since there is wide variation in state regulations governing labor, minimum wages, industrial insurance, and the like.

Any study of plant sites must, of course, take taxation into account —not federal taxation, which has no special bearing on location, but levies made by the states and their subdivisions.

State taxation may be divided into two general categories:

1. Income, franchise, sales, and license taxes.
2. Ad valorem or property taxes.

In the first classification the income tax is the one that must be given the most thought, especially where in the locality under consideration there is already heavy plant investment. The reason for this is readily apparent when it is realized that many states in setting up the basis for the income levy use in their apportionment factor only the amount of property owned and not the volume of business done. Such practice results in a direct burden on production. Consequently, the most equitable form of impost is usually found in those states which embody in the apportionment factor not only property holdings but also the receipts from business transacted.

In its inception the state income tax was intended largely to replace the general property tax; however, its result has been merely alleviating and, it acts as an additional toll.

In considering the general property, or ad valorem tax, it must be remembered that in the United States there are more than 175,000 independent and semi-independent political units, each with powers permitting the raising and spending of money. This condition produces a wide divergence in methods of administration and procedure.

Depending somewhat on the type of community, urban or rural, rates of tax differ, the approximate range being from $5 to $100 per $1,000 of valuation. Some localities make special concessions to manufacturers in the form of (1) low assessments; (2) exemption of machinery, manufactures, and raw materials; (3) exemption of plant real estate from taxation for a term of years.

The present trend toward decentralization and the placing of plant units in widely separated agrarian communities makes this tax worthy of special study.

Unit Cost.—The most important of all steps in location study is the summation and analysis of all costs, actual or estimated, of every item that enters into the construction and operation of the plant, and into the marketing of the finished product at each location considered.

These costs include the cost of all purchases, such as raw materials, fuel, power, supplies of various kinds; all labor, direct and indirect, production labor, service labor, office help, supervision and plant management; transportation charges; and overhead expense including taxes, insurance, and capital charges on cost of land, buildings, equipment, and service facilities including village if required.

The summation of all these direct and indirect charges is the total operating cost at that particular location.

The unit production cost is the total of all expenses to operate the plant per year divided by the actual number of units produced or estimated to be produced annually at the specific location under investigation. It is the lowest unit cost that is so diligently sought. The unit cost figure indicates the economic value of a location. When two or more locations are under consideration, unit costs will indicate which is the optimum.

The cost study must be prepared with greatest accuracy as unit cost figures may differ by only a small amount.

The best location for a factory is where the finished product can be produced and marketed at least expense (that is, site with lowest unit cost) and should be the final selection, unless overruled by some intangible factor such as advertising value, political value, competitive reasons, or consideration of future needs, trade trends, or business policy.

Conclusions.—The methods and procedures outlined herein have been used in numerous location studies and in determining the relation of plant location to production costs. This relationship is sometimes ignored by manufacturers who fail to realize the importance of location either as a handicap or an advantage in their struggle for minimum production costs. Regardless of how elaborate or highly scientific the layout or how modern the equipment of the plant, or how intelligently managed and adequately financed a company may be, if the plant is improperly located, the production cost will be adversely affected. An error in plant location may result in high production costs during the entire life of the plant. When land is bought and buildings constructed, the investment is usually so substantial that the location can be changed only at great expense.

A location which was ideal at the time the plant was built may subsequently become decidedly less efficient. Sometimes long-established firms are apt to disregard changing social and business conditions as factors influencing the economic value of an established plant even though a new location might show sufficient savings to justify a change.

Although cost analysis determines the value of a specific location, there may be special cases where other reasons justify a location arbitrarily in contradiction to the findings of the cost study. Competition, trade trends, or business policy may exert greater influence than the immediate actual cost of operation. Nevertheless, the success of any business depends importantly on the ability of the management to meet changing conditions. No manufacturer can afford to disregard the vital relation of location to operating costs.

CHAPTER IV

PLANT DESIGN

By R. P. Genereaux[1]

Industrial plant design involves use of engineering knowledge, experience, judgment, ingenuity, and common sense. In very general terms, design consists of translating functions or ideas to defined facilities for changing materials chemically and physically. The definition of plant facilities must permit their construction and operation to produce an adequate return on the investment. Consideration must be given to safety, low capital investment, low inventory, adequate operability, economical minimum of operators, low maintenance, and consideration of future changes, including production increases.

Plant design is only one of many functions required in the development from an idea to produce a material to the operation of a successful commercial plant. Other functions that require complete integration include chemical, mechanical, and physical research, market research, economic studies, process development, machine development, operating know-how, financial backing, purchasing of raw materials, sales and sales development of finished products, selection of plant site, production and purchasing of equipment and construction materials, and plant construction. To assist effectively in this integration, the design engineer should take time to know the people in the other groups, to know their functions, their capabilities, and their problems. It is advisable to seek means for exchanging information understandably.

Sequence of Design.—The sequence in development from an idea to a plant varies with the magnitude and nature of each project. Each project should be studied so that unique factors are analyzed. It is highly advisable to review a given project at intervals in the sequence to determine the justification for proceeding. As the project develops, the information becomes more firm for calculating return on

[1] Assistant Manager, Design Division, Engineering Department, E. I. du Pont de Nemours & Company, Wilmington 98, Del.

investment, which is the real pay-off. The following sequence pertains to a complete chemical plant and is subject to modification to suit each specific case. Steps in the sequence are

1. The idea.
2. Process development.
3. Preliminary design.
4. Estimating.
5. Final design.

1. *The Idea.*—The idea to enter the commercial field with a product might come as a result of a research discovery, or from a market survey on an existing product. Research might be necessary to secure a workable process, a suitable product, or an adequate market. It is then important to evaluate at this early stage the probable success to determine if further work is justified.

2. *Process Development.*—The next step might include further process development in pilot plant or semiworks equipment, in order to

a. Determine on a large scale the workability of the process.
b. Secure design data for full scale plant.
c. Produce material for market evaluation.

During this stage a description can be prepared of the chemical process with material and heat balances and the process conditions, such as temperature and pressure ranges, cycles, methods of addition or separation, evaluation of continuous and batch operations, preliminary study of materials of construction. During this time the design engineer should become acquainted with the project to secure firsthand background and to participate in suggesting types of pilot-plant equipment and the kind of design data that will be required.

An approximate economic evaluation can now be prepared to determine if the prospects for a sound venture are adequate. The evaluation can include a rough estimate of

a. Market.
b. Capital investment.
c. Inventory of raw, intermediate, and final materials.
d. Other working capital, such as cash and accounts receivable.
e. Production cost.
f. Sales cost.

3. *Preliminary Design.*—The next step can be called "preliminary design" of the full scale plant. This is the most important phase for the design engineer, as it offers the greatest opportunity to crystallize a balanced plant. This is the stage where ingenuity and experience on

the part of the design engineer pay off. There are two objectives:

a. To secure a firm definition of the scope of the plant.

b. To secure a firm estimate based on the minimum of drafting.

It is necessary to determine the true requirements in facilities and not to accept unstudied desires for specific items. It is too easy to do things as they have been done before. If the same facilities for a given function have been selected or used for 8 or 10 years, that is perhaps reason enough for consideration of change. Alternative types of equipment and materials of construction must be studied and compared as to suitability, simplicity, and low maintenance. In translating the process functions into equipment, there is opportunity to design or select the most suitable types to minimize the number of pieces, to select operable equipment with low maintenance, and to minimize on such facilities and equipment as storages, spare equipment, and control instruments, and to utilize a maximum of standard equipment. Design should keep in mind the value of the construction viewpoint of low cost by eliminating unnecessary refinements.

For designing and selecting equipment and facilities, it is necessary to have certain data. Time would be wasted if the engineer waited for all the necessary data to be collected before commencing his design. Following are factors that are generally required to commence active work assuming the process is firm:

a. A block chemical flow sheet has been prepared, showing complete chemical and thermal balances representing the chosen process.

b. Rates of reaction and time cycles and yields for each step have been determined.

c. Required temperatures and pressures, including tolerances, are known within reasonable limits.

d. Materials of construction have been chosen for corrosion test evaluation.

e. Commercial specifications for raw materials and products have been determined within reasonable limits.

An excellent tool to prepare at this time is an equipment flow sheet, sometimes called a "piping diagram." It should be simple and indicate all equipment, pipelines, valves, drives, and controls, indicating sizes and materials of construction. Such a diagram need not necessarily include quantity flows, temperatures, or pressures, as these are included on the process flow sheet. The equipment flow sheet serves as a basis of discussion with operating, process development, and research men. It is a definition of the scope of process facilities that can be understood by all and modified until it suits all requirements, including consideration of the economic life of the equipment and the usual increase in plant capacity after 6 months operation.

Following agreement on the equipment is the preparation of preliminary arrangement sketches to secure the most adequate location to allow for movement of materials and equipment, the location of centralized controls, provision of a minimum of building by placing a maximum of equipment outdoors, accessibility to piping, equipment, and other items for ease of maintenance and repairs. Consideration must be given to fire, health, and explosion hazards, and to personal safety. Specialists in the fields of electrical, power, architectural, and civil engineering can contribute.

When the following data are available a reasonably complete facilities definition can be developed by judgment, calculation, and application of known engineering principles and processes:

a. Firm specifications on raw materials, reagents, and products.

b. Unit processes, not susceptible to reasonably accurate calculation to determine facilities requirements, have been demonstrated by test.

c. Corrosion rates have been determined on the critical materials of construction.

d. Raw material, intermediate, and final product storage and packaging requirements are specified.

e. Manufacturing costs can be predicted for use in calculating return on investment.

f. Sales forecast is available, including some prediction of probable future expansion requirements.

Determination can now be made of the process requirements for steam, water, electricity, inert gas, fuel, air, and other services. Preliminary design for estimating purposes can be prepared for the building with heating, ventilation, lighting, electric power, plumbing, drainage, instrumentation, etc. This requires considerable discussion with other engineers skilled in such engineering fields as architectural, steel, concrete, electrical, ventilating, and power. All the information thus developed is a definition of the scope of work to be estimated. In addition, there is involved power plants, water supply, air supply, electrical power supply, warehouses, change houses, laboratories, gate houses, first-aid rooms, offices, cafeterias, fire equipment, and waste disposal.

Consideration should be given to building materials and the types of buildings, such as mill or functional; multistory or single story.

For a firm estimate, it is necessary to have selected the plant site. Selection involves such factors as

a. Source of raw materials.

b. Source of water and its characteristics.

c. Source of fuel and electric power.

d. The factors involved in treating and disposing of wastes.

e. Drainage and soil conditions.

f. Transportation facilities, such as by water, railroad, and highway.

g. Markets for products.

h. Labor and housing.

i. Climate.

j. Taxes.

Plant layout can now be prepared and consideration should be given to future expansion with a minimum of immediate expenditure. Layout includes consideration of flow of materials in and out, requiring docks, railroad tracks, and roads. Pipelines, power lines, sewers, ditches, adequate waste disposal, fences, outside lighting, parking lots, etc., must be arranged to avoid interferences and unnecessary costs. Each part should be considered on its own merits and in its relation to the rest of the plant. Climate plays an important part in deciding on type and need of certain facilities. Wind and snow loads, amount of rainfall, and temperature ranges are the principal items. Borings and soil analysis are required for determination of type of substructure. For a complicated plant, considerable judgment and critical attention are required to achieve a well-defined scope of work with a minimum of detailed development, suitable for preparation of an estimate of adequate accuracy.

4. *Estimating.*—Estimating is a field in itself, and there is no substitute for experience and up-to-date information on construction and material costs. The estimator must have a good knowledge of the site and of the proposed plant. He must have a sense of what is missing in the definition. Discussion with the design engineer can be of considerable value in achieving a sound estimate.

The accuracy of an estimate is in direct proportion to the time available, the firmness of definition of the scope of work, and completeness of drawings and specifications. When drawings and specifications, while preliminary, are adequate for defining the scope of work except for details, it can be expected that estimates will be firm and within ±10 per cent. Based on preliminary drawings and specifications, firm estimates can be considered little more than budget estimates as compared to contractors' estimates used for bidding, which are based on complete plans and specifications.

There are four general classifications, as follows:

a. Order-of-magnitude Figures.—These figures are based on a very general definition of work, usually agreed upon between the operating and design personnel after relatively short discussion. Drawings and specifications are not prepared. Based on a broad, general appreciation of scope of work, the figures are prepared by using cost data from similar completed work factored up to current construction cost index, by cubing buildings or by using engineering judgment in the absence of cost data for similar work. These figures are used only for broad, quick process or project evaluations, and prior to preparation of preliminary design. Time is the important consideration, and accuracy may vary up to ±35 per cent.

b. Preliminary Estimates.—These estimates are based on an essentially complete definition of work as of the date the estimate is prepared. However, because of time limitation, design work is not carried beyond the preliminary stage, and as design develops numerous changes in the scope of work often occur. The estimate is figured from very preliminary drawings, flow sheets or sketches, and rough specifications. It is largely based on cost data from similar completed work factored up to the current construction index and by cubing buildings. Usually there is not sufficient time for an inspection of the site to evaluate job conditions, interferences, and dismantling and moving. The estimate does not contain much detail. These estimates are used for process and project evaluations, and also for securing authorization to proceed with final design and procurement when facilities are urgently needed and the return on investment is sufficiently high to absorb possible extra capital investment occasioned by firming up the work after authorization. These estimates are usually accurate to within ±20 per cent.

c. Firm Estimates.—These estimates are based on essentially complete definition of work firmed up by design study. Drawings and specifications, while preliminary, are complete except for details and will permit a fairly complete quantity take-off to be made. Quotations from vendors are obtained for equipment. The estimate is completely detailed. If the scope of work is not changed, these estimates should be sufficiently accurate to permit the work to be completed within ±10 per cent.

d. Check Estimates.—These estimates are based on complete information and are usually made when the construction work is 60 per cent physically complete, taking into account actual expenditures and commitments and an evaluation of the work to be completed. These estimates are used when necessary for supplementary requests.

On completion of the estimate, it should be reviewed critically by personnel from the operating, estimating, construction, and design groups in meeting. This is an opportunity to check on possible omissions, and frequently the dollar value of an item may eliminate differences of opinion on the necessity of certain items. Most of these last-minute decisions can be eliminated by individual estimates during preliminary design.

The final cost sheets on manufacturing and sales can be prepared simultaneously with the estimate, following which the return on investment can be calculated, knowing

a. Net profit, which is selling price less the manufacturing and sales cost.

b. The total investment consisting of plant investment, allocated facilities, material inventory, and working capital.

Papers can then be prepared to present the complete picture to management for approval.

5. *Final Design.*—If the project is approved, final design is launched. This phase can be divided into two parts:

a. Design for purchasing.

b. Design for construction.

Design for purchasing includes preparation of detailed drawings for fabrication of equipment and specifications for nonspecial and standard equipment and materials. It is important to prepare lists and to keep them up-to-date. Functions involved in procurement are

a. Preparation of details and specifications.

b. Securing of quotations.

c. Review of quotations for prices, delivery dates and adequacy of meeting specifications.

d. Placing order.

e. Securing vendors' certified drawings.

f. Inspection in vendors' shops.

These functions require close working between design, construction, and purchasing.

Design for construction includes preparation of drawings and specifications for the work to be done on the plant site, including the procurement of materials specified but not procured by the design group.

Timing is an important factor to secure an operating plant at the earliest time commensurate with the availability and delivery of equipment and materials. Timing is important throughout all phases of research, process development, design, estimating, procurement, and construction. Interlocking schedules must be prepared and reviewed at intervals. Schedules should be tight enough to show up bottlenecks. Schedules can assure that first things are being done first.

Design Costs.—Design costs should be estimated at the beginning of preliminary design to determine the approximate amount for complete design. In general about 30 per cent of this design cost should be allowed for preparation of the preliminary design and firm estimate. The total design cost as a per cent of the total plant investment in general varies inversely with the total investment. There is no definite measure of how much design money should be spent. Factors influencing it are novelty of process, time allowance, and degree of perfection required. As a caution, changes are often costly and to minimize them requires very close cooperation of all personnel and straightforward thinking, with a minimum of opinion and a maximum of fact.

Detail drawings for fabrication of special equipment and specifications for standard equipment come first. Steel drawings at an early stage are needed to avoid late delivery. Then follows the preparation of equipment arrangements, building drawings, electrical, ventilating, etc. Consideration should be given to sequencing construction drawings so the construction work can be done in orderly sequence, such as underground lines, foundations, drainage, roads, etc. The design man should visit the site to follow the job, to adjust the design schedule to meet changing construction requirements, to interpret unique features, and to learn how to do the job better the next time.

CHAPTER V

OPERATIVE INVESTMENT

By R. A. Kinckiner[1]

Investment is one of the major elements in chemical engineering economics. Functionally it can be viewed from several different viewpoints. The banker looks at investment from the viewpoint of finance: How can capital be procured and under what terms? What is the risk which is involved? The accountant looks at investment from the viewpoint of bookkeeping: How should the investment be classified in the financial structure of the company? What is the proper rate of depreciation, or obsolescence? What adjustments in the capital accounts are required to reflect the changes in physical equipment? The chemical engineer looks at investment from the viewpoint of the cost of construction required for plant installations: What are the elements which make up plant investment? Which of these elements can the chemical engineer influence in the design, construction, and operation of plant units? What means can the chemical engineer utilize in effecting economies in investment? It is with the viewpoint of the chemical engineer that this chapter deals.

Course of Construction Costs.—Construction costs have risen steadily over the past 30 years. It is, therefore, important that the chemical engineer know the answer to the foregoing questions so that investments can be held to a minimum consistent with economy of manufacture, quality of product, and safety.

To illustrate the magnitude of the rise in the costs of construction, a plot of the index of construction costs[2] for the period 1915–1946 inclusive, is shown in Fig. 1. The general trend clearly has been upward. The costs increased rapidly during the war period 1914–1918 and for 2 years thereafter. Following a brief period of correction in 1920, 1921, and 1922, costs leveled off until the rise began again at the

[1] Assistant Director, Engineering Research Laboratory, Engineering Department, E. I. du Pont de Nemours & Company, Wilmington 98, Del. The content of this chapter is based largely on material presented before the American Institute of Chemical Engineers, Atlantic City, N. J., Dec. 1–4, 1946.

[2] Compiled monthly by *Eng. News-Record.*

start of the war period in 1940. As of the end of 1946, the index was over three times that at the outset of the war in 1914. It will also be

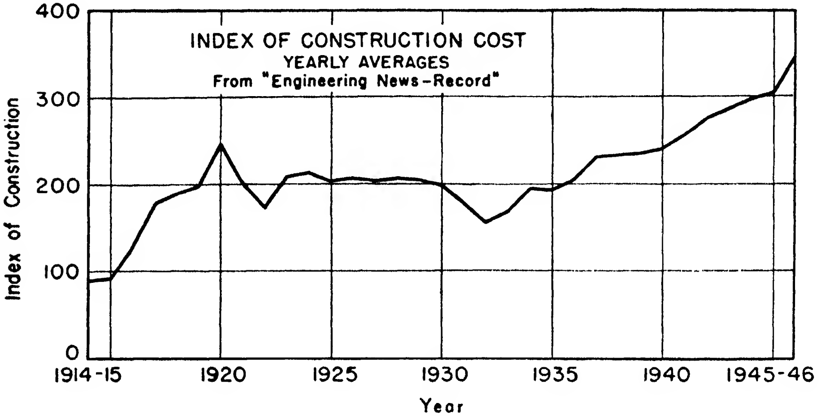

Fig. 1.—Index of construction cost.

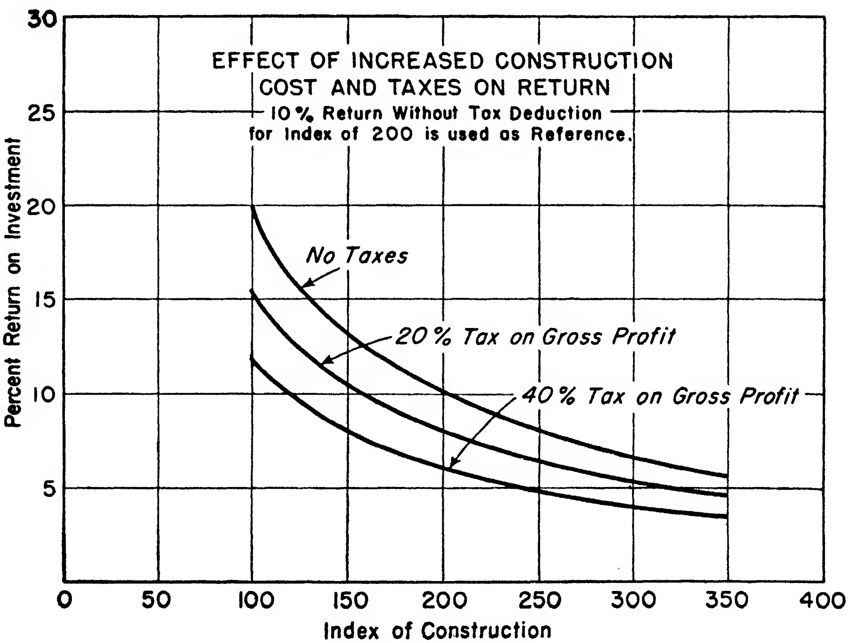

Fig. 2.—Effect of increased construction cost and taxes on return.

noted that after the First World War, the index leveled at a point approximately 100 per cent higher than it stood just previous to that war.

Return on Investment.—What is the effect of an increase in construction costs on the return on investment? Figure 2 shows the relationship and illustrates the extent to which the problem of procuring an adequate return can be intensified by high tax levels. Percentage return is plotted as the ordinate and the construction index as the abscissa. The top curve shows the return without deductions for taxes. To produce this relationship, it has been arbitrarily assumed that a 10 per cent return would be earned at an investment level corresponding to a construction index of 200 (which was approximately the level in the period just prior to the Second World War); the return for the other levels has been calculated for the same dollar income. At 1946 levels of construction costs (approximately 350) the return would be less than 6 per cent. The other two curves show, respectively, the return after deduction of arbitrary tax rates of 20 per cent and 40 per cent from gross profit. It will be seen that the return at the index of 200 falls to 8 per cent and 6 per cent, respectively, and at 350 to 4.5 per cent and 3.5 per cent.

As a compensating factor for higher costs of construction and increases in tax rates, commodity prices tend to rise correspondingly. Business must earn a profit over a reasonable period or it will cease to exist. The dollar value of economics also tends to keep pace with changes in construction cost, thus justifying higher investments. However, commodity prices are also determined by competition, and companies with investments made at peak levels of construction cost are often at decided economic disadvantage over considerable periods of time. Moreover, increases in the costs of construction make financing more difficult.

Analysis of Investment.—To understand thoroughly the important part that the engineer can play in maintaining investments at a minimum level, it is desirable to analyze the investment in a manufacturing plant, the unit of industry on which the chemical engineer's efforts are largely expended. Plant investment can be divided into four classifications: the first, and most important class, covers manufacturing facilities; the second, power facilities; the third, general facilities; and the fourth, working capital.

The investment which is grouped under "manufacturing facilities" includes equipment, buildings, and land involved directly in the manufacture of the product. The remaining classifications are not so well known, and the make-up of each is presented in some detail to permit more thorough examination.

"Power facilities" usually include all equipment, buildings, and land required for the generation and distribution of

Steam.
Electricity.
Compressed air.
Process water.
Cooling water.
Refrigeration.
Vacuum.
Fuel gas.
Inert gas.

Items of investment usually grouped under "general facilities" include all equipment, buildings, and land for such things as

Change-houses.
Cafeterias.
Roadways.
Railroad sidings.
Shops.
Administrative offices.
Shipping facilities.
Warehouses.
Laboratories.
Hospital.
Fire protection facilities.
Drainage and sewage.
Industrial waste disposal.

The fourth classification, "working capital," is probably the least known and least understood. Yet it is just as real an investment as any of the others. It includes

a. The value of raw materials and supplies which are carried in stock.

b. The value of material in the process of being manufactured.

c. The value of finished products which are carried in stock.

TABLE I.—DISTRIBUTION OF INVESTMENT FOR THREE PLANT INSTALLATIONS

	Case 1, %	Case 2, %	Case 3, %
Manufacturing facilities	78	49	35
Power facilities	6	19	9
General facilities	4	10	9
Working capital	12	22	47
Total investment	100	100	100
Indicated return based on manufacturing facilities alone (assumed)	20	20	20
True return based on total investment	16	10	7

d. Accounts receivable, which represent the value of the finished product which has been shipped to the consumers and for which payment has not yet been made.

e. Cash and miscellaneous items.

When considering a manufacturing project, it is essential that all elements which make up these four classes of investment be included and carefully weighed if a sound conclusion is to be reached. A common mistake in economic studies is to base justification for a capital expenditure solely on the investment for manufacturing facilities. Manufacturing facilities constitute a portion only of the total investment. Significant errors will be introduced if decisions are based on this class of investment alone. Table I substantiates this statement. It shows the distribution of investment for three plant installations: In Case 1, the investment in manufacturing facilities is 78 per cent of the total, the remaining 22 per cent being distributed fairly uniformly over the other three classes. In Case 2, the manufacturing facilities are of lesser magnitude, being only 49 per cent of the total. Power facilities and working capital are fairly high, being 19 per cent and 22 per cent, respectively. Case 3 was included to illustrate the effect on working capital of a manufactured product which has a high unit value. The working capital constitutes 47 per cent of the total investment.

The lower part of Table I compares the return based on the total investment with that based on manufacturing facilities alone. If the indicated return based on manufacturing facilities alone is assumed to be 20 per cent for each case, then the true return on total investment would be 16 per cent for Case 1, 10 per cent for Case 2, and only 7 per cent for Case 3. In Cases 2 and 3 the difference is certainly of sufficient magnitude to affect the possible success of the venture.

Allocated Investment.—It is next necessary to consider methods of handling the investments involved in these various classifications. How are they determined? How are they used? When a new integrated plant (that is, a plant in which all facilities are being supplied to the exact extent that is required) is under consideration, the problem is simple. In these circumstances, estimates of construction costs, which are made directly from design drawings and various project data, cover the manufacturing, power, and general facilities, and it is only necessary to determine and to add working capital in order to obtain the total investment. But problems involving integrated plants are far less frequently met in practice than those involving additions, rearrangements, and modernizations. In these latter cases, it is usually not necessary and not practical to provide physically the exact amount of facilities that will be required, except for manufacturing facilities, where the same procedure is followed as for an integrated plant.

Power and general facilities are not usually installed to fit exactly the immediate needs of the manufacturing facilities, but rather in block units which offer the greatest degree of economy over the near future. In these circumstances, to get a correct picture of the total investment contemplated, the proportion of the various power and general facilities that will actually be used in the proposed production is estimated and added (together with the estimated investment in working capital) to the investment required for the direct manufacturing facilities. Such apportioning of investments is commonly known as "allocation," and the apportioned investments are called "allocated investments." Likewise where common manufacturing facilities are involved—for example, in grinding, in drying, or in catalyst preparation—it is also necessary to allocate that proportion of such common manufacturing facilities which are to be used.

Determination of Allocated Investments.—Allocated power facilities are preferably determined by estimating the quantities of steam, electricity, water, etc., which will be consumed and then multiplying these quantities by the unit investment for each facility. Allocated general facilities are likewise determined, but in this instance the quantities on which the estimates are based involve manpower for change houses, cafeterias, and hospitals; investment in manufacturing facilities for shops and fire protection; the weight or bulk of the product for shipping facilities and warehouses; and a combination of these factors for the other elements. Allocated investments in power and general facilities may also be based on existing ratios of these facilities to investment in manufacturing facilities, but this practice cannot be fully recommended since under some circumstances it can lead to significant errors.

Question may arise regarding the proper unit value of the various power and general utilities in order to estimate the magnitude of the allocated investments. A conservative rule is to use the higher figure of either replacement or book value. However, there are exceptions to this rule because under some circumstances such facilities may have no value. To illustrate, consider a case where for sound reasons no further expansion is to be made at a given plant site except in the manufacture of those products that are already being produced. Suppose that the power facilities that are installed are more than sufficient for existing production or for any expansion thereof that can be foreseen. Under these conditions, it may be entirely proper not to charge power investment to any contemplated investment in manufacturing facilities, since in fact the investment in power facilities has already been made, and the investment in these facilities will be idle if existing production is not expanded. It would clearly be shortsighted to refuse to expand manufacturing facilities where this could be justified without allocation of power facilities but not with allocation of power facilities.

It must also be recognized that at times allocated facilities, both power and general, can be credited. Where the modernization of manufacturing facilities results in a net reduction in the use of power and general facilities, and where future use for these facilities exists, it is sound practice to credit such facilities to the extent that their use is reduced.

Determination of Working Capital.—To determine working capital, it is necessary to estimate the amount of raw materials and supplies to be carried in stock, the amount of material involved in the processing, and the amount of finished products to be carried in stock. In pricing these inventories, the raw materials, supplies, and finished product can be taken at actual or at book values. The material in process must be given an estimated value which represents the cost of the raw material plus the approximate cost of the manufacturing effort which has been expended. Average values are usually used. Accounts receivable covers the finished product which has been shipped to the customer and for which payment has not been received. The usual figure is the value of gross sales for one month, but this obviously depends on the sales terms that are extended to the customers. Cash is usually taken at one month's cost of operations, and covers all cash requirements for payment of wages, power if purchased, maintenance materials, and similar items.

Certain rules and practices have been discussed here, and other rules and practices will be met in accounting. Consequently it is necessary to emphasize one point. In every instance, the actual investment that is involved should be determined for the particular circumstances that surround each proposition or problem. Too much reliance must not be placed in general rules, which though sound enough for the majority of cases cannot cover the exceptional ones. Reliance should rather be placed on judgment and common sense to uncover the facts of each particular proposition, and few errors will then be made.

The Engineer's Responsibility for Investment.—To make a significant contribution to the reduction of plant investment, the chemical engineer must recognize not only the elements that he can influence but also the ways in which he can influence them. Actually every element in the four classifications is under some control of the engineer with the exception of accounts receivable and cash. This statement requires emphasis because engineers, whether in development, in design, or in operation, too frequently think largely in terms of processing equipment, which, as has been shown, is only a fraction of the total investment.

The engineer can affect the investment in power facilities by minimizing the use of steam, electricity, etc., in manufacturing, by increasing the efficiency of generation and by minimizing the cost of installation through effective design and erection.

The engineer can affect the investment in general facilities by minimizing the use of manpower in manufacture (in design and operation), by effecting economies in warehousing and materials handling (reducing the amount of warehouse space), and by minimizing the cost of installation through design and erection.

The engineer can affect the investment in working capital by minimizing raw materials in storage through effective scheduling of receipts, materials in the process of manufacture by proper design and control, and finished product in storage through reduction in the time of manufacture and through proper control of quality.

Elimination of Overdesign.—Some important means by which the development and the design engineer can reduce investment will now be considered. One of the greatest contributions that can be made is the elimination of overdesign. This responsibility does not rest solely with the design engineer, as many may at first think. It rests equally on the development engineer. The determination of accurate and significant data in the experimental stages of the development—whether it be in the laboratory, in the pilot plant, or in the semiworks—is a fundamental requisite for the elimination of overdesign. The extension of knowledge of the quantitative relationships that are involved in unit operations and unit processes is also necessary in order to provide a more accurate scale-up of experimental data. The design engineer, for his part, must resist a tendency to use an unnecessarily high "factor of safety." He must also resist a tendency on the part of the manufacturing personnel to demand more elaborate equipment and buildings than are needed for reasonable and economical operation. Above all, the pyramiding of factors of safety by the development engineer, the operating engineer, and the design engineer must be avoided. As an example of overdesign the erection of a $450,000 plant unit for a desired capacity of 5,000,000 lb. of product per year is cited. Because of the pyramiding of too strict quality specifications and of an unduly high factor of safety, the unit was overbuilt to the extent that it ultimately produced 12,000,000 lb. per year of salable product. That the excess capacity could eventually be used was fortunate. But many overdesigned installations are rejected because of inability to show a satisfactory return.

Continuous vs. Batch Processing.—A second important means of reducing investment is the use of continuous processing. The trend in recent years has been toward the substitution of continuous for batch processing. However, the pace can be accelerated. Of the many

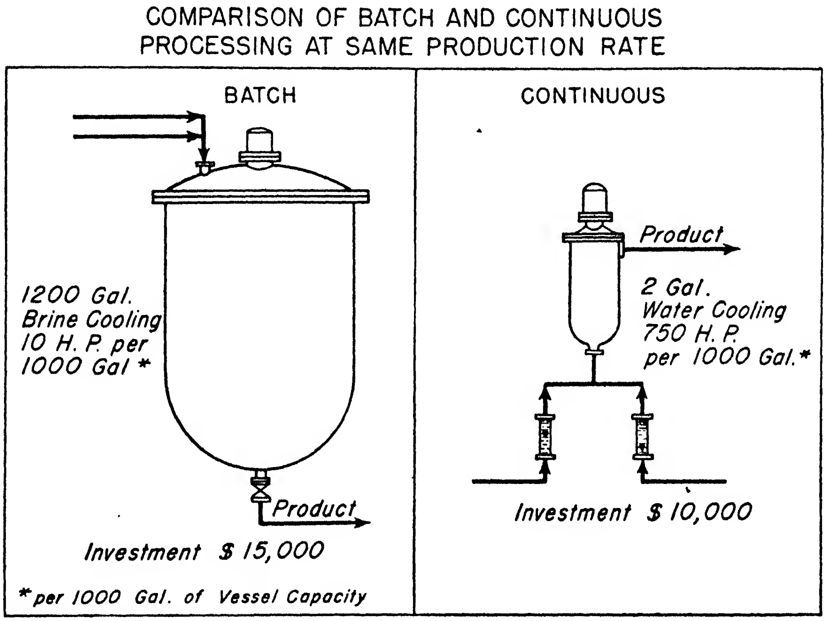

Fig. 3.—Comparison of batch and continuous processing at same production rate.

advantages, a reduction in the amount of investment per unit of output is among the more important. Although the cost of the processing equipment alone is sometimes greater for continuous operation, when all components of the investment are considered, the total investment is frequently lower. Contributions to a reduction in investment may be made through the more efficient use of power in continuous equipment and through a reduction in "material in process." The latter item, of course, becomes of greater importance as the unit value of the product increases.

Figure 3 shows an actual case involving the replacement of batch with continuous processing. For the batch process, a 1,200-gal. reactor with brine cooling was used; for the continuous process, a 2-gal. unit with water cooling. The rate of agitation was substantially higher in the continuous unit. For exactly the same production rate, although in this case using substantially higher power, the continuous process was installed for an investment of two-thirds that of the batch unit. Moreover, in respect to quality and manufacturing costs, the continuous unit was equal to or better than the batch unit.

Instrumentation.—The effective use of instrumentation to record and to control the various steps in the operation constitutes a third important method of reducing investment. The advantages of instrumentation for other purposes is better known than is its effect on investment. However, it has the advantage of keeping equipment operating at peak efficiency, thus providing greater capacity and permitting a reduction in its size. Instruments can detect the first deviation from the control point and can make the necessary correction immediately. Any variation from the desired rate of operation is thus held to a minimum. With manual operation, this is not the case. Experience indicates that the addition of instrumentation may increase capacities from 10 to 20 per cent. Since the increase in total investment due to instrumentation amounts to perhaps 5 per cent at a maximum, a significant decrease in the investment per unit capacity can thus be obtained.

Materials of Construction.—The proper selection of materials of construction must certainly be included as a fourth important means of reducing investment. There is little need to expand this statement. The importance is more generally recognized than is the case with the aforementioned methods. New materials, new types of construction, and new methods of testing are continually being perfected, and methods of fabrication and materials of construction, today, can meet almost any requirement of processing.

Equipment Development.—Lastly, no mention of methods of reducing investment would be complete without listing the development and the selection of the most efficient types of equipment. This point seems obvious, yet experience indicates repeatedly that the wrong equipment has been used. What is the reason? Fundamentally it is the failure to analyze or visualize properly the reactions and operations which take place. Much selection is by guesswork, even in the development stages, rather than by the painstaking analysis of the underlying factors of flow, heat transfer, reaction thermodynamics, and reaction kinetics. It is further necessary to project this analysis or visualization to operations of commercial scale, a task that is not easy but one that pays richly in dividends.

Summary.—To summarize, there is need for strenuous and persevering efforts to maintain investments at a minimum consistent with safety, economical operation, and salable quality of product. Construction costs have increased steadily over the past 30 years, and this trend will probably continue. Returns are further diminished by the high level of federal taxes. In competitive markets, excessive investments will be seriously jeopardized.

The make-up of plant investments has been analyzed, and the importance of properly recognizing power facilities, general facilities, and working capital has been demonstrated. It has also been shown that the chemical engineer can exert some measure of control over practically every element that enters the total investment.

Finally, five means of minimizing investments have been cited, namely,

1. Elimination of overdesign.
2. Use of continuous processing.
3. Use of control instruments to maintain capacity at a maximum.
4. Use of proper materials of construction.
5. Development and use of the most efficient types of equipment.

CHAPTER VI

PROCESS EQUIPMENT COSTS

PART 1. DATA FOR COST ESTIMATION

By Harding Bliss[1]

The chemical engineer is frequently confronted with the problem of estimating the manufacturing cost of a product, a significant portion of which is overhead cost of equipment. This figure, on an annual basis, is arrived at by the application of a reasonable percentage to the investment for equipment. In order to determine such investment accurately, it is necessary to carry out a refined design and to submit the resulting information to manufacturers for quotations. This is a time-consuming process, and in many instances such a period is not available. In such cases, it usually suffices to make preliminary estimates only of the sizes of various equipment items involved and to estimate the cost of such items rather than to depend on quotations. It is the purpose of this chapter to present generalizations with which it is possible to estimate the cost of various pieces of equipment, provided only the most important factors influencing costs are known.

Previous attempts at such generalizations[2] have been on the whole satisfactory, and the figures here given represent essentially a modernizing and extension of those beginnings. The costs given in this chapter are correct as of Autumn, 1945, with minor exceptions noted later. Percentage corrections to 1947 are indicated in most cases.

It must be realized at the outset that process equipment is usually specialized, and certain small changes may affect the cost to a considerable degree. These figures have been collected for equipment meeting the approximate specifications described in the text. While attempts have been made to provide factors by which costs for other specifications may be estimated, it should be noted that they are approximations only. For refined estimates, recourse must be had to manufacturers' quotations.

[1] Professor of Chemical Engineering, Yale University, New Haven, Conn.

[2] Bliss, H., *Trans. Am. Inst. Chem. Engrs.*, **37**, 763–804 (1941). Fowler, F. C., and G. G. Brown, *ibid.*, **39**, 241–254 (1943).

PIPE AND TUBING

The variables that govern the cost of pipe and tubing are, in general, the construction material, diameter, thickness, length, and quantity ordered. The first three of these are of considerably greater importance than the last two and are used as the principal variables in the compilations to follow. The last two have been eliminated by assuming random lengths, and quantities large enough to expect no further discounts for this reason. These quantities vary widely among materials but are of the order of several hundred to several thousand pounds. If cutting to special lengths is required, the costs should be increased by about 10 to 15 per cent for stainless and seamless steels, 3 to 5 per cent for nickel alloys, and practically not at all for copper alloys. The unit costs for various materials as functions of diameter and thickness are summarized herewith.

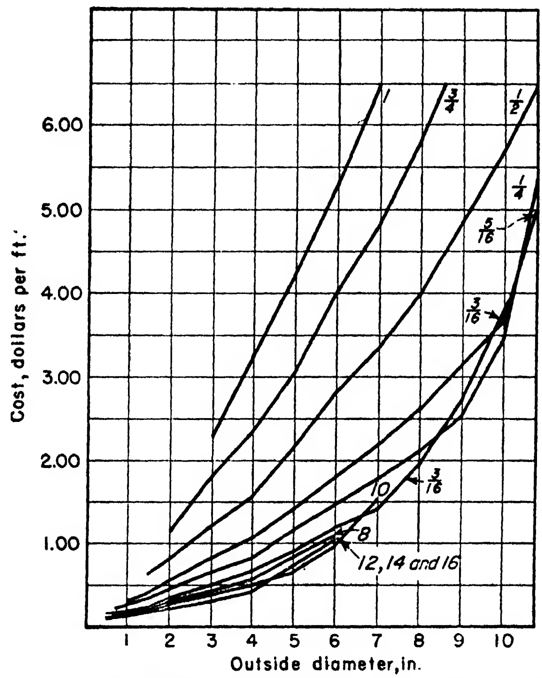

FIG. 1.—Cost of seamless steel tubing; thickness, inches or B.W.G.

Steel.—The cost of standard and extra strong steel pipes in sizes larger than 1 in. is approximately constant at 3.6 cts. per pound. For smaller sizes than these manufacturers' price lists should be consulted. Large outside diameter wrought-steel pipe (plain ends) costs 4 cts. per pound. The weights per foot of all these pipes are listed in the "Chemical Engineers' Handbook."[1] Spiral-welded steel pipe costs about 6 cts. per pound except in sizes below 6 in. where it is about 20 per cent higher. These figures should be increased by about 30 per cent for 1947. The cost of seamless steel tubing, much more

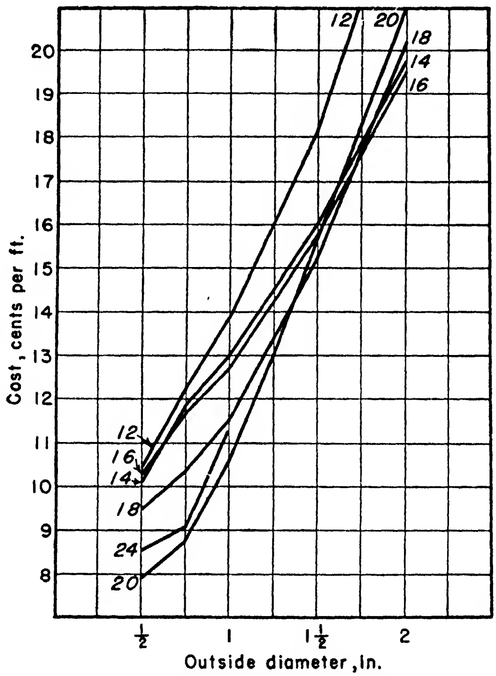

FIG. 2.—Cost of seamless steel tubing; thickness, B.W.G.

dependent on diameter and thickness, is illustrated in Fig. 1. This shows the cost in dollars per foot as a function of outside diameter for various wall thicknesses. No attempt has been made to draw these as smooth curves, since they are essentially irregular functions.

Because of the scale of Fig. 1, another chart with a larger scale has been prepared to show the cost of seamless steel tubing in smaller sizes. Such is the purpose of Fig. 2, which shows the cost in cents per foot as a function of diameter and thickness.

[1] Perry, J. H. (Editor), "Chemical Engineers' Handbook," 2d ed., McGraw-Hill Book Company, Inc., New York, 1941.

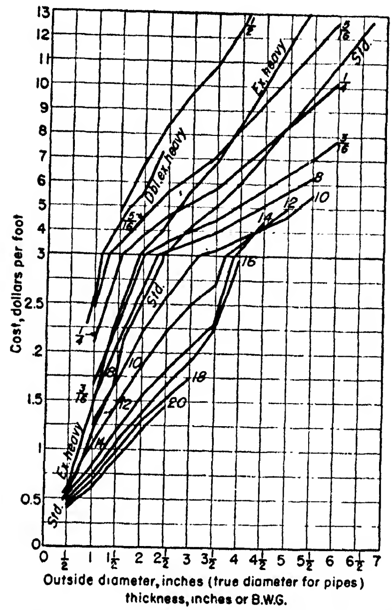

FIG. 3.—Cost of 18-8 stainless-steel pipe and tubing.

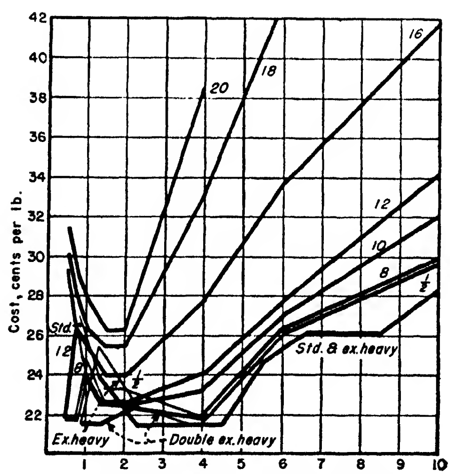

FIG. 4.—Cost of yellow-brass pipe and tubing; thickness, inches or B.W.G.

18-8 Stainless Steel.—The cost of this metal in seamless tubing and standard and extra heavy pipe is shown in Fig. 3 as a function of diameter and thickness. In the case of the pipes, the cost was considered as only a function of the "true" outside diameter.

Yellow Brass (65 Per Cent Cu, 35 Per Cent Zn) and Other Similar Copper Alloys.—The cost in cents per pound of yellow-brass pipe and tubing is shown in Fig. 4 as a function of the usual variables. The change of ordinate from cents per foot to cents per pound was made to permit the representation of many metals by a common line, since these metals differ in price from one another only by small constant factors, independent of size. For the other metals listed herewith the following figures in cents per pound should be added to the yellow-brass cost read on Fig. 4:

Yellow brass (72% Cu)	0.2
Red brass (80% Cu)	0.6
Red brass (85% Cu)	0.8
Red brass (90% Cu)	1.2
Admiralty	2.9
Tobin bronze (60% Cu, 39.25% Zn, 0.75% Sn)	5.3
Copper	−0.9

Since tables of weights per foot of ordinary yellow-brass seamless tubing[1] and standard pipe[2] are available, it is necessary to have only a table of conversion factors by which the weight of brass tubes can be multiplied to yield the weight of the metal in question. These factors are

Yellow brass, 72%	1.01
Red brass, 80%	1.02
Red brass, 85%	1.03
Red brass, 90%	1.04
Admiralty	1.01
Tobin bronze	0.99
Copper	1.05

Everdur 1010 (95.8 Per Cent Cu, 3.1 Per Cent Si, 1.1 Per Cent Mn) and Similar Alloys.—The cost of tubing made of this metal as a function of the same variables is shown in Fig. 5. For the other metals the following figures in cents per pound must be added to the cost read on Fig. 5:

[1] Badger, W. L., and W. L. McCabe, *op. cit.*, p. 635.

[2] Perry, J. H., (Editor), "Chemical Engineers' Handbook," 2d ed., p. 783, McGraw-Hill Book Company, Inc., New York, 1941.

Everdur 1015 (98.25% Cu, 1.5% Si, 0.25% Mn)	−16.0
Ambrac (75% Cu, 5% Zn, 20% Ni)	1.3
Super-nickel (70% Cu, 30% Ni)	6.8
Phosphor-bronze (95% Cu, 5% Sn)	−5.8
Phosphor-bronze (92% Cu, 8% Sn)	−3.0
Phosphor-bronze (89.5% Cu, 10.5% Sn)	−0.3

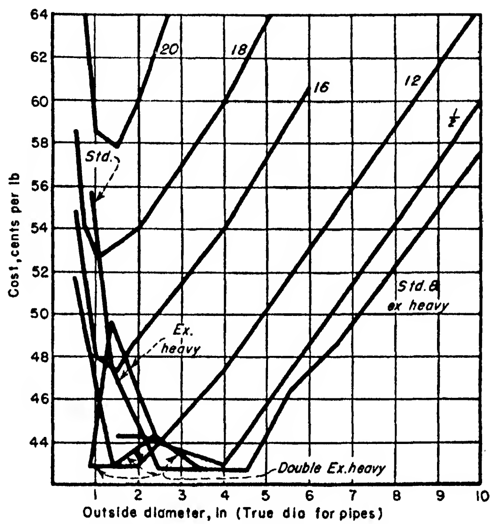

FIG. 5.—Cost of Everdur 1010 pipe and tubing; thickness, inches or B.W.G.

The conversion factors by which weights of brass tubes must be multiplied to yield the weight of the metal in question are

Everdur 1010	1.01
Everdur 1015	1.03
Ambrac	1.05
Super nickel	1.06
Phosphor-bronze, 5%	1.05
Phosphor-bronze, 8%	1.04
Phosphor-bronze, 10%	1.04

Monel, Nickel, and Inconel.—The cost of Monel pipe and tubing is plotted in Fig. 6 in the usual manner. For nickel it is necessary to add 10 cts. per pound to the costs as shown. The weight of either Monel or nickel tubes or pipes can be calculated from that of the corresponding steel tubes or pipes[1] by multiplying by 1.13.

[1] Perry, *op. cit.*, pp. 763, 771.

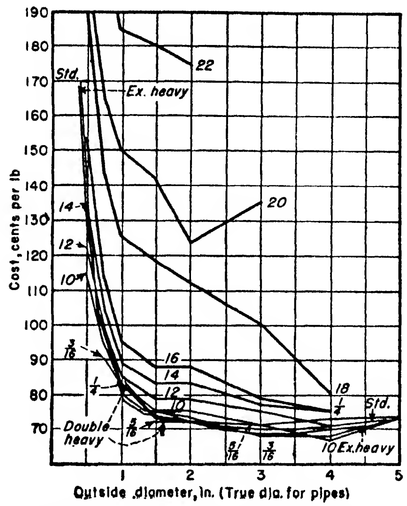

FIG. 6.—Cost of Monel pipe and tubing; thickness, inches or B.W.G.

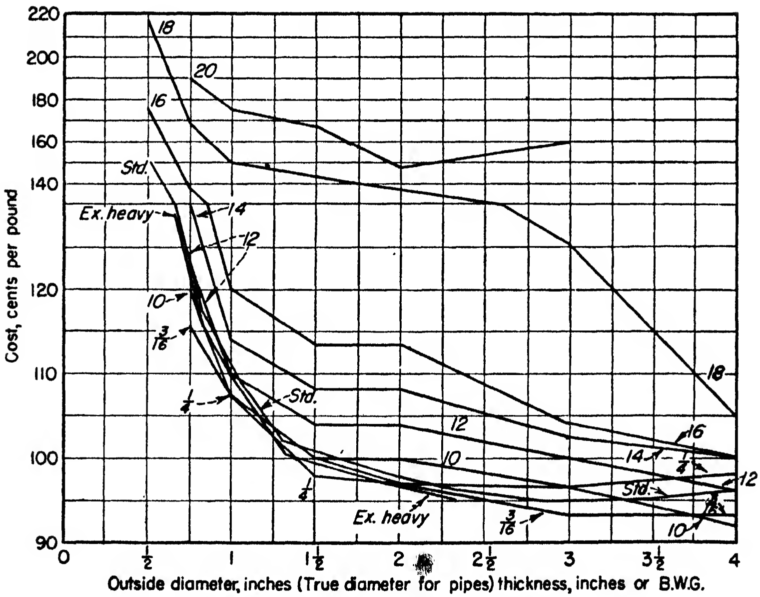

FIG. 7.—Cost of Inconel pipe and tubing.

The cost of Inconel pipe and tubing must be presented on another chart, Fig. 7. The ratio of the weights of Inconel tubes and pipe to those of steel is 1.09.

Nonmetallic Piping.—Carbon pipe is available in standard 6-ft. lengths, and the costs of such pipe and a few representative accessories are summarized herewith:

Size pipe	Cost per foot	Elbows	Tees	Valves
1 in. I.D.	$0.75	$ 1.40	$ 1.75	$18.
3 in. I.D.	3.70	6.50	7.00	
4 in. I.D.	6.00	11.	11.50	

The figures in the above table should be approximately doubled for 1947.

Porcelain pipe is available in standard 5-ft. lengths, and the costs of such piping, fittings, and valves may be summarized thus:

Size pipe	Cost per foot	Elbows	Tees	Angle or *Y*-valves
1 in. I.D.	$0.90	$ 4.00	$ 5.20	$ 39.
2 in. I.D.	1.50	6.20	8.50	49.
3 in. I.D.	2.40	9.70	12.90	75.
4 in. I.D.	3.40	12.40	16.20	110.

Special fittings, bends, and other unusual applications act to increase the unit cost of the pipe to a considerable degree.

Glass pipe (Pyrex) is available in standard lengths of 10 ft. and less. The costs of such pipe in 10-ft. lengths and of a few representative fittings are as follows:

Size pipe	Cost per foot	Elbows	Tees	Flanges for assembly
1 in. I.D.	$0.45	$ 3.25	$ 3.35	$0.50
2 in. I.D.	1.03	5.25	5.50	0.80
3 in. I.D.	1.61	8.25	8.50	1.50
4 in. I.D.	3.00	12.50	16.50	3.50

These figures should be increased by about 30 per cent for 1947.

FITTINGS

The principal variables which govern the cost of fittings are the construction material, operating pressure, jointing method, external finishing, and size. The last is most convenient for graphical representation, and therefore the costs of specific fittings representative of a group have been plotted against size. Factors are then presented by which the values, read from the curve, may be multiplied to yield the costs of other fittings within the same group but differing from the representative one by one or more of the foregoing variables. Such a method implies that fittings whose costs are to be calculated by such factors are available in the same size as the representative one. This

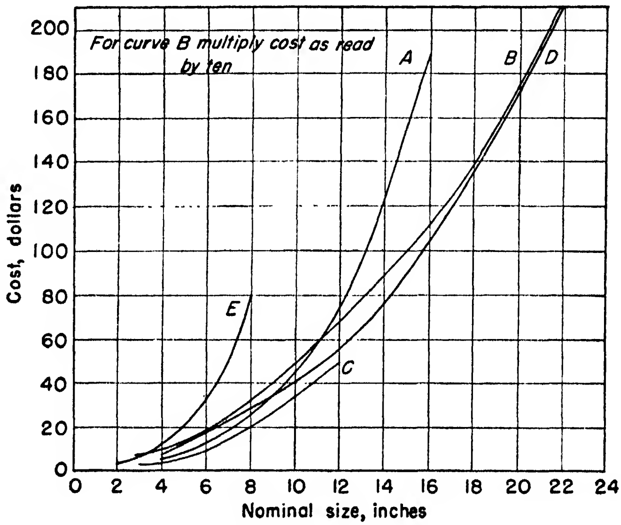

FIG. 8.—Cost of elbows.

is not always the case, and therefore only a manufacturer's catalogue and not these figures should be taken as indication that a given type of fitting is available in a certain size. The pressures referred to are water, oil, or gas nonshock ratings, abbreviated W.O.G., for the larger sizes of any one group. The smaller sizes may be used at higher pressures. With steel fittings, however, the pressure rating is only nominal.

Elbows.—The cost of elbows as a function of nominal diameter is shown in Fig. 8. Curve *A* is for malleable-iron, 600-lb.-pressure, 90° screwed elbows. The factors for other types are as follows:

600 lb., galvanized	1.5
350 lb	0.64
300 lb	0.40
300 lb., galvanized	0.53

For 45° elbows of this group, the 90° elbow cost should be multiplied by 1.2.

Curve *B* (note that the ordinate is to be multiplied by 10) is for alloy cast steels, 900-lb.-pressure, 90° and 45° flanged elbows. Factors for other cases are as follows:

Carbon molybdenum (A.S.T.M., A157, Grade C1), 900 lb.	Curve *B*
Chrome molybdenum (A.S.T.M., A157, Grade C5), 900 lb.	1.34
Carbon molybdenum, 1500 lb	1.6
Chrome molybdenum, 1500 lb	2.1
Carbon molybdenum, 600 lb	0.52
Chrome molybdenum, 600 lb	0.70
Carbon molybdenum, 400 lb	0.37
Chrome molybdenum, 400 lb	0.50
Carbon molybdenum, 300 lb	0.23
Chrome molybdenum, 300 lb	0.31
0.3 per cent Carbon steel (A.S.T.M., A95), 150 lb	0.18

Curve *C* is for cast-iron, 400-lb.-pressure, 90° screwed elbows. Factors for other types are

400 lb., galvanized	2.0
175 lb	0.5
175 lb., galvanized	1.0

For 45° elbows, the above figures should be multiplied by 1.2.

Curve *D* is for cast-iron, and Ferrosteel (A.S.T.M., A126, Class B) 350-lb., 90° flanged elbows. The factor for 150-lb. pressure rating is 0.67. For 45° elbows in this group, the above figures should be multiplied by 1.1 in small sizes and 1.0 in large sizes.

Curve *E* is for 400-lb. brass, rough-surfaced, 90° and 45° screwed elbows. Factors are as follows:

400 lb., polished	1.4
200 lb., rough	0.6
200 lb., polished	0.95

Tees and Crosses.—The cost of tees and crosses as a function of nominal diameter is shown in Fig. 9. Curve *A* is for malleable-iron, 600-lb.-pressure, screwed tees. The factors for others are as follows:

600 lb., galvanized	1.5
350 lb	0.64
300 lb	0.34
300 lb., galvanized	0.44

For crosses of the 600- and 350-lb. classes, the corresponding tee cost should be doubled, and for the 500-lb. class, the factor is 1.3.

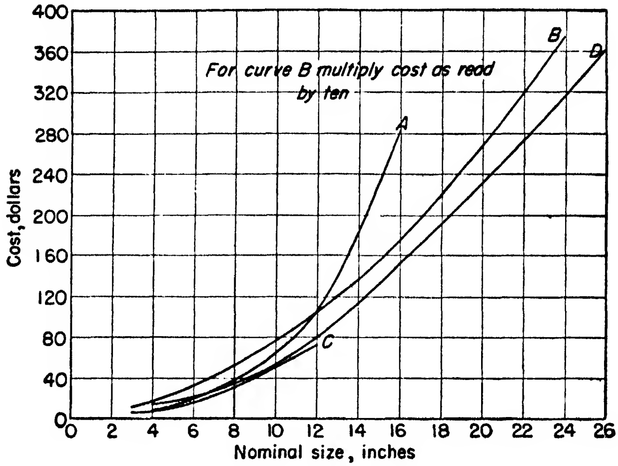

FIG. 9.—Cost of tees and crosses.

Curve *B* (note that ordinate is to be multiplied by 10) is for alloy cast steels, 900-lb.-pressure, flanged tees. Appropriate factors are

Carbon molybdenum (A.S.T.M., A157, Grade C1), 900 lb.	Curve *B*
Chrome molybdenum (A.S.T.M., A157, Grade C5), 900 lb.	1.33
Carbon molybdenum, 1500 lb.	1.6
Chrome molybdenum, 1500 lb.	2.1
Carbon molybdenum, 600 lb.	0.52
Chrome molybdenum, 600 lb.	0.70
Carbon molybdenum, 400 lb	0.37
Chrome molybdenum, 400 lb.	0.50
Carbon molybdenum, 300 lb.	0.23
Chrome molybdenum, 300 lb.	0.31
0.3 per cent Carbon steel (A.S.T.M., A95), 150 lb.	0.18

For crosses of all the above classes, the corresponding tee cost should be multiplied by 1.4.

Curve *C* is for cast-iron, 400-lb.-pressure, screwed tees. Other factors are

400 lb., galvanized	2.0
175 lb.	0.5
175 lb., galvanized	1.0

For 400-lb. crosses the tee cost should be multiplied by 1.3, and for 175-lb. by 1.8.

Curve *D* is for cast-iron and Ferrosteel, 350-lb., flanged tees. For 150-lb. pressure rating, the cost should be multiplied by 0.67. Crosses cost about 50 per cent more than tees in the both cases.

Flanges.—The costs of flanges are shown in Fig. 10. Curve *A* is for cast-iron and Ferrosteel, 350-lb., faced and drilled, screwed flanges. The factor for 150-lb. rating is 0.61.

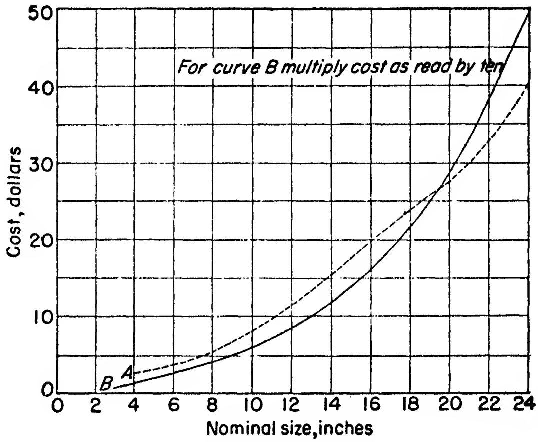

FIG. 10.—Cost of flanges.

Curve *B* (note that ordinate is to be multiplied by 10) is for forged carbon steel (A.S.T.M., A105), 900-lb., faced and drilled, screwed and slip-on welding flanges. For other pressures, the cost should be multiplied by

1500 lb.	1.4 in small sizes to 1.8 in large
600 lb.	0.65 in small sizes to 0.36 in large
400 lb.	0.4 in small sizes to 0.25 in large
300 lb.	0.27 in small sizes to 0.2 in large
150 lb.	0.17

For welding neck flanges, the corresponding screwed flange cost should be multiplied by

1500 lb.	1.2
900 lb.	1.4
600 lb.	1.6
400 lb.	1.6
300 lb.	1.3
150 lb.	1.4

VALVES

Gate Valves.—The cost of a gate valve is largely a function of body construction material, trim material (seats and stem), type of gate, pressure, stem arrangement (outside screw and yoke or nonrising stem), jointing method, and size. The last is again most convenient for graphical representation, and therefore Fig. 11 shows the costs of various representative valves as functions of the nominal sizes. The effect of each single variable can be calculated by the factors to follow, and if two or more variables change, two or more of the factors can be multiplied together to give the appropriate correction for all changes.

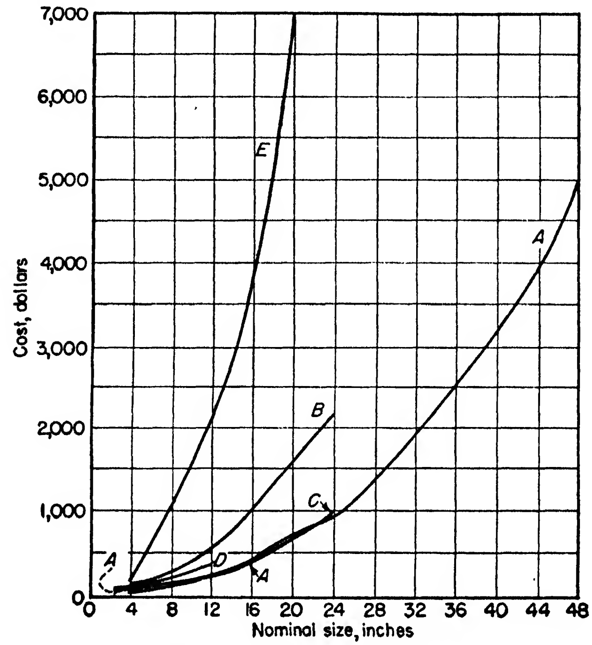

FIG. 11.—Cost of gate valves.

As with fittings, only by consulting the manufacturers' catalogues can one be certain that one of the nonrepresentative valves is available in the same size as the representative one. Whenever possible, limits of availability are mentioned below.

Curve *A* is for iron-body, iron-trimmed, single-wedge, 200-lb.-pressure, outside screw and yoke (hereafter abbreviated O.S. & Y.), flanged gate valves. These costs should be multiplied by the following factors for these modifications:

Brass trimmed	1.0
Screwed (available to 12 in.)	0.9
Nonrising stem (abbreviated hereafter N.R.S.)	
2 to 10 in	0.78
12 to 24 in	0.85
30 to 48 in	0.88

Exelloy ($11\frac{1}{2}$–13% Cr stainless) trimmed	
2 to 6 in	1.9
8 to 12 in	1.8
18-8 stainless trimmed	
2 to 6 in	2.0
8 to 12 in	1.9
50 lb-pressure (available only in flanged valves, all iron or brass trimmed)	0.86
Malleable iron body (available only below 8 in., all iron or brass trimmed)	1.7

Curve *B* is for Ferrosteel (A.S.T.M., A126, Class B) iron-trimmed, single-wedge, 400-lb., O.S. & Y., flanged gate valves. Other factors are

Brass trimmed	1.0
Screwed valves (available only to 12 in.)	0.97
N.R.S., 2 to 10 in	0.85
12 to 24 in	0.93
800-lb. pressure	3.0

Curve *C* is for iron-body, iron-trimmed, double-disk, 150-lb., O.S. & Y., flanged gate valves. Factors for modifications are as follows:

Brass trimmed	1.0
Screwed, less than 6 in	0.96
6 to 12 in	1.0
N.R.S., less than 12 in	0.8
over 12 in	0.87
160 lb	0.75
35 lb	0.68

Curve *D* is for Ferrosteel (A.S.T.M., A126, Class B) body, iron-trimmed, double-disk, 400-lb.-pressure, O.S. & Y., flanged gate valves. For modifications these factors apply:

Brass trimmed	1.0
Screwed	0.98
N.R.S	0.8
500 lb., less than 8 in	1.15
more than 8 in	1.33
800 lb., 2 to 4 in	1.5
6 to 8 in	1.9
10 to 12 in	2.8

Curve *E* is for cast-steel body, Exelloy trimmed, single-wedge, 600-lb. (nominal) pressure, O.S. & Y., flanged gate valves. Other factors are

1500 lb. nominal pressure 1.9 in small sizes to 2.7 in large		
900 lb. nominal pressure 1.7 in small sizes to 1.5 in large		
400 lb. nominal pressure 0.83 in small sizes to 0.65 in large		
300 lb. nominal pressure 0.71 in small sizes to 0.37 in large		
150 lb. nominal pressure 0.5 in small sizes to 0.25 in large		

Screwed (available only to 6 in. and not at all above 300 lb.)	0.95
Hub ends for welding	1.0
Body of chrome-molybdenum steel (4–6% Cr, A.S.T.M., A157, Grade C5)	1.1
18-8 stainless trimmed	1.2

Globe and Angle Valves.—The same principles as previously discussed have been recognized as applying in this case. Accordingly,

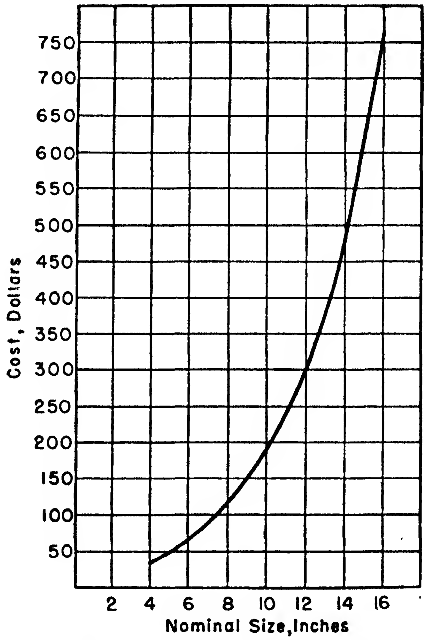

FIG. 12.—Cost of globe valves.

Fig. 12 shows the cost of iron body, brass- or iron-trimmed, 125-lb.-nominal-pressure, flanged globe and angle valves. For other types these factors apply:

Screwed	0.9
Composition disk	1.15
250 lb., Ferrosteel body	2.1 in small sizes to 1.5 in large

HEAT EXCHANGERS

The cost of heat exchangers depends on the material, diameter, thickness, and length of tubes, materials and size of tube sheets, material, size, and thickness of shell and such special features of design as floating heads and baffles, etc. Obviously no simple method could be derived by which the effect of all these variables on cost could be predicted. Therefore, this correlation has been limited to include only the effect of tube construction material and dimensions on total cost. The shell has been assumed to be fixed at a common and widely used type, that is, steel, 150 lb. pressure, floating head, with an average number of baffles and satisfying A.P.I.-A.S.M.E. construction code. Even with such a limitation graphical presentation of heat exchanger costs in the most useful form, that is, cost in dollars per square foot vs. total heat transfer area, would require different graphs for each possible construction material of the tubes, and each graph would require various tube diameters, thicknesses, and lengths as parameters. To obviate this multiplicity of figures and curves, except for a few commonly used metals and sizes, the following method has been evolved which should be suitable for almost any tube material. The cost of any exchanger is assumed to be made up of the tube cost and the shell cost, the latter including headers, baffles, etc. The former can be estimated for any number of tubes of any diameter, thickness, and material by the methods discussed under Pipe and Tubing. The latter can be estimated by the following figures:

Total Heat Transfer Area, Sq. Ft.	Cost of Shell per Sq. Ft. of Heat Transfer Area
200	$5.25
500	3.00
1,000	2.10
2,000	1.70
3,000	1.60
4,000	1.50

These figures should be increased by about 30 per cent for 1947.

It should be emphasized that this shell cost assumes the construction details listed previously. Area as used here refers to outside tube area. For types substantially different, manufacturers should be consulted. The effects of a few variations have been observed and can be noted, but they are only approximations.

Item	Multiply Shell Cost by
For 4-16 chrome steel construction	4.0–6.0
For 18-8 stainless steel construction	8.0–9.0
For fixed-head construction	0.7
For 75 lb. pressure	0.9
For 300 lb. pressure	1.2

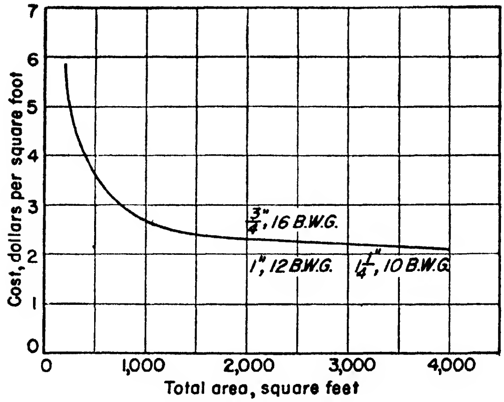

Fig. 13.—Cost of heat exchangers, steel tubes.

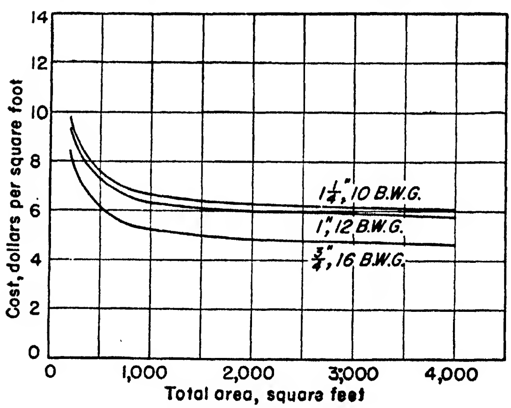

Fig. 14.—Cost of heat exchangers, 18-8 stainless-steel tubes.

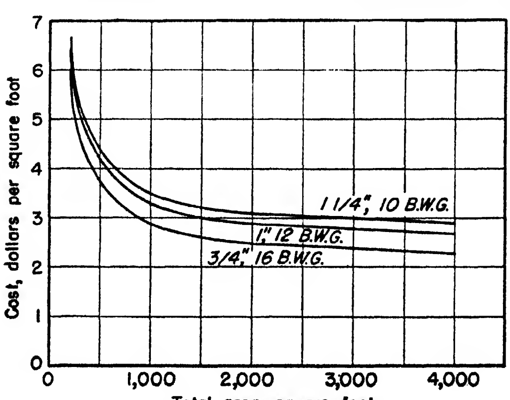

Fig. 15.—Cost of heat exchangers, Admiralty tubes.

The more useful form of presentation, that is, cost per square foot versus total area in square feet, is shown in Figs. 13, 14, and 15 for heat exchangers with tubes of seamless steel, 18-8 stainless steel, and Admiralty and with shell construction as outlined. Costs for three representative tube dimensions are given. No attempt to separate the individual effects of tube diameter and thickness is made, because such effects can best be determined by the more elaborate method. It is apparent that even the more elaborate method will not predict the effect of tube length (which effect is small), because this is a matter of shell cost, and shell cost has been correlated on the basis of total heat transfer area and not the shell dimensions. Therefore, the effect of length is not shown on these figures.

FILTERS

Filter Presses.—The cost of plate-and-frame presses of cast iron and of yellow pine and that of cast-iron recessed plate presses is shown

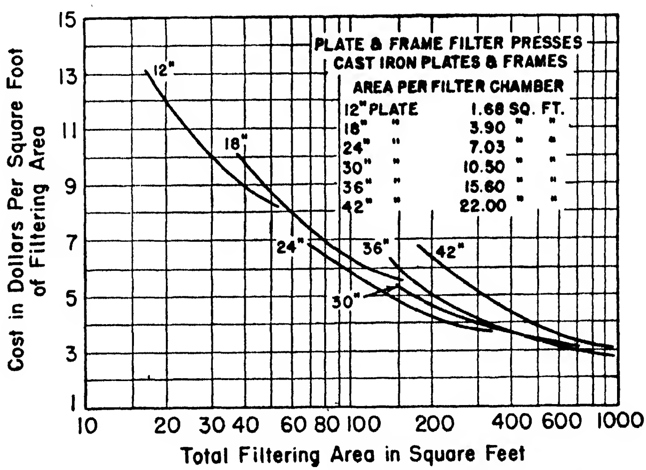

FIG. 16.—Cost of cast-iron plate-and-frame filter presses.

in Figs. 16, 17, and 18. These are 1947 figures. For presses of other metals the cast-iron cost should be multiplied by the following factors:

Aluminum	1.70
Bronze	2.75
Lead	2.50
18-8 stainless	5.50

Sweetland.—The cost of Sweetland filters is shown in Fig. 19 as functions of total area and leaf spacing. These curves are for cast-iron

Sweetland filters with cotton filter cloth and without accessories. Since the area of these presses is determined by the use of discrete numbers of leaves and not any variable number, the presentation of these costs as continuous curves is somewhat misleading, and they

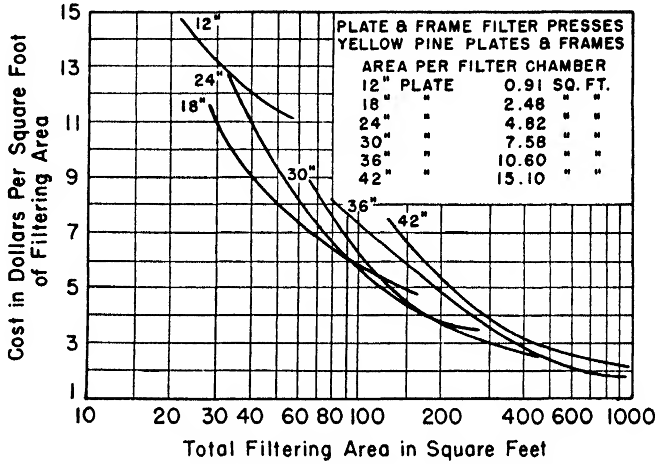

FIG. 17.—Cost of yellow-pine plate-and-frame filter presses.

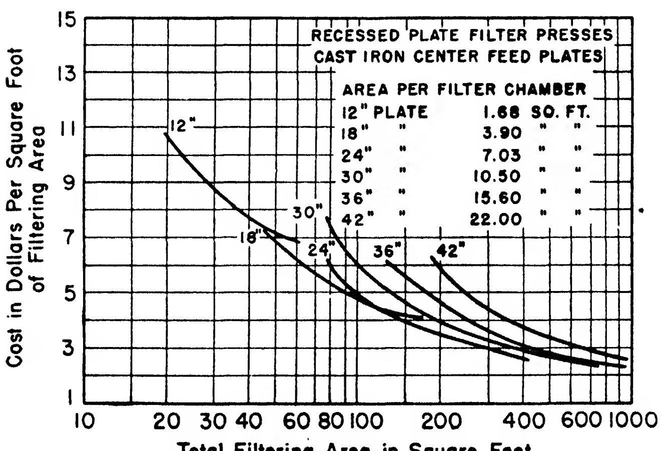

FIG. 18.—Cost of recessed plate filter presses.

should be used only in conjunction with manufacturers' catalogues so that the exact area and standard sizes are known.

Oliver Continuous Vacuum Filters.—The cost of these filters can be represented as a function of total drum area as in Fig. 20. These costs are for steel- and wood-drum Oliver filters with steel tanks, vacuum receiver, trap, and feed and vacuum pumps. Motors are excluded.

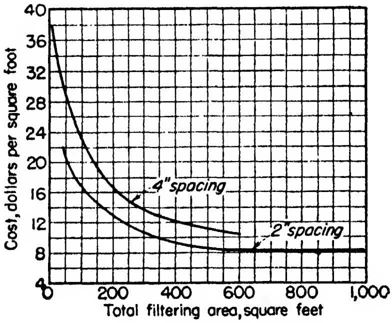

FIG. 19.—Cost of cast-iron Sweetland filters with cotton cloths.

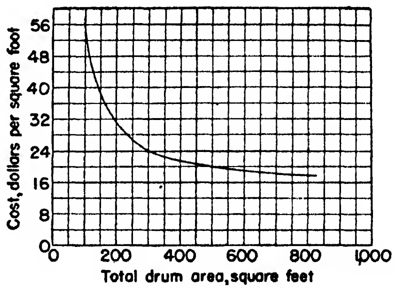

FIG. 20.—Cost of steel- and wood-drum Oliver filters, without motor.

The following approximate installation and accessories costs may be cited:

	Installation, %	Accessories, %
Sweetland	30	25
Plate-and-frame	30	25–30
Oliver	30	Included in curve

THICKENERS

The cost of a single compartment thickener can be estimated by considering it as made up of two parts, that of the tank and that of the mechanism. The first of these can be estimated by the methods described later for steel or wood tanks, and for concrete tanks the unit cost of this material may be taken at $30 per cubic yard. The mechanism including erection but excluding drive costs about $80 per foot of diameter in sizes below 60 ft. and about $100 per foot in sizes above 80 ft. Such figures are for ordinary iron and steel construction.

The cost of the mechanism, (that is, excluding the tank) of a two-compartment tray thickener can be taken as varying from $160 per foot of diameter at 20 ft. to $190 per foot at 50 ft.

Suitable slurry pumps may be estimated by interpolation of the following data:

1 gal./min	$ 200
17 gal./min	600
100 gal./min	1,100

PRESSURE VESSELS AND PRESSURE FRACTIONATING COLUMNS

Fowler and Brown[1] presented a thorough review of this subject with costs as of early in 1941. Price rises to 1945 were negligible, and corrections to 1947 are shown on the figures.

Fowler and Brown itemized the total cost of such equipment as follows:

1. Vessel shell, including heads, skirt, hand and manholes, nozzles, tray supports, and stress relief.
2. Bubble trays.
3. Platform, ladders, and handrails.
4. Insulation.
5. Freight.

Their costs were computed on the basis of actual quotations for specific installations, and therefore no errors in estimating or waste were

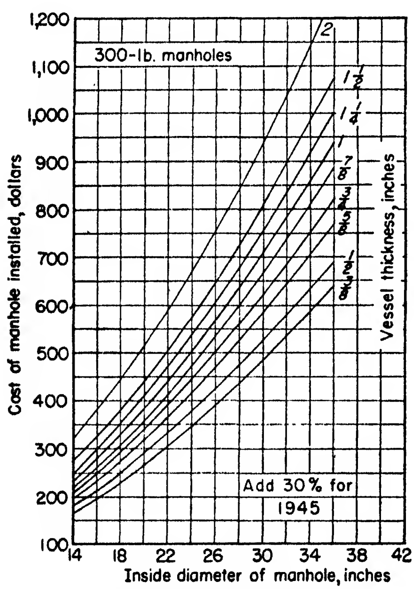

FIG. 21.—Cost of 300-lb. manholes.

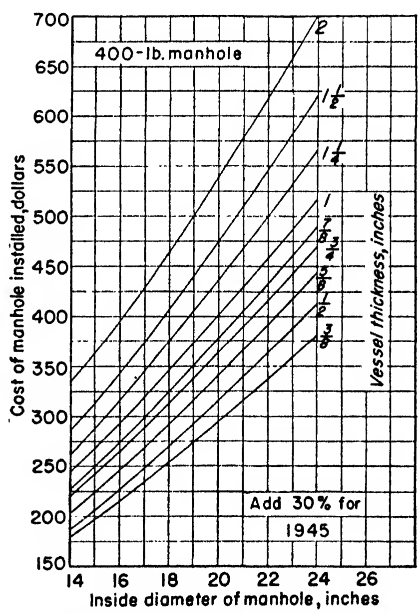

FIG. 22.—Cost of 400-lb. manholes.

included. For estimating purposes they suggested adding 10 per cent to the costs discussed herewith.

The shell, heads, and skirt may be computed from the weight thereof at a unit cost of 7 cts. per pound for steel and 10 cts. per

[1] Fowler and Brown, *op. cit.*

pound for molybdenum-steel (A.S.T.M., A-204, firebox quality). Alloy liners (A.S.T.M., A-176, type 410) for the shell should cost $4.25 per square foot for $\frac{5}{64}$-in. thickness and $5.00 for $\frac{7}{64}$-in. thickness. These figures should be increased by about 50 per cent for 1947. Base angles cost about 15 cts. per pound for steel and 20 cts. for 5 per cent chromium. These figures should be quadrupled for 1947.

Manholes contribute markedly to the cost as Figs. 21, 22, and 23 show. In these figures only 300-lb., 400-lb., and 900-lb. ratings are shown. Approximate costs for the 150-lb. class may be determined by multiplying the corresponding cost in the 300-lb. class by 0.92, although the 150-lb. class is not ordinarily available for shell thickness greater than $1\frac{1}{4}$ in. Similarly, approximate costs for the 600-lb. class may be determined by multiplying the 900-lb. figure by 0.73, although the 600-lb. group is not ordinarily made for vessel thicknesses above 3 in. It should be noted that these costs are for the installed manhole.

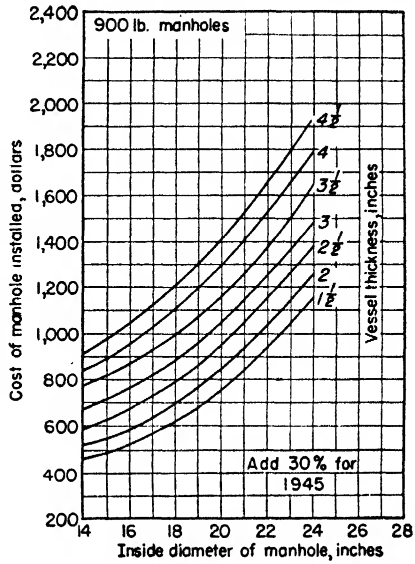

FIG. 23.—Cost of 900-lb. manholes.

The installed cost of handholes may be taken as approximately $70 for 8-in. handholes increasing linearly to about $190 for the 16-in. size. The former figure should be increased 150 per cent and the latter by 50 per cent for 1947.

The installed cost of nozzles is given in Figs. 24 and 25. The cost of 150-lb. rating nozzles can be approximated by multiplying the 400-lb. curve by 0.86, and the cost of 300-lb. nozzles can be estimated by multiplying the same curve by 0.93. The figures for 600-lb. nozzles may be estimated by multiplying the 900-lb. figures by 0.96, although the 600-lb. class is not ordinarily made for vessel thicknesses in excess of 3 in.

Alloy liners (same composition as shell liners) for nozzles and manholes are available at about 20 cts. per square inch.

The installed cost of couplings is about $2.00 for 1-in. size varying approximately linearly to about $12 for 4-in. size. These figures should be trebled for 1947.

Tray supports, if the shell is to be used as a column, may be estimated at 15 cts. per pound for steel and 20 cts. per pound for 5

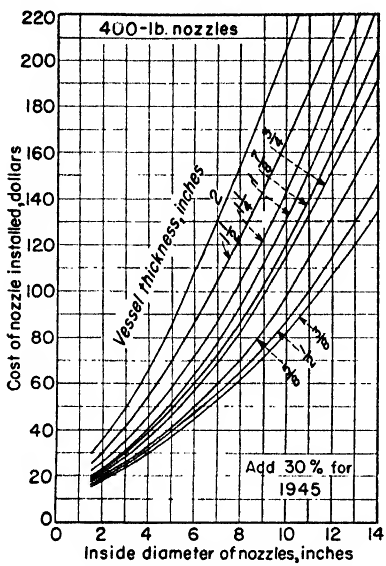

FIG. 24.—Cost of 400-lb. nozzles.

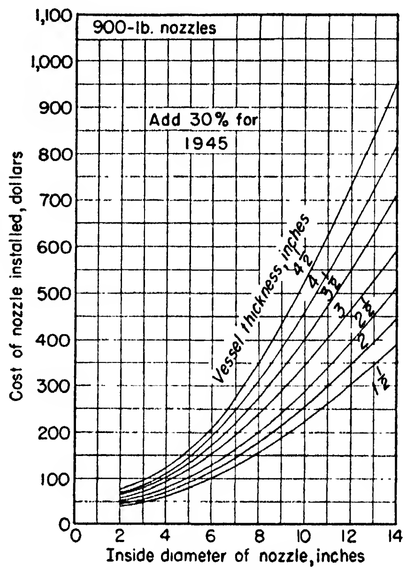

FIG. 25.—Cost of 900-lb. nozzles.

per cent chromium. These figures should be quadrupled for 1947. The necessary weights are as follows:

Column Diameter, Ft.	Weight of Tray Supports, Lb.
2 to 4	75
5	125
5½	135
6	325
7	375

The cost of stress relief may be estimated as 1 per cent of the sum of all items above which make up the complete shell, not to exceed $500. X-ray inspection should be reckoned at about 3 per cent.

The cost of a bubble tray is shown in Fig. 26, which cost includes decks, downpipes, bubble caps, packing, and bolts. These are 1947 figures.

External column fittings, such as ladders, handrails, and platforms may be estimated as costing 9 cts. per pound. A ladder should weigh about 30 lb. per ft. and the platform and handrails from about 1,250 lb. for a 2½-ft. diameter column to 3,700 lb. for an 11-ft. column, approximately linear interpolation being permissible.

Total installed cost of column insulation is about 60 cts. per square foot for 1½-in. thickness to 90 cts. per square foot for 5-in. thickness.

External fittings costs should be increased by 30 per cent and insulation costs doubled for 1947.

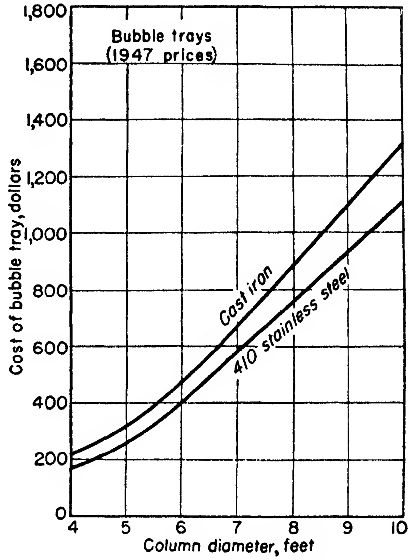

Fig. 26.—Cost of bubble trays.

EVAPORATORS AND CRYSTALLIZERS

The cost per square foot of heating surface of horizontal tube, basket, and calandria-type evaporators is shown as a function of total area in Fig. 27. Such costs are for cast-iron construction with copper heating surfaces, complete with piping, condenser, and pumps, but without motors and supporting framework. This might be called "standard construction," and for certain deluxe features, such as corrosion resistant fittings, about 25 to 30 per cent should be added to the costs illustrated in Fig. 27.

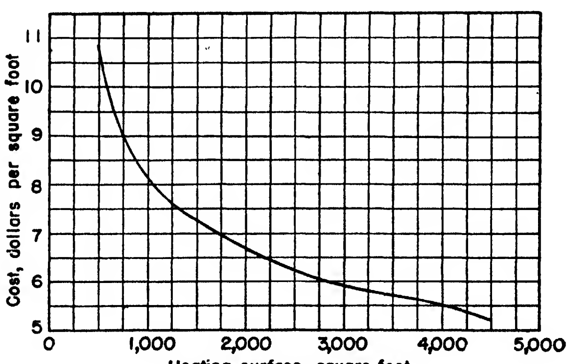

Fig. 27.—Cost of horizontal tube, basket, and calandria-type evaporators.

The cost of long-tube vertical film-type evaporators is shown in Fig. 28. The upper curve is for cast-iron construction with copper heating surface, and the lower curve is for all welded-steel construction, both with accessories as above. An additional cost of about 10 per cent should be allowed for deluxe features.

The cost of forced-circulation evaporators is shown in Fig. 29. The upper curve is for nickel cast-iron construction with nickel heating surface, and the lower curve is for cast-iron bodies with copper heating surfaces, both with accessories as above. For deluxe features, 25 per cent should be added.

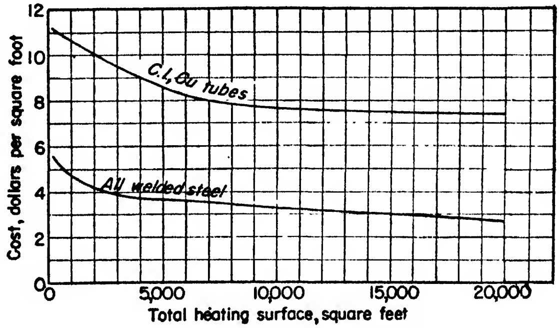

Fig. 28.—Cost of long-tube vertical film-type evaporators.

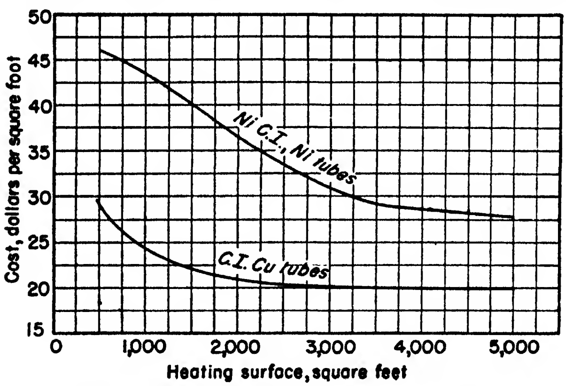

Fig. 29.—Cost of forced-circulation evaporators.

The cost of steel crystallizers (Swenson-Walker type), complete with suitable drives may be estimated as follows:

Total Length of Crystallizer, Ft.	Dollars per Foot of Length
20	$90
60	70
90	67
120	60
240–360	58
400–800	55
1,000–1,200	54

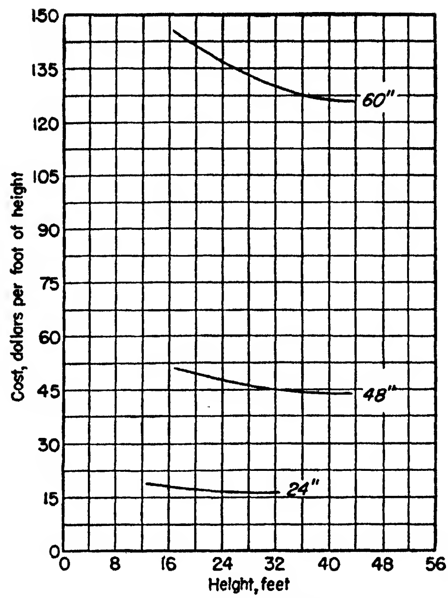

FIG. 30.—Cost of chemical stoneware towers.

These are usually built in units 10 ft. long, a maximum of four of which may be connected in series and driven from one shaft. Greater lengths are attained by installation of the quadruple units one above another. These figures should be increased by about 20 per cent for 1947.

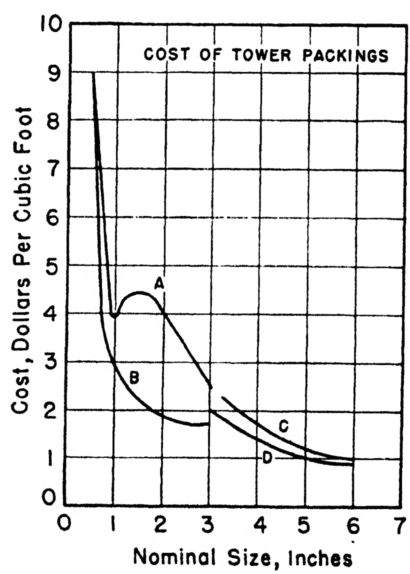

FIG. 31.—Cost of carbon and stoneware packings.

ABSORPTION TOWERS AND PACKINGS

The cost of steel towers for this purpose may be computed as described above for pressure vessels and columns. The cost of chemical stoneware towers per foot of height is shown in Fig. 30 as functions of nominal diameter and tower height. Aluminum towers may be estimated at about $1.25 per pound. These costs are without piping and accessories which, of course, must be estimated by methods previously discussed. Erection costs will equal or exceed the cost of the tower itself in small sizes and will approximate 25 to 50 per cent of the tower cost in large sizes.

The cost of carbon and stoneware rings in dollars per cubic foot is shown as a function of nominal size in Fig. 31. Curve *A* is for carbon Raschig rings and curves *B*, *C*, and *D* are for stoneware Raschig, partition, and spiral rings. Porcelain Raschig rings cost about 15 to 30 per cent more than stoneware, the higher figure referring to the smaller sizes, and aluminum rings about 3½ times as much. Berl saddles cost about 2½ times as much as stoneware, but they are not usually available above 1½-in. size.

TANKS, STORAGE VESSELS, AND LININGS

The cost of ordinary steel tanks with a minimum of fittings may be computed according to the weight as follows:

100 lb.	$0.13 per lb.
500 lb.	0.09 per lb.
2,000 lb.	0.07 per lb.
4,000 lb.	0.065 per lb.
10,000 lb.	0.060 per lb.

Galvanized steel tanks cost about twice as much as the above. For heavier tanks of perhaps ½-in. plate thickness the unit costs should be increased by about 25 per cent. These figures should be 25 per cent higher for 1947.

Nickel-clad steel tanks (10 per cent cladding) may be taken at 30 cts. per pound and Monel and Inconel-clad at 38 cts. per pound. For 20 per cent cladding, the nickel ones should be computed at 38 cts. per pound and the Monel and Inconel ones at 55 cts. per pound.

The cost of wooden tanks, complete with hoops and connectors but not erected may be estimated as follows:

Quantity, bd. ft.	Dollars per board foot	
	Cypress and redwood	Fir and yellow pine
500	$0.48	$0.36
1,000	0.42	0.34
2,000 and over	0.35	0.32

A "board foot" is one square foot one inch thick. Costs should be increased by about 8 per cent to include galvanized fittings. Erection costs should be about 40 to 60 per cent of the tank cost, but for tanks below about 400 gal. the erection cost will probably approach 100 per cent of the tank cost. These figures should be increased by 30 to 50 per cent for 1947.

Lead linings (approximately 1/8-in. lead) cost about $2.00 per square foot installed. Acid resistant lining of asbestos felt and asphalt can be estimated at about $1.25 to $1.50 per square foot, and a bituminous paint lining at about $0.40.

LIQUID PUMPS

Centrifugal.—The cost of centrifugal pumps is largely a function of construction material, type (ordinary, nonclogging, sump, etc.), dis-

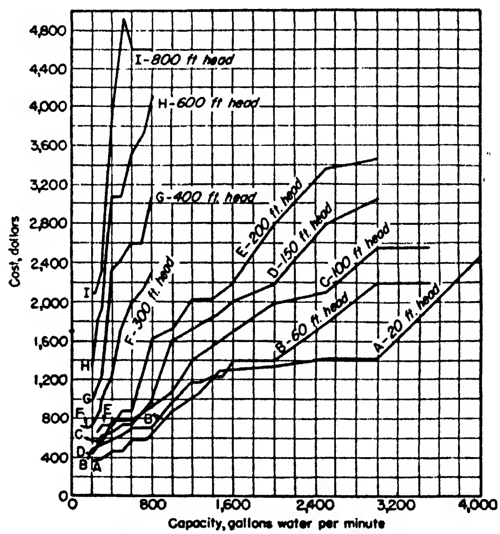

FIG. 32.—Cost of standard centrifugal pumps with motor.

charge head at rated capacity, rated capacity, speed, number of inlets per impeller, number of stages, and the casing split arrangement (horizontal or vertical). The last three variables were found to be unimportant and were neglected. This does not imply that the number of stages does not have an important effect on the cost of pumps, but rather that it is not a variable independent of discharge head, already considered. Thus to reach a given head, a certain number of stages are required and if the cost has already been shown as a function of head, there is no further major effect of staging. The principal variables above are the capacity, speed, and head, and costs for various construction materials and types can be presented graphically as functions of those variables.

Figure 32 shows costs with motor and starter of ordinary enclosed impeller pumps with cast-iron casing, bronze wearing rings and impeller, and steel shaft as functions of rated capacity, head, and speed. Because of the many variations among manufacturers, deviations of quotation from these curves as large as 20 per cent may be expected. The conditions for each of the curves of Fig. 32 and the effects of variations in a certain range are as follows:

Curve *A* is for single-stage, 20-ft. head, 860 r.p.m.
  For 1,150 r.p.m. multiply by 0.92 below 750 g.p.m. and by 0.75 for 1,000 to 1,500 g.p.m.
  For 680 r.p.m. multiply by 1.4 above 400 g.p.m.
  For 600 r.p.m. multiply by 1.46 above 1,000 g.p.m.
Curve *B* is for single-stage, 60-ft. head, 1,150 r.p.m.
  For 1,750 r.p.m. multiply by 0.75 below 2,000 g.p.m.
  For 860 r.p.m. multiply by 1.1 above 1,000 g.p.m.
Curve *C* is for single-stage, 100-ft. head, 1,150 r.p.m.
  For 1,750 r.p.m. multiply by 0.80 below 600 g.p.m. and by 0.9 above 1,000 g.p.m.
Curve *D* is for single-stage, 150-ft. head, 1,750 r.p.m.
  For 3,450 r.p.m. multiply by 1.0 below 500 g.p.m.
  For multistage multiply by 1.24 below 300 g.p.m.
Curve *E* is for single-stage, 200-ft. head, 1,750 r.p.m.
  For 3,450 r.p.m. multiply by 1.0 below 500 g.p.m.
  For multistage multiply by 1.32 below 800 g.p.m.
Curve *F* for multistage, 300-ft. head, 1,750 r.p.m.
  For 3,450 r.p.m. multiply by 1.1 below 600 g.p.m.
Curve *G* is for multistage, 400-ft. head, 1,750 r.p.m.
Curve *H* is for multistage, 600-ft. head, 1,750 r.p.m.
Curve *I* is for multistage, 800-ft. head, 1,750 r.p.m.

The cost of a pump of alternate construction materials can be estimated by multiplying the standard construction cost by the following factors. (It should be observed that these factors are to be applied to the net pump cost and therefore the motor and starter cost must be subtracted from the costs of Fig. 32 before applying these factors).

All-iron	1.05
Ni-Resist casing and trim	1.10
All-bronze	1.50
Everdur	1.5–1.75
Monel or 18–8 stainless	
Shafts and sleeves	1 2
Wearing rings	1.2
Impeller	1.2
All-Monel or all-stainless	3–5

Nickel	4–6
Illium	5–7
Stoneware, lead (available only in low-head, small sizes)	2–3
Rubber-lined (low-head, large sizes)	2
Hastelloy	7–9
Inconel	5–7

The smaller figure usually refers to the more expensive units and the larger figure to the less expensive ones. It is important to observe in the case of stainless steels, however, variation in cost of different grades is included.

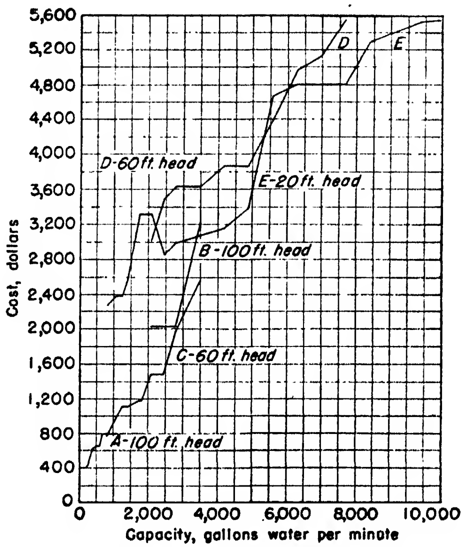

Fig. 33.—Cost of nonclogging centrifugal pumps with motor.

Another centrifugal pump in wide use is the horizontal nonclogging type, which may be open or closed impeller. The cost of this type with motor as functions of rated capacity and head at rated capacity is shown in Fig. 33. The factors for other construction materials previously mentioned should apply to this type and in addition Manganese steel (usually used only for the nonclogging type) can be supplied at approximately twice the standard cost.

The curves of Fig. 33 are as follows:
Curve *A* is for 100-ft. head, 1,750 r.p.m.
Curve *B* is for 100-ft. head, 1,150 r.p.m.
Curve *C* is for 60-ft. head, 1,150 r.p.m.
For 1,750 r.p.m. multiply by 0.75 below 800 g.p.m.
Curve *D* is for 60-ft. head, 700 r.p.m.

Curve E is for 20-ft. head, 435 r.p.m.

For 690 r.p.m. multiply by 0.4 below 2,000 g.p.m. and by 0.75 from 2,000 to 4,000 g.p.m.

For 575 r.p.m. multiply by 0.45 below 2,000 g.p.m. and by 0.8 from 2,000 to 4,000 g.p.m.

For 490 r.p.m. multiply by 0.85 below 8,000 g.p.m.

A third centrifugal pump in wide use is the nonclog sump pump. This is merely a nonclogging single-suction centrifugal pump placed at the bottom of the sump with vertical shaft connecting to a motor at the top. The cost of such pumps in cast iron with motors included is shown in Fig. 34. The standard depth is 6 ft., and the cost increases

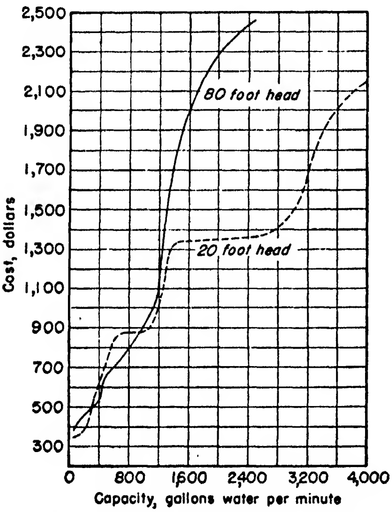

FIG. 34.—Cost of cast-iron sump pumps with motor.

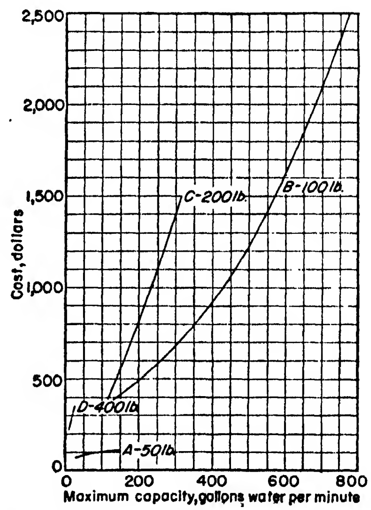

FIG. 35.—Cost of cast-iron rotary pumps without motor.

by about 10 per cent for each additional 6 ft. or fraction thereof. These additions are for added material alone and do not allow for the increased cost of larger motors required. This must be estimated separately.

Rotary.—The cost of cast-iron rotary pumps without motors is presented in Fig. 35 as a function of maximum rated capacity and discharge head. The maximum is stressed because rotary pumps are positive displacement pumps and can be run at any reasonable speed to yield a corresponding capacity. The speed chosen for this correlation is the maximum rotational speed as recommended by the manufacturer, which will of course decrease with increased pump size. In Fig. 35 curve A is for gear pumps at 50-lb. pressure, and curves B, C, and *D* are for double helical types at the pressures indicated. The effects of certain modifications can be approximated as follows:

All-bronze construction, multiply by	2.0
Speed reducers included (ready for motor)	1.2

GAS PUMPS

Centrifugal.—The cost of centrifugal gas pumps or turbo-blowers is a function of material and type of construction, number of stages, rated capacity, and discharge pressure at rated capacity.

The simplest type is the single-stage, light standard construction turbo-blower, the costs of which are shown in Fig. 36. The cost

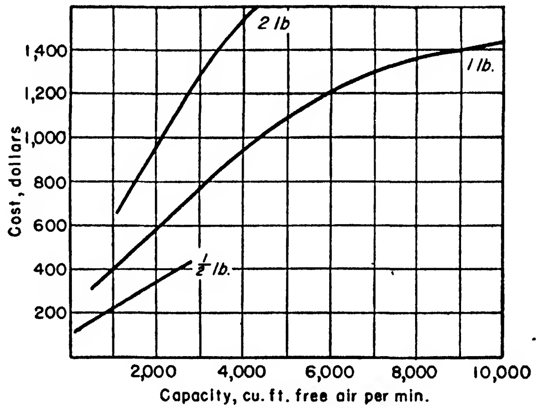

FIG. 36.—Cost of single-stage turbo-blowers, with motor.

including motor is shown as a function of rated capacity for several discharge pressures. Standard construction usually implies steel casings and aluminum or steel impellers. It is necessary to add about $50 for gastight construction if gases other than air are to be handled or if the pump is to be used for recirculation. Casing and impeller of *KA*-2, Everdur, or Monel can be supplied at about a 50 per cent increase in cost.

Higher pressures and larger capacities require a multistage turbo-blower. The cost, including motors, is shown in Fig. 37. The same factor for alternate construction materials applies in this case, but for gastight construction $50 should be added below 50 hp. and $100 above that.

For very large capacities, higher pressures, and longer life it is necessary to turn to a heavier type of construction, better designed to give higher efficiencies. These have casings of cast iron and impellers of cast-aluminum alloy or high-grade steel. The cost of such machines with motors is shown in Fig. 38. No increase is necessary for gas-tight construction, and it is impossible to generalize on the effects of alternate construction materials.

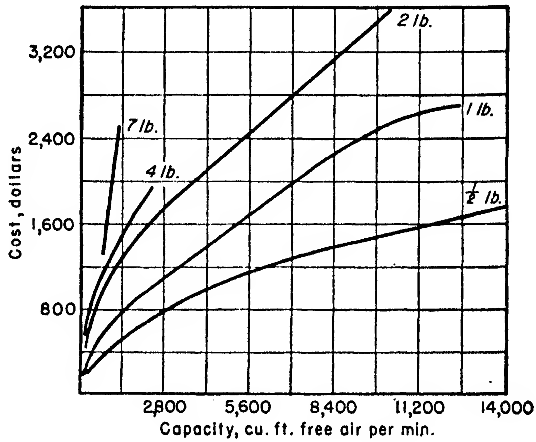

FIG. 37.—Cost of multistage turbo-blowers, with motor.

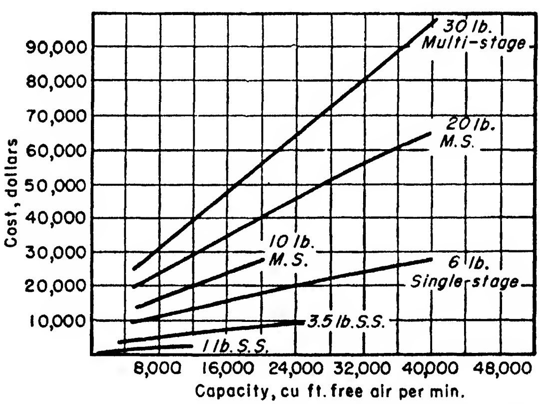

FIG. 38.—Cost of single-stage and multistage heavy-duty turbo-blowers, with motor.

Rotary.—The cost of rotary pumps for 15-lb. pressure without motors is shown in Fig. 39. As in the case of liquid rotary pumps, the capacity is a function of speed, and as before the maximum recommended speed has been chosen. In Fig. 39 the cost in dollars is plotted against the maximum rated capacity in cubic feet of free air per minute. These data are for the sliding vane type pumps at 15-lb. pressure, although pressures in the range of 5 to 15 lb. can be handled in the same type of pump at negligible change in cost. In the smaller sizes pressures as high as 40 lb. can be handled without significant change in cost. Costs of rotary gas pumps vary among manufacturers because of certain changes in design, but the curve of Fig. 39 represents a reasonable average.

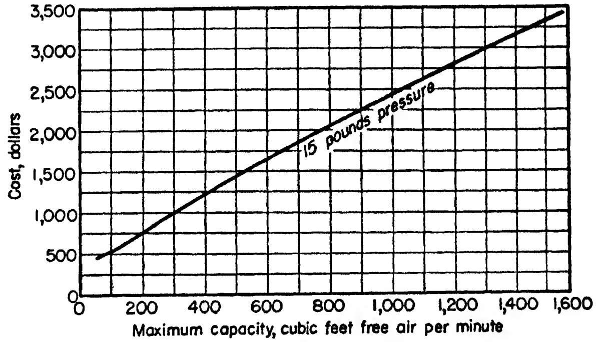

Fig. 39.—Cost of rotary gas pumps, without motor.

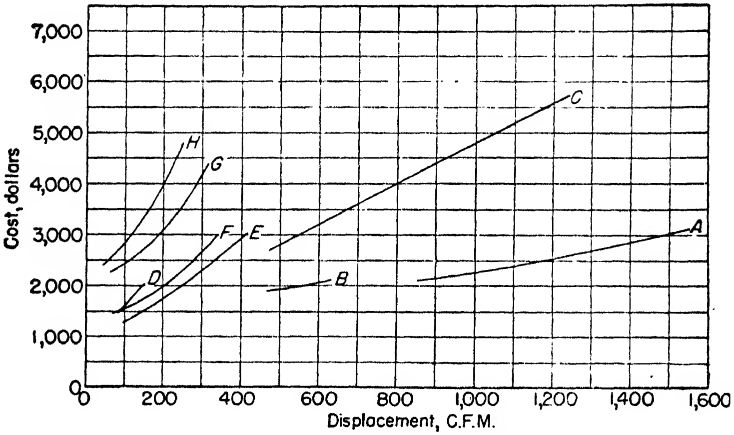

Fig. 40.—Cost of reciprocating compressors without motor.

Reciprocating Compressors.—The cost of horizontal, double-acting, reciprocating compressors for air, ammonia, or other relatively non-corrosive service as a function of displacement is summarized in Fig. 40. A word of caution is necessary about volumetric efficiency, because of which the delivery volume corrected to inlet conditions will be less than the displacement. These costs are for the bare compressor with intercoolers but without drive or aftercooler.

Curve *A* represents single-stage compressors for 20 to 30 lb. discharge pressure.
Curve *B* represents single-stage compressors for about 100 lb. discharge pressure.
Curve *C* represents two-stage, tandem compressors for about 100 lb. discharge pressure.
Curve *D* represents two-stage, tandem compressors for 400 lb. discharge pressure.
Curve *E* represents two-stage, in-line compressors for about 350-lb. discharge pressure.
Curve *F* represents the same as *E* except 500 lb. pressure.
Curve *G* represents three-stage, in-line compressors for about 1,500 lb. discharge pressure.
Curve *H* represents the same as *G* except 2,500 lb. pressure.

It may be noted that a vertical compressor, when available, is usually cheaper by about 25 per cent than the corresponding horizontal one. Four-stage machines for pressures as high as 3,500 to 4,000 lb. are highly specialized, but at a displacement of 180 c.f.m. a cost of about $7,000 with motor but without aftercooler is reasonable. Reciprocating compressors of small displacement to be used as boosters are so specialized as to be incapable of generalization of this sort.

CRUSHING AND GRINDING EQUIPMENT

Due to the wide variety of materials which may be subjected to size reduction, there is a large number of equipment types for such an operation. As is well-known, the type to be chosen is affected by the nature of the material to be handled and the size of such material as well as by other factors. It would be difficult to consider all the various types and applications, and, as a result, only a few suitable for grinding of more common ores of average hardness will be considered.

Jaw Crushers.—The cost of jaw crushers may be estimated by determining, for the duty at hand, the size of machine suitable and the recommended horsepower. The cost will approximate $90 per horsepower.

Crushing Rolls.—A method similar to that for jaw crushers may be used for two-roll crushing rolls. The cost per horsepower will approximate $105. Single-roll and four-roll crushers may be estimated in the same way, but the former costs about 50 per cent more and the latter about 200 per cent more than the two-roll type.

Swing Hammer Mills.—The same method will apply, as an approximation at least, for swing hammer mills, except that the cost per unit horsepower is not constant. Thus with standard machines of this type the cost is about $45 per horsepower at 10 hp. and about $30 at 75 hp. With heavy duty machines of this type the figures are about $55 at 15 hp. and $40 at 300 hp.

Ball Mills.—The method outlined above is not satisfactory for ball mills because any particular mill may have a power requirement within fairly wide limits depending on the duty. It is desirable in this case to present the cost as dollars per unit of capacity, the latter expressed as tons per day. Such capacity, of course, depends on the material being ground, manner of grinding, and size range involved. For this correlation the capacity chosen is that of a common ore of medium hardness, being reduced from 1½ in. to 90 per cent through 100-mesh, in closed circuit dry grinding. The cost of ball mills without motors or ball charges is shown as a function of such capacity in Fig. 41. In order to use this figure for cases other than the specific one represented, it would be necessary to pick the mill for the particular case at hand, to convert the capacity of that mill to the conditions here considered, and to determine the cost accordingly. For example, suppose it were necessary to dry grind the same material in open circuit from ½-in. size to 10-mesh at 120 tons per day. According to the "Chemical Engineers' Handbook,"[1] this duty would require the same mill as would be required for 360 tons per day with the conditions presented in the figure. The cost would therefore be 360 times $28, or $10,000. All crushing and grinding equipment has increased in cost about 30 per cent for 1947.

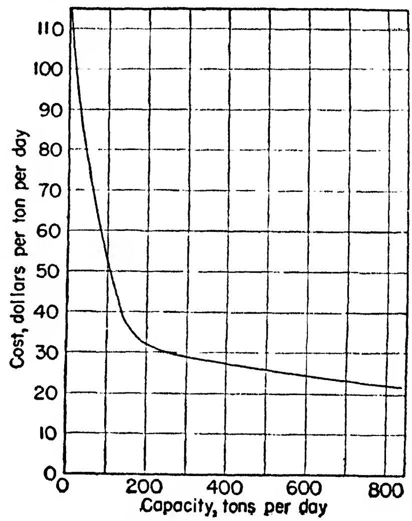

FIG. 41.—Cost of ball mills without motor.

DRIERS

Driers are for the most part specially designed and built to order so that cost generalizations are somewhat difficult to make. It is possible to do so, however, for a few standard types of the most common design. Those here discussed are largely of iron construction, and the use of other materials would require consultation with manufacturers.

[1] Perry, *op. cit.*

Drum Driers.—The cost of steam-heated drum driers is shown in Fig. 42. Curve *A* is for atmospheric single-drum, Curve *B* is for atmospheric double-drum, and Curve *C* (note that ordinate is to be multiplied by 10) is for vacuum single-drum driers. These costs include motors and feed conveyors for the atmospheric types and motors and receivers for the vacuum type.

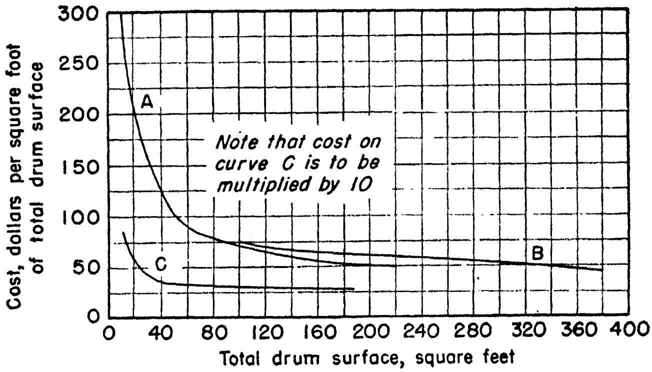

FIG. 42.—Cost of drum driers with motor.

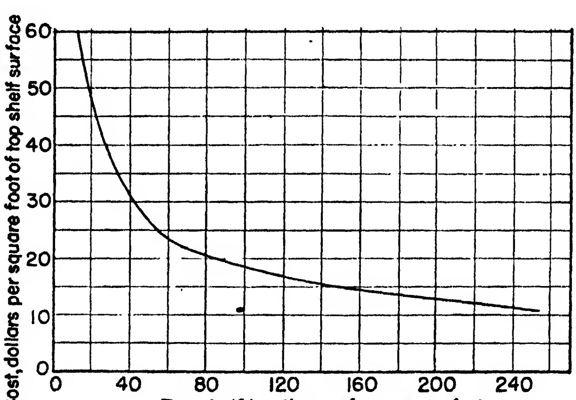

FIG. 43.—Cost of vacuum shelf driers.

Vacuum Shelf Driers.—The cost of steam-heated driers of this type without accessories is shown in Fig. 43.

Vacuum Rotary Driers.—The cost of steam-heated rotary vacuum driers varies from about $60 per square foot at 100 sq. ft. to about $25 at 600 sq. ft. Such figures include vacuum pump and condensers. These figures should be increased by 35 to 45 per cent for 1947.

Atmospheric Rotary Driers.—The cost of three variations of this type of drier may be estimated as follows:

	Cost per square foot of peripheral area	
	At 200 sq. ft.	At 1,200 sq. ft.
Flue-gas heated, direct-indirect	$28	$25
Flue-gas heated	24	16
Hot-air heated, direct	20	14

These figures should be increased by 25 per cent for 1947. Such costs include motors, cyclones, and heating equipment but exclude insulation, piping and ducts, and erection. Labor cost of erection of rotary driers approximates 15 per cent of the drier cost.

REACTION VESSELS

It is extremely difficult to generalize on the cost of agitated reaction vessels because they are subject to extremely wide possible variations in pressure rating, heating method, type of construction, drive, and in many other features. Crude average figures can be cited, however. Thus, for a jacketed steel reaction vessel of 500 gal. capacity for 50 lb. steam pressure or below with an anchor agitator of moderate speed, an installed cost of about $4,500 would represent a reasonable average. This would include erection, piping, electrical work, and other such matters but would ordinarily exclude instruments. For a 2,000-gal. vessel the figure should be increased to about $6,000. Glass-lined vessels are more expensive, of course, but not as much as one might expect when installation costs are included. Thus a 500-gal. glass-lined reaction vessel, installed, should cost about $5,500 and a 2,000-gal. one about $8,000. These figures should be increased by at least 30 per cent for 1947.

ELECTRIC MOTORS

The cost of electric motors may be represented by an equation of the form Cost (dollars) $= A + B \times$ horsepower. The values of A and B for a few types of motors are approximately as follows:

Type	A	B
Open construction, general purpose, 220–440–550 volts, 3-phase, 60-cycle, 1,800 r.p.m.	$ 40	$ 6.6
Same, except 514 r.p.m.	240	12
Totally enclosed for Class 1, Group *D* location, 220–440–550 volts, 3-phase, 60-cycle, 1,800 r.p.m.	60	12
Same, except 600 r.p.m.	270	20.6

All these figures are for ball-bearing motors without base or pulley. It is difficult to generalize on starting equipment, but the most costly starters vary between $20 per horsepower in small sizes (approximately 10 hp.) and $6 per horsepower in larger sizes (approximately 200 hp.).

ACKNOWLEDGMENT

The help of Mr. T. R. Olive in computing corrections for 1947 costs is acknowledged. The above work could not have been done without the excellent cooperation of a number of manufacturers. The author wants particularly to acknowledge the help of these firms:

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Allen Billmyre Co.
Alliance Tank Co.
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American Brass Co.
American Locomotive Co.
American Smelting and Refining Co.
Babcock and Wilcox Tube Co.
C. O. Bartlett and Snow Co.
Black, Sivalls, and Bryson, Inc.
Buffalo Foundry & Machine Co.
Chemical Engineering
Corning Glass Works.
Crane Co.
Denver Equipment Co.
Dorr Co.
Economy Pumps, Inc.
Peter A. Frasse and Co.
General Electric Co.
Globe Steel Tubes Co.
Goulds Pumps, Inc.
Griscom-Russell Co.
Hardinge Co., Inc.
Ingersoll-Rand Co.
International Nickel Co., Inc.
Jeffrey Mfg. Co.
Jenkins Bros.
Kinney Mfg. Co.
Lammert and Mann Co.
Lapp Insulator Co., Inc.
Lukens Steel Co.
Lummus Co.
National Carbon Co., Inc.
National Tube Co.
New England Tank and Tower Co.
Oliver United Filters, Inc.
Pfaudler Co.
Proctor and Schwartz, Inc.
Roots-Connersville Blower Corp.
Ross Heater and Mfg. Co., Inc.
T. Shriver and Co., Inc.
Spencer Turbine Co.
Sprout-Waldron Co.
F. J. Stokes Machine Co.
Struthers-Wells Corp.
Swenson Evaporator Co.
Taber Pump Co.
Taylor Forge and Pipe Works
U.S. Stoneware Co.
Whitlock Mfg. Co.

PART 2. STANDARDIZING COST DATA ON PROCESS EQUIPMENT

By Roger Williams, Jr.[1]

Lack of published information on costs of chemical equipment needs no proof, and only driblets have been printed in the past few years. Although these more recent, previously published data are interesting and valuable, many of them fail to fulfill their function. Primarily this is because the data in one article are not comparable with those in the next.

Published equipment cost information is seldom, if ever, used for the final firm construction estimates that managements require before making appropriations. For these estimates actual quotations can be and are obtained since the estimate is based on a complete design and equipment has been fully specified. Published cost ranges and curves for equipment are used primarily by those who make order-of-magnitude economic analyses, particularly those made during research on new processes or products. The publishers of cost information should aim their data at these users.

The major failing of the equipment cost information that is now available in the literature is that it is not on a consistent basis. It is not consistent as to price and wage levels, which may vary widely from year to year (currently, from month to month); it is not consistent as to inclusion of necessary accessories such as starters for motors, or heaters and cyclones for rotary driers; it is not consistent in including or excluding installation cost; and finally it is not consistent in including or excluding construction overhead. It appears that the chemical publications and the entire chemical industry should agree on some common ground for the presentation of such data.

CONSISTENT CORRELATIONS

The economic analyst who uses equipment cost data daily is at a loss if he does not correlate the information he collects on some consistent basis, or at the very least he needlessly complicates his job. This correlation is not difficult and merely means the choice and use of one basis. In general that basis should be picked so that the resultant information is most useful in building up plant investment estimates. As his basis the author has chosen the following:

1. All figures include cost of construction and construction overhead as well as the purchase price of the unit.

[1] Assistant Editor, *Chemical Engineering.*

2. All figures have been revised to a reference construction cost index. The author uses a modification of the index published in *Engineering News-Record* and has chosen 150 (*ca.* January, 1945) on that index as his constant value.

3. All figures include accessories. For example all pump costs include drive, starter, wiring, foundation, and so forth. In addition they include insulation, painting, and similar necessary work.

RANGES NOT WANTED

As enough data are collected curves are drawn for the cost of each type of equipment and it is these curves that are used in building up

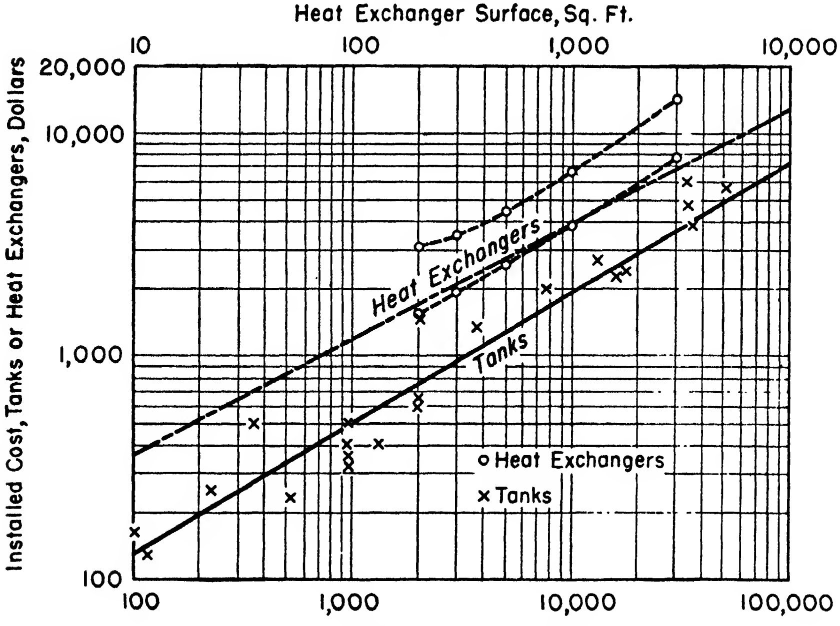


FIG. 44.—Cost of mild-steel tanks, installed, and cost of heat exchangers, including condensers and calandrias, installed.

plant investment estimates. These curves are only accurate to within plus or minus 10 or 20 per cent but they provide a figure, and the estimator has to pick one figure, not a range, when he is working up a plant cost. As an example, the lower, solid line on the accompanying chart shows the curve derived for low-pressure, mild-steel tanks. The plotted points have been revised to the above basis and include foundations and other accessories. No differentiation has been made between upright and horizontal tanks, or other small modifications. The correlation is reasonably good and the plotted line is adequate for analytical estimates. It is interesting to note that the plotted line closely follows the old rule-of-thumb six-tenths factor, the equation derived from the plotted points being $y = 8.36\ x^{0.594}$. For those not familiar with the factor, it is used as follows: If a cost is known at one capacity and the cost is desired at a second capacity x times the first, multiply the initial cost by $x^{0.6}$ to obtain the second cost.

As a second example, the upper dot-dash line in the chart shows a cost curve for mild-steel heat exchangers in which cost is plotted against square feet of heat exchange surface. Heat exchange area is used as a basis for capacity since it usually can be calculated readily from flow sheet data. Again the costs are for installed equipment and include overhead, supports, foundations, connections, and so forth.

Also plotted, as dotted curves, are the data of Happel *et al*[1] revised to the author's basis. This was done by adding to Happel's heat exchanger costs the percentages given in his article for installation labor, foundations, structural steel, insulation, fire protection, painting, indirect construction expense, and contractor's fee. It will be noted that there is good agreement between the author's data and the adjusted minimum published figures. It is seldom, however, that enough data are presented to make such comparisons as this possible. For example, Bliss[2] gave no installation cost data, and the data of Millet[3] are based on B.t.u. per hour per dollar of selling price.

CURVES PLUS PERCENTAGES

Once curves of this type have been developed for most unit process equipment, the estimation of plant cost is relatively easy. Costs of the major pieces of equipment (the accessories do not need to be calculated in detail) are taken from the curves, totaled, and adjusted to today's construction cost. Percentages can then be added for piping, instruments, buildings (sometimes estimated in more detail), outside lines, and service equipment (for example, hoists, furniture, safety equipment, etc.). Adding these and a percentage for contingencies, the plant cost estimate is completed. As pointed out by Eckhardt,[4]

[1] Happel *et al.*, "Estimating Chemical Engineering Equipment Costs," *Chem. Eng.*, October, 1946, pp. 99–102; December, 1946, pp. 97–100.

[2] Bliss, H., *Trans. Amer. Inst. Chem. Eng.*, **37**, 763–804 (1941); *Chem. Met. Eng.*, December, 1941, pp. 87–98.

[3] Millet, K. B., *Ind. Eng. Chem.*, **30**, 367–372 (1938).

[4] Eckhardt, H., "Needed: Standard Cost Estimating Data for the Process Industries, *Chem. Eng.*, September, 1940, pp. 104–105.

it is surprising how close such rough estimates can come to actual plant costs.

The basis chosen by the author is shown purely as an example. The basis can be the purchase cost of the pieces of equipment, as Happel *et al*[1] have chosen. In this case data on accessories as a percentage must also be accumulated. If this basis is used, all costs except the equipment purchase cost can be, and usually are, added by factor. This method is widely used but appears unduly detailed.

The author makes no claim that the basis he has chosen is the best, and he would like to see better ones proposed. But the necessity for choosing, and adhering to, one basis is obvious and that choice should be made soon. It appears equally obvious that the chemical and chemical engineering journals and technical society publications should agree on a common basis since it is in these publications that future cost data will appear. The basis described here is suggested with this need in view.

[1] Happel *et al.*, *op. cit.*

CHAPTER VII

ECONOMIC BALANCE

By W. H. McAdams[1]

In designing many types of apparatus for a fixed duty, the engineer can select optimum conditions from the standpoint of costs. This is true whenever, as a certain design factor is varied, some costs increase and others decrease, and hence the total cost goes through a minimum.

First, consider a simple case in which there is only one variable affecting costs. For example, assume it is required to design a steam-heated preheater to warm a given weight rate of flow of air from a fixed inlet temperature to a specified outlet temperature, using a specific type of heat-transfer surface, heated by steam condensing at a fixed temperature. In view of the heat balance the steam requirement is fixed and hence the cost of steam, although a substantial fraction of total costs, is not a variable in the design. However, the designer is free to use any desired mass velocity G of the gas past the heat-transfer surface. As this velocity is increased, the over-all coefficient of heat transfer U from steam to gas will increase, and consequently the fixed charges on the heater will decrease. At the same time the power required to force the gas through the heater will increase. At the optimum velocity the sum of fixed charges and power costs will be a minimum.

This problem can be solved by two methods. In the first, for each of a number of gas velocities the annual costs are computed for both fixed charges and power. By inspecting the results in the form of a table or preferably a graph, that velocity is selected at which the sum of fixed charges and power is a minimum.

Alternatively the problem can be solved analytically. From a knowledge of the unit operations involved (flow of heat and flow of fluids) the annual apparatus charges y_A (fixed charges on the heater) equals k_1G^{-n}, where k_1 is a constant proportional to the unit fixed charge (say C_A dollars per year per unit heat-transfer area) and which

[1] Professor of Chemical Engineering at the Massachusetts Institute of Technology, Cambridge 39, Mass.

includes other factors specific to the problem, and the exponent n is a constant; the annual power cost y_p equals k_2G^m, where k_2 is a constant proportional to the unit energy cost (say C_E dollars per foot-pound delivered to the fluid) and which includes other factors specific to the problem, and the exponent m is a constant. The total variable cost is given by

$$y_A + y_p = k_1G^{-n} + k_2G^m \tag{1}$$

and will go through a minimum or maximum when the derivative with respect to G is equated to zero:

$$-nk_1G_o^{-n-1} + mk_2G_o^{m-1} = 0 \tag{2}$$

Since all the constants (k_1, k_2, n and m) are positive, inspection of Eq. (1) shows that the point of zero slope corresponds to a *minimum* total cost. Hence the optimum velocity G_o is given by

$$G_o = \left(\frac{nk_1}{mk_2}\right)^{1/(n+m)} \tag{2a}$$

The most economical velocity is seen to depend not only on the known magnitudes of the dimensionless exponents n and m, but also upon the dimensional constants k_1 and k_2, which involve unit costs C_A and C_E, as well as other factors.

At the optimum velocity, the ratio $(y_A + y_p)_o$ of apparatus charges to power costs depends only on the exponents and is independent of the constants k_1 and k_2 as can be seen by multiplying both sides of Eq. (2) by G_o and rearranging

$$\frac{k_1G_o^{-n}}{k_2G_o^m} = \frac{m}{n} \quad \text{or} \quad \left(\frac{y_A}{y_p}\right)_o = \frac{m}{n} \tag{3}$$

This fact would have escaped notice when using the first method. However, the second method has the drawback of not giving directly the variation of costs with velocity. Thus if the total costs varied but little with velocity this fact might be overlooked using the second method.

A variation in the second method consists in expressing both variable costs in terms of some variable such as power loss per square foot of heat-transfer surface, P, rather than mass velocity. Let A represent the heat-transfer surface. The total variable cost, $y_A + y_P$ equals $C_AA + C_EPA$. For a fixed heat-transfer rate q and mean temperature difference Δt_m from steam to air (since $A = q/U\Delta t_m$),

A is inversely proportional to the heat-transfer coefficient U, which is a power function of mass velocity. But since power loss per unit surface is also a power function of mass velocity, the heat-transfer area is an inverse power function of P: A equals k_3P^{-a} where k_3 is a dimensional constant containing factors specific to the problem and a is the dimensionless exponent of P.

$$y_A + y_P = C_A k_3 P^{-a} + C_E P k_3 P^{-a} = C_A k_3 P^{-a} + C_E k_3 P^{1-a} \qquad (4)$$

Setting the derivative equal to zero, to find the minimum $y_A + y_P$:

$$\frac{d(y_A + y_P)}{dP} = -aC_A k_3 P_o^{-a-1} + (1 - a)C_E k_3 P_o^{-a} = 0 \qquad (5)$$

$$P_o = \frac{aC_A}{(1 - a)C_E} \qquad (5a)$$

It is now seen that the minimum total cost is obtained at the optimum power loss P_o, which in turn involves only the known exponent a and the ratio of two known unit costs.

The first method (designing for a series of velocities, and then comparing costs) has another advantage in some cases. Thus with flow normal to a bank of tubes (bare or with fins) it is necessary to use an integral number N of rows over which the air flows. In such cases from the relations that can be set up between N and G, one fixes N and solves for the compatible value of G rather than arbitrarily fixing G, which might call for say N of 1.5 rows deep. Or in designing a small-scale heater with flow inside tubes of a given diameter, the maximum velocity is that obtainable with all the fluid flowing inside a single tube. The velocities considered must then be those obtainable with 1, 2, 3, etc., tubes in parallel. In general, if in the process under study, the design variable may be changed only by finite increments, then the first method should be used, since use of the calculus is only an approximation in such cases.

With heat-transfer apparatus of moderate size the fixed charges may depend on the number of square feet purchased, and the same is true of certain filters and other types of apparatus. In such cases the first method of tabulating costs of specific sizes of apparatus is the more convenient.

At times it is helpful to use the analytical method to find the optimum value of the design variable, and then to tabulate costs for various values of the variables to determine the shape of the curve of total cost in the vicinity of the optimum point, thus combining both methods of attack.

In a process with a fixed output, involving a number of pieces of apparatus (for example, an absorber, a heat exchanger, a preheater, a stripper, and a cooler), there are a number of design variables, some of which affect the cost of several of the operations. For the moment assume that there are two major independent variables x and z. For a given value of z, the total costs are tabulated for various values of x, and the minimum total cost is noted; this procedure is repeated for other values of z, and that combination of values of x and z is selected which gives the minimum of the minima. If the values of x and z can be varied by differential increments, the same result can be obtained by first setting up an equation for total costs y_T in terms of both x and z, setting the partial derivatives $\partial y_T/\partial x$ and $\partial y_T/\partial z$ equal to zero, and solving simultaneously for the optimum values of x and z. Similar procedures could be used where there are more than two design variables. Careful study of the particular process may show that certain design variables affect costs of several but not all parts of the process. In such cases the problem is thereby simplified.

In the important problem of estimating the optimum production of a plant, similar methods of attack may be followed, although in this case maximum annual profit (or minimum annual loss) are the criteria, since here[1] the output can be varied, whereas in the cases considered above the output was fixed, hence minimum sum of variable costs could be used. In case of operating at a loss, the plant should not be shut down until the out-of-pocket income would fall below the out-of-pocket expenses, thus excluding fixed charges. If continuity of supply is stipulated in a contract, the plant may be operated at loss on the out-of-pocket basis.

In the case of a proposed expenditure that is not essential to the success of the process, decision is often based on whether or not the pay-off time is attractive. The pay-off time is defined as that period in which actual savings, due to the proposed change, would equal the original investment. The novice sometimes credits more towards savings than would actually be realized. For example, the total cost of 1,000 lb. of steam might be 35 cts. If the bare steam mains were insulated the required steam load on the power plant might be reduced by 1,000 lb. per hr. At first inspection the insulation is credited with a saving of 35 cts. per hour. Further analysis of steam costs might

[1] Lewis, W. K., *Chem. Met. Eng.*, **28**, 988–991 (1923).

show that the 35 cts. per 1,000 lb. consisted of 10 cts. for fuel and 25 cts. for fixed charges. Since the latter would not be changed by insulating the steam mains, the true saving is only the cost of the fuel saved, 10 cts. per hour, and the pay-off time should consequently be based only on the value of the fuel saved.

The problems that follow illustrate some of the methods of attack.

Illustration No. 1.—A boiler house contains 5 coal-fired boilers, each with a nominal rating of 300 boiler horsepower. If economically justified, each boiler can be operated at a rating of 350 per cent of nominal. Due to the growth of manufacturing departments, it is necessary to install additional boilers. Referring to the data and notes given below, determine the per cent of nominal rating at which the present boilers should be operated.

Data and Notes.—The cost of fuel, including the cost of handling coal and removing cinders, is $7 per ton, and the coal has a heating value of 14,000 B.t.u. per lb. The over-all efficiency of the boilers, from coal to steam, has been determined from tests of the present boilers operated at various ratings:

R, % of Nominal Rating	E, % Over-all Thermal Efficiency
100	75
150	76
200	74
225	72
250	69
275	65
300	61

Annual fixed charges y_A on each boiler are given by the equation:

$$y_A = 14{,}000 + 0.04R^2$$

Assume 8,550 hr. of operation per year.

Solution.—Basis: 5 boilers, 1 hr. (1 boiler hp. = 33,500 B.t.u./hr. for R = 100)

C_F = hourly cost of fuel at $7 per ton:

$$C_F = \frac{(5)(300)(R/100)(33{,}500)(7)}{(E/100)(14{,}000)(2{,}000)} = 12.56\frac{R}{E} \tag{1}$$

C_A = hourly fixed charges:

$$C_A = \frac{5(14{,}000 + 0.04R^2)}{8{,}550} = 8.18 + 0.0000234R^2 \tag{2}$$

T = total output, actual boiler hp. developed:

$$T = 5(300)\left(\frac{R}{100}\right) = 15R \tag{3}$$

Optimum results will be obtained when the sum of the variable costs, divided by the output, is a minimum.

TABLE I

R	E	R/E	C_F Eq. (1)	C_A Eq. (2)	$C_F + C_A$	T Eq. (3)	$\left(\frac{C_F + C_A}{T}\right)$ 1,000
100	75	1.33	16.7	8.4	25.1	1,500	16.7
150	76	1.97	24.8	8.7	33.5	2,250	14.9
175	75	2.33	29.3	8.9	38.2	2,625	14.6
200	74	2.70	33.9	9.0	42.9	3,000	14.3
225	72	3.12	39.2	9.4	48.6	3,375	14.4
250	69	3.62	46.5	9.6	56.1	3,750	15.0
275	65	4.23	53.2	10.0	63.2	4,125	15.3
300	61	4.92	61.8	10.3	72.1	4,500	16.0

As shown by Table I and Fig. 1, the optimum costs per unit output are found at 200 per cent of nominal rating, corresponding to a cost of $14.3 per 1,000 boiler hp. developed (33.5 million B.t.u.), or $0.428 per million B.t.u. exclusive of cost of labor. This cost is higher than that in a large power plant, in which the fixed

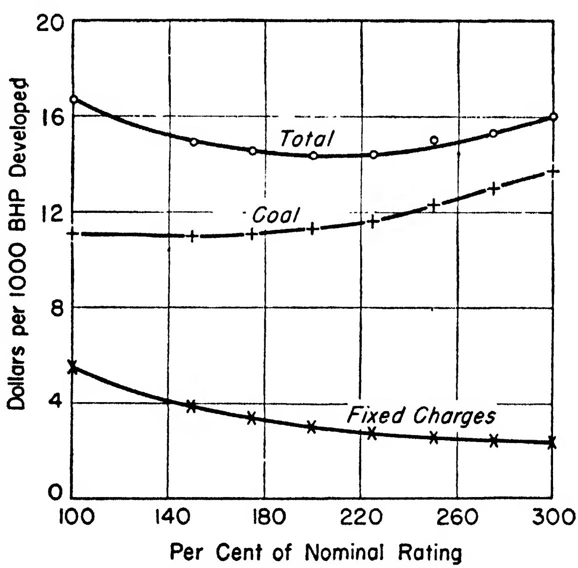


FIG. 1.—Optimum cost for boiler operation.

charges per boiler horsepower developed would be less than with these small boilers, and the efficiency would be higher.

Illustration No. 2.—Vegetable oil is decolorized by passing it through beds of fuller's earth (clay). After the desired decolorization is accomplished the filter is drained, washed with solvent to recover adhering oil, and is then dried. The dried clay, containing the adsorbed color, is removed and revivified by burning in a furnace of the Herreschoff type. After cooling, the revivified clay is recharged to the filter to decolorize an additional quantity of vegetable oil. While the revivified clay properly decolorizes the oil, its decolorizing capacity decreases with each revivification. Assume a successive depreciation in adsorptive capacity of 10 per cent with each burning, that is, a ton of freshly burned new clay removes 100 units of color, a ton of once-used clay will remove 90 units, a ton of twice-used clay will remove 81 units, etc. Note that the new clay is burned before being used in the color filtration. Cost data are given below.

Assume that a new plant of this type is being designed to treat a given quantity of oil per unit time.

a. How many times should the clay be burned before discarding it?

b. What will be the adsorptive capacity of the rejected clay, compared to that of the new clay?

Data and Notes.—New clay, unburned, costs $30 per ton. Cost of burning clay, new or old, is $1.20 per ton. Each time a clay is used, the cost of filtration, extraction, drying, and handling is $15 per ton. Neglect change in weight of clay due to addition or removal of color, and neglect loss of clay due to processing and handling.

Solution.—Nomenclature:

u = units of color removed in each filtration.
Σu = total units of color removed in N filtrations.
C = total cost of fresh clay, burning clay, and filtration.

$$C = 30 + 1.2N + 15N = 30 + 16.2N$$

Table II

N	u	Σu	C	$C/\Sigma u$
1	1.0	1.0	46.2	46.2
2	0.9	1.9	62.4	32.8
3	0.81	2.71	78.6	29.0
4	0.729	3.44	94.8	27.6
5	0.656	4.10	111.0	27.1
6	0.590	4.69	127.2	27.2
7	0.531	5.22	143.4	27.5
8	0.479	5.70	159.6	28.0

Table II shows that the minimum total cost, per unit output, is 27.1 with five filtrations. Before the last use, the clay has an adsorptive capacity 65.6 per cent of that of new freshly burned clay; if reburned the adsorptive capacity would be 59 per cent of that of new freshly burned clay, but it should be discarded after 5 filtrations.

Illustration No. 3.—At present the following conditions obtain in the evaporator department of a certain plant. During the operating year of 8,400 hr., the total liquor fed to the effect evaporator amounts to 178,000,000 lb. The feed, containing 15 per cent dissolved solute by weight, is concentrated to a 25 per cent solution in a single-effect evaporator supplied with exhaust steam condensing at 220°F. During an operating cycle the feed at 120°F. enters continuously and boils under vacuum at 120°F., and concentrated 25 per cent solution is withdrawn for

18 hr. The over-all coefficient U of heat transfer is 500 B.t.u. per hour per square foot per degree Fahrenheit over-all difference at the start, and it falls to 150 B.t.u. at the end of 18 hr. The evaporator is then shut down, the heating surface is cleaned, and another operating cycle is started.

If a new evaporator is to be designed for the same average yearly capacity as at present, specify

a. Square feet of heat-transfer surface.

b. Length of each complete cycle.

c. Length of each cleaning operation.

DATA AND NOTES.—One hour is required to drain off solution and open the manhole. The actual time of cleaning will be assumed proportional to the square root of the amount of scale on the heating surface. One additional hour is required to flush out the scale, close the manhole, refill the evaporator, and restore operation. At present the total cleaning time is 6 hr. (1 + 4 + 1). The cost of cleaning is \$1.5 per hour of actual cleaning time.

The operator of this evaporator also has other duties, and the charges for that fraction of his time devoted to this evaporator is \$0.30 per hour, regardless of whether the evaporator is operating or being cleaned. Fixed charges C_A on the evaporator and accessories, expressed in dollars per year, are given by the equation: $C_A = 360 + 1.3A$, where A is expressed in square feet of heat-transfer surface. The latent heat of evaporation may be taken as 1,024 B.t.u. per lb. The exhaust steam costs \$0.20 per million B.t.u. of latent heat. Assume U varies with time according to the equation:[1]

$$\frac{1}{U^2} = a + b\theta$$

where θ is expressed in hours and a and b are constants. By definition

$$\frac{dQ}{d\theta} = UA(t_s - t)$$

where dQ is the heat transferred in the time $d\theta$, t_s is the saturation temperature of the steam and t is the temperature of the boiling solution.

SOLUTION.—The problem will be solved by setting up the appropriate equations, fixing the number N of complete cycles per year, tabulating and comparing annual costs, and selecting that value of N corresponding to minimum total costs.

Nomenclature:

A = area of heat-transfer surface, square feet.
N = number of complete cycles per year.
Q = quantity of heat transferred per cycle, B.t.u.
U = over-all coefficient of heat transfer, B.t.u./(hr.) (sq. ft.)(deg. F.).
θ = operating time per cycle, hours.
θ_c = actual cleaning time per cycle, hours.
$\Sigma\theta$ = total length of a complete cycle, hours.

TIME BALANCES

$$\Sigma\theta = \theta + 2 + \theta_c \qquad (1)$$

$$N = \frac{8400}{\Sigma\theta} \qquad (2)$$

[1] McCabe, W. L., and C. S. Robinson, *Ind. Eng. Chem.*, **16**, 478–479 (1924).
Badger, W. L., and D. F. Othmer, *Trans. Am. Inst. Chem. Engrs.*, **16**, Part 2, 159–168 (1925).

HEAT TRANSFER

$$QN = 178 \times 10^6 \times 0.15 \left(\frac{0.85}{0.15} - \frac{0.75}{0.25}\right) (1{,}024) = 72{,}900 \times 10^6 \text{ B.t.u./year}$$

$$Q = 72{,}900 \times \frac{10^6}{N} \tag{3}$$

$$\frac{1}{U^2} = a + b\theta$$

For $\theta = 0$, $$a = \left(\frac{1}{500}\right)^2 = \frac{4}{10^6}$$

For $\theta = 18$, $$\left(\frac{1}{150}\right)^2 = \frac{4}{10^6} + b(18); \qquad b = \frac{2.25}{10^6}$$

$$\left(\frac{1{,}000}{U}\right)^2 = 4 + 2.25\theta, \qquad U = \frac{1{,}000}{\sqrt{4 + 2.25\theta}}$$

$$\int_0^Q dQ = \int_{\theta=0}^{\theta=\theta} \left(\frac{1{,}000}{\sqrt{4 + 2.25\theta}}\right) (A)(220 - 120)\, d\theta$$

$$Q = 89{,}000\, A(\sqrt{4 + 2.25\theta} - \sqrt{4}) \tag{4}$$

PRESENT CONDITIONS

By Eq. (1), $\theta = 18, \qquad \Sigma\theta = 18 + 2 + 4 = 24$

By Eq. (2), $$N = \frac{8{,}400}{24} = 350$$

By Eq. (3), $$Q = \frac{72{,}900}{350} = 208 \times 10^6$$

By Eq. (4), $208 \times 10^6 = 89{,}000A\,(\sqrt{4 + 2.25(18)} - 2); \qquad A = 500$

Given $\theta_c = k\sqrt{\frac{Q}{10^6}}; \qquad 4 = k\sqrt{208}; \qquad k = 0.277$

$$\theta_c = 0.277\sqrt{\frac{Q}{10^6}} \tag{5}$$

ANNUAL COSTS

$$C_A = 360 + 1.3A \tag{6}$$

$$C_c = \text{cost of cleaning} = 1.5\theta_c N \tag{7}$$

$$C_L = \text{cost of operating labor} = 8{,}400(0.3) = 2{,}520$$

$$C_H = \text{cost of heat} = 72{,}900(0.2) = 14{,}580$$

Since these last two costs are constant, they can be omitted in finding optimum conditions. Values of N are now selected, and the equations are used to compute the values shown in Table III.

TABLE III

N	$Q/10^6$ Eq. (3)	θ_c Eq. (5)	$\Sigma\theta$ Eq. (2)	θ Eq. (1)	A Eq. (4)	C_A Eq. (6)	C_c Eq. (7)	$C_A + C_c$
350	208	4.00	24.0	18.0	500	1,010	2,100	3,110
200	365	5.29	42.0	34.7	581	1,115	1,587	2,702
100	729	7.48	84.0	74.5	737	1,318	1,120	2,438
50	1,460	10.6	168.	155.4	977	1,628	795	2,423
30	2,430	13.7	280.	264.3	1,214	1,938	616	2,554
75	972	8.62	112.	101.4	824	1,430	972	2,402

The tabulation shows that the minimum sum of annual costs of fixed charges and cleaning is $2,402, when using 824 sq. ft. of heat-transfer surface and 75 cycles per year, each of 101 hr., of which 8.6 hr. are devoted to cleaning (see also Fig. 2). The total costs with the proposed new evaporator would be $3,110 minus $2,402, or $708 less than with the present evaporator. The annual costs would be as follows:

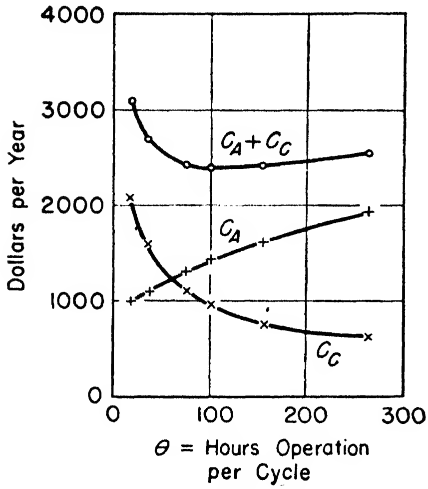


FIG. 2.—Optimum cost for evaporator operation.

$ 1,430	for fixed charges
972	for labor for cleaning
2,520	for labor for operating
14,580	for steam
$19,502	total

for transfer of $72{,}900 \times 10^6$ B.t.u., or a total cost of $0.268 per million B.t.u.

If a new evaporator department were to be built, it would be advisable to reduce the load on the present evaporator and increase that on the new evaporator, which would require purchase of a larger evaporator than that calculated above.

Illustration No. 4.—A condenser must be designed for a fixed duty of transferring q B.t.u. per hour. Since the size of the condenser is substantial, the fixed charges are independent of the amount of heat-transfer surface and are constant to C_A dollars per year per square foot; the condenser is to operate θ hours per year. Cooling water under adequate pressure costs C_w dollars per pound. The over-all coefficient of heat-transfer is fixed at U B.t.u. per hour per square foot per degree Fahrenheit difference from vapor to water based on the logarithmic mean temperature difference, and will be assumed independent of temperature.

a. Derive a general equation for obtaining the optimum rise in water temperature, and find the temperature of the outlet water for the following conditions: t_v of 176°F., t_1 of 80°F., a water cost of $0.1 per 1,000 cu. ft. (62,300 lb.), fixed charges on the condensing surface of $0.6 per square foot, θ of 8,400, and U of 200 per square foot of condensing surface. The specific heat c_p of water may be assumed constant at 1 B.t.u. per pound per degree Fahrenheit.

b. Derive an equation for the Δt at the hot end of a counterflow exchanger in which the warmer fluid cools from t_{H1} to t_{H2}, again assuming U is constant and the cost of coolant is proportional to the amount used. Find Δt at the hot end for U of 100, θ of 8,400, t_{H1} of 176°F., t_{H2} of 90°F., t_{C1} of 80°F., for the same unit costs as in part *a*.

SOLUTION.—Let A represent the square feet of condensing surface, w the water rate in pounds per hour, and y the annual costs (y_w for water and y_A for fixed charges on A).

$$\Sigma y = y_w + y_A = w\theta C_w + AC_A$$

In view of the heat balance, $q = wc_p(t_2 - t_1) = wc_p(\Delta t_1 - \Delta t_2)$ and the rate equation, $q = UA\ \Delta t_m$, where

$$\Delta t_m = \frac{\Delta t_1 - \Delta t_2}{\ln_e \dfrac{\Delta t_1}{\Delta t_2}}$$

Upon eliminating w and solving for the total cost of transferring 1 B.t.u. annually, one obtains

$$\frac{\Sigma y}{q\theta} = \frac{C_w}{c_p(\Delta t_1 - \Delta t_2)} + \frac{C_A \ln_e \dfrac{\Delta t_1}{\Delta t_2}}{U\theta(\Delta t_1 - \Delta t_2)} \tag{1}$$

Since U is independent of temperature, it is also independent of temperature difference. As Δt_2 is decreased, the cost of water will decrease, and the fixed

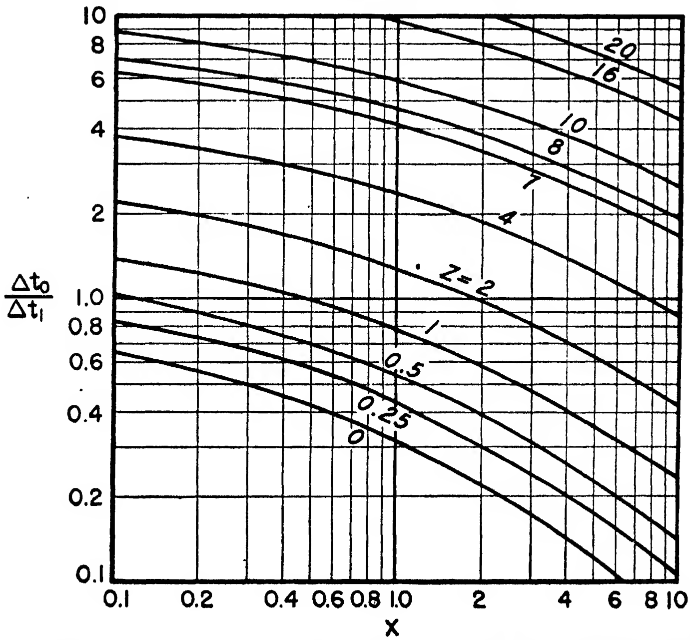


FIG. 3.—$\Delta t_0/\Delta t_1$ vs. X for various values of Z. (*From Perry, "Chemical Engineers' Handbook," McGraw-Hill Book Company, Inc.*, 1941.)

charges will increase; consequently the sum of these costs will go through a minimum at an optimum value of Δt_2, designated as Δt_0. The derivative of Eq. (1), with respect to Δt_2, will be set equal to zero, giving

$$\frac{\Delta t_1}{\Delta t_0} - 1 - \ln_e \frac{\Delta t_1}{\Delta t_0} = \frac{UC_w\theta}{C_A c_p} \tag{2}$$

$$X = \frac{UC_w\theta}{C_A c_p} = \frac{200(0.1/62{,}300)(8{,}400)}{0.6(1)} = 4.5$$

From Eq. (2) by trial procedure, $\Delta t_0/\Delta t_1 = 0.133 = \Delta t_0/96$, whence $\Delta t_0 = 12.8°F$.

By rearranging Eq. (1) the optimum ratio of costs of water and fixed charges is

$$\left(\frac{y_w}{y_A}\right)_0 = \frac{X}{\ln_e \frac{\Delta t_1}{\Delta t_0}}$$

and since $\Delta t_0/\Delta t_1$ equals 0.133 and X equals 4.5, $(y_w/y_A)_0$ equals 2.2, which means that the water costs are 2.2 times those for fixed charges.

Figure 3[1] gives curves of $\Delta t_0/\Delta t_1$ vs. X to avoid trial and error procedure. The curve marked $Z = 0$ is based on Eq. (2). For the case of an exchanger where the heat transferred from the warmer fluid ($q = w_H c_H(t_{H1} - t_{H2})$ is absorbed by the cooling medium, $q = w_c c_c(t_{c2} - t_{c1})$, a similar derivation gives

$$\left(\frac{Z + 1 - \frac{\Delta t_0}{\Delta t_1}}{\frac{\Delta t_0}{\Delta t_1} - 1}\right)^2 \left(\frac{\Delta t_1}{\Delta t_0} - 1 + \ln_e \frac{\Delta t_0}{\Delta t_1}\right) = X \qquad (3)$$

In Fig. 3, Eq. (3) is shown plotted as $\Delta t_0/\Delta t_1$ vs. X for various values of the parameter $Z = (t_{H1} - t_{H2})/(\Delta t_1)$, which is zero for condensation of a single pure vapor, in which case Eq. (3) reduces to Eq. (2)

$$X = \frac{UC_w\theta}{C_A c_p} = \frac{(100)(0.1/62{,}300)(8{,}400)}{0.6(1.0)} = 2.25$$

$$Z = \frac{t_{H1} - t_{H2}}{t_{H2} - t_{c1}} = \frac{176 - 90}{90 - 80} = 8.6$$

If $\Delta t_0/\Delta t_1 = 4$, Eq. (3) gives

$$\left(\frac{8.6 + 1 - 4}{4 - 1}\right)^2 (0.25 - 1 + 2.3 \log 4) = 2.05 \text{ vs. } 2.25$$

If $\Delta t_0/\Delta t_1 = 3.95$, Eq. (3) gives 2.30 vs. 2.25.

If $\Delta t_0/\Delta t_1 = 3.97$, Eq. (3) balances (2.25 vs. 2.25).

Since Δt_1 is 10°F., $\Delta t_0 = 39.7$°F. at hot end, and $t_2 = 136$°F. Note that the cooling water should not rise so much in temperature as in part *a*. This would have been true had U been the same as in part *a*.

Illustration No. 5.—A bare pipe line carrying steam under pressure loses 1.2 million B.t.u. per hr. and delivers 100 million B.t.u. per hr. of latent heat to the process department. If insulated at an initial cost of $800, the line would lose 0.2 million B.t.u. per hr. When bare, the fuel cost is $10.12 per hour, and fixed charges on the boiler plant and line are $25 per hour. Calculate the time for the actual savings to equal the first cost of the insulation. In either case the process department requires 100 million B.t.u. per hr.

SOLUTION.—Since insulating the line will not affect the fixed charges, actual savings must be based on the value of the fuel saved, which is 10.12/101.2 = $0.10 per million B.t.u. Since this insulation saves 1 million B.t.u. per hr., the hourly saving is $0.10, and the pay-off time is 800/0.1 = 8,000 hours of operation.

Illustration No. 6 (Optimum Operating Conditions in Rectification).—A continuous rectifying column is to be designed to produce 200 pound-moles per hr. of distillate and 200 pound-moles per hr. of bottoms from 400 pound-moles per hr. of

[1] Perry, *op. cit.*, p. 995.

feed; the flow sheet is shown in Fig. 4. It is agreed to design the column for a superficial vapor velocity of 2.2 ft. per sec. at the top of the tower, and to use a plate spacing of 1 ft. Calculations show that the required number of plates N

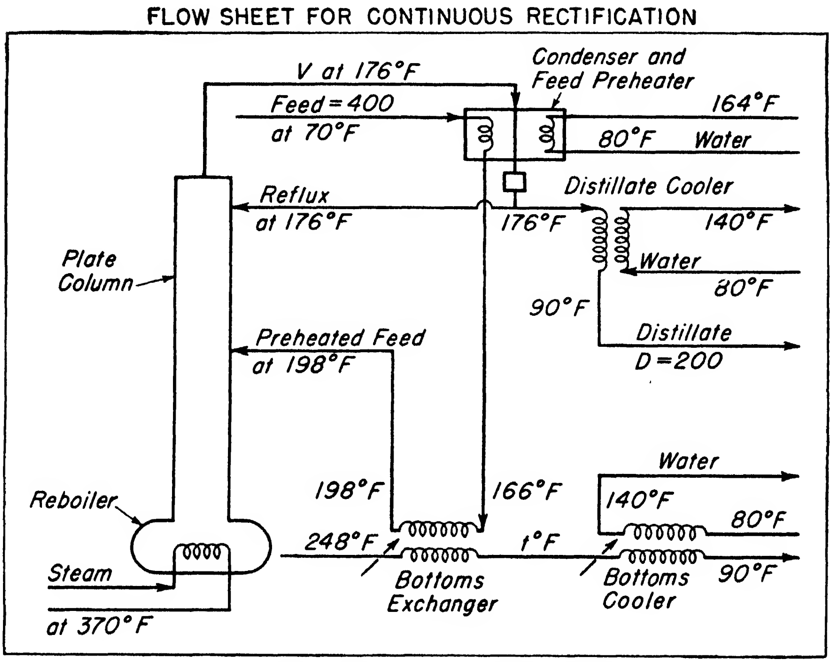


FIG. 4.—Flow sheet for continuous rectification.

decreases with increase in the mole ratio r of reflux R to distillate D, as shown in Table IV.

TABLE IV

$r = R/D$	1.42	1.50	1.56	1.70	2.10	3.10	3.60	∞
N	∞	42	36	31	25	20	19	13

The first cost C of the copper column in dollars is given by the equation:

$$C = 30ND_c^{1.23},$$

where D_c is the inside diameter of the column in feet and N is the number of plates.

Annual fixed charges will be taken as 15 per cent of the first cost, and the column is to operate 8,400 hr. per year. The available steam condenses at 370°F., and costs \$0.40 per million B.t.u. of latent heat; heat losses will be neglected. Untreated cooling water (at 80°F.) for the condenser costs \$0.10 per thousand cubic feet (62,300 lb.). First cost in dollars of heat-transfer surface is given by the equation $C_A = 90\sqrt{A}$, where A is expressed in square feet; fixed charges will be taken as 15 per cent. The over-all coefficients of heat transfer (expressed in B.t.u.

per hour per square foot of heat transfer surface per degree Fahrenheit logarithmic mean-temperature difference) will be assumed as follows: 100 for the reboiler, 100 for the condenser, 50 for the distillate-feed exchanger, 50 for the bottoms cooler, 50 for the distillate cooler and 25 for the bottoms-feed exchanger. Further data are given below.

a. Determine the optimum reflux ratio, the corresponding column diameter and number of plates, and the hourly steam and water requirements.

b. Tabulate the corresponding annual fixed charges and the annual costs of steam and water.

c. What reflux ratio corresponds to minimum investment?

d. What reflux ratio is recommended?

Data and Notes.—The feed enters as saturated liquid at 198°F. The vapors leaving the top of the column have a molal latent heat of vaporization of 12,700 B.t.u. per pound-mole, and are at 176°F. and 1 atmosphere absolute. The vapors entering the bottom of the column are at 248°F. and 1.4 atmospheres absolute. The molal heat capacities of the various streams vary with temperature as shown in Table V.

Table V

Temperature, degrees Fahrenheit	176°F.	198°F.	248°F.
Molal heat capacity of distillate	35.9	36.9	38.5
Molal heat capacity of bottoms	39.7	40.5	41.5
Molal heat capacity of feed	37.8	38.7	40.0

The molecular weight of the distillate is 78.2 and that of the bottoms is 92.0, 1 pound-mole of distillate occupies 10.7 U.S. gallons. To simplify the problem; the water will be heated to a fixed temperature of 110°F. in the coolers and to within 12°F. of the vapor temperature in the condenser.

Solution.—As the reflux ratio increases the number of plates decreases, but the vapor rate V and the corresponding cross section increases; consequently the relative volume of the column (proportional to NV/D) can readily be computed (Table VI).

Table VI

$R/D = r$	1.42	1.50	1.56	1.70	2.10	3.10	3.60	∞
$V/D = 1 + r$	2.42	2.50	2.56	2.70	3.10	4.10	4.60	∞
N	∞	42	36	31	25	20	19	13
$NV/D = N(1 + r)$	∞	105	92.2	83.8	77.5	82	87.4	∞

It is found that the volume of the column goes through a minimum at a reflux ratio of 2.1. If the fixed charges on the column were strictly proportional to the volume of the column ND_c^2 instead of to $ND_c^{1.23}$, it would be unnecessary to investigate reflux ratios larger than 2.1, since the cost of heat would also be increasing. The problem will be solved by calculating the variable costs and locating the reflux ratio corresponding to minimum sum of the variable costs. In view of the part *b*, some of the constant costs are calculated.

Nomenclature:

A = area of heat transfer surface, square feet.

C = first cost, dollars; C_A for heat transfer apparatus = $90\sqrt{A}$; C_c for column = $30ND_c^{1.23}$.

D_c = inside diameter of column, feet.

q = heat-transfer rate, B.t.u. per hour; q_c for condenser and q_r for reboiler.

r = mole ratio of reflux R to distillate D.

S = cross section of column, square feet.

t = temperature, degrees Fahrenheit; Δt over-all difference between hot and cold streams, degrees Fahrenheit

$$\Delta t_m = \frac{\Delta t_1 - \Delta t_2}{\ln_e \dfrac{\Delta t_1}{\Delta t_2}}$$

U = over-all coefficient of heat transfer, B.t.u. per hour per square foot per degree Fahrenheit.

$$U = \frac{q}{A\Delta t_m}$$

V = pound-moles of vapor leaving column per hour.

w = weight rate; w_s for steam and w_w for water.

y = annual costs in dollars; y_A on heat-transfer surface, y_H for heat, and y_w for water.

Annual Fixed Charges on the Column

The pound-molal volume of the vapors at top of the column is

$$359\left(\frac{460 + 176}{460 + 32}\right) = 465 \text{ cu. ft.}$$

and the required cross section, to give the design velocity of 2.2. ft. per sec., is

$$S = \frac{465V}{(2.2)(3{,}600)} = 0.0587V$$

and since S equals $(\pi/4)D_c^2$, the corresponding inside diameter is

$$D_c = 0.273\sqrt{V} \qquad (1)$$

Since the annual fixed charges on the column are to be 15 per cent of the first cost of $30ND_c^{1.23}$,

$$y_c = 0.15(30ND_c^{1.23}) = 4.5ND_c^{1.23} \qquad (2)$$

Annual Steam Cost for Reboiler

Heat Balance (input equals output):

$$q_r + 400\left(\frac{37.8 + 38.7}{2}\right)(198 - 176) = 12{,}700V + 200\left(\frac{39.7 + 41.5}{2}\right)(248 - 176)$$

$$q_r = 249{,}000 + 12{,}700V, \qquad \text{or} \qquad w_s = \frac{q}{850} \text{ lb. steam per hour.}$$

Since steam costs \$0.40 per 10^6 B.t.u., the annual cost y_H for steam is

$$y_H = \frac{(8{,}400)(0.4)(249{,}000 + 12{,}700V)}{10^6} = 837 + 42.7V \qquad (3)$$

FIXED CHARGES ON REBOILER

$$A = \frac{q_r}{U\Delta t} = \frac{249{,}000 + 12{,}700V}{100(370 - 248)} = 20.4 + 1.04V \qquad (4)$$

$$y_A = 0.15(90)\sqrt{A} = 13.5\sqrt{A} \qquad (5)$$

DISTILLATE-FEED EXCHANGER

$$q = 400\left(\frac{34.6 + 37.8}{2}\right)(166 - 70) = 1{,}380{,}000 \text{ B.t.u./hr.}$$

which requires condensation of 1,380,000/12,700 = 109 pound-moles of vapors per hr., vs. the minimum vapor of 484 lb. per hr.

$$\Delta t_1 = 176 - 70 = 106; \qquad \Delta t_2 = 176 - 166 = 10; \qquad \Delta t_m = 40.6$$

$$A = \frac{1{,}380{,}000}{(50)(40.6)} = 680 \text{ sq. ft.}$$

$$y_A = 0.15(90\sqrt{680}) = 352 \qquad (6)$$

BOTTOMS EXCHANGER

To heat feed from 166 to 198°F. requires 400(37.6)(198 − 166) = 481,000 B.t.u. per hr., to be removed by cooling bottoms from 248°F. to t degrees F. By the heat balance, neglecting losses:

$481{,}000 = 200(40.9)(248 - t)$; $t = 189$°F.

$$\Delta t_1 = 248 - 198 = 50°\text{F.}; \qquad \Delta t_2 = 189 - 166 = 23°\text{F.}; \qquad \Delta t_m = 34.8°\text{F.}$$

$$A = \frac{481{,}000}{25(34.8)} = 553 \text{ sq. ft.}$$

$$y_A = 0.15\,(90\sqrt{553}) = 318 \qquad (7)$$

BOTTOMS COOLER

To cool bottoms from 189 to 90°F. with water rising from 80 to 140°F.:

$$\Delta t_1 = 189 - 140 = 49°\text{F.}; \qquad \Delta t_2 = 90 - 80 = 10°\text{F.}; \qquad \Delta t_m = 24.5°\text{F.}$$

$$q = 200(39.3)(189 - 90) = 777{,}000$$

$$A = \frac{777{,}000}{50(24.5)} = 635 \qquad (8)$$

$$y_A = 13.5\sqrt{635} = 340$$

Annual cost of cooling water, at \$0.10 per 62,300 lb.:

$$y_w = \frac{(8{,}400)(777{,}000)(0.1)}{(1)(140 - 80)(62{,}300)} = 175 \qquad (9)$$

CONDENSER

Since the distillate exchanger condenses 109 pound-moles per hr., and the latent heat of condensation is 12,700 B.t.u. per pound-mole, the cooling water will absorb

$$q_c = (12{,}700)(V - 109) \text{ B.t.u. per hr.}$$

Since it is agreed that the water is to be heated within 12°F. of the vapor temperature

$$\Delta t_2 = 176 - 164 = 12°\text{F.}; \qquad \Delta t_1 = 176 - 80 = 96°\text{F.}; \qquad \Delta t_m = 40.4°\text{F.}$$

$$A = \frac{12{,}700(V - 109)}{(100)(40.4)} = 3.14(V - 109)$$

$$y_A = 13.5\sqrt{A} \tag{10}$$

The annual cost of cooling water is

$$y_w = \frac{12{,}700(V - 109)(8{,}400)(0.1)}{(1)(164 - 80)(62{,}300)} = 2.04(V - 109) \tag{11}$$

Distillate Cooler

To cool the distillate from 176 to 90°F. by water rising from 80°F. to 140°F.:

$$q = 200(34.6)(176 - 90) = 595{,}000 \text{ B.t.u. per hr.}$$

$$\Delta t_1 = 176 - 140 = 36°\text{F.}; \qquad \Delta t_2 = 90 - 80 = 10°\text{F.}; \qquad \Delta t_m = 20.3°\text{F.}$$

$$A = \frac{595{,}000}{(50)(20.3)} = 587 \text{ sq. ft.}$$

$$y_A = 13.5\sqrt{587} = 328 \tag{12}$$

The annual cost of water is

$$y_w = \frac{(8{,}400)(595{,}000)(0.1)}{(1)(140 - 80)(62{,}300)} = 134 \tag{13}$$

Table VII.—Results

Reflux ratio, R/D	1.42	1.50	1.56	1.70	2.10	3.10	3.60	∞
Number of plates	∞	42	36	31	25	20	19	13
Column diameter, feet	6.00	6.12	6.18	6.35	6.80	7.82	8.28	∞
Investment								
Column	∞	11,700	10,130	9,030	7,930	7,570	7,700	∞
H. T. apparatus	14,080	14,170	14,250	14,420	14,850	15,840	18,930	∞
Total	∞	25,870	24,380	23,450	22,780	23,410	26,630	∞
Fixed charges								
Column	∞	1,755	1,520	1,355	1,190	1,135	1,155	∞
H. T. apparatus	2,122	2,126	2,138	2,163	2,227	2,376	2,844	∞
Water cost	1,077	1,107	1,132	1,189	1,353	1,761	1,967	∞
Heat cost	21,500	22,100	22,700	23,900	27,300	35,800	40,200	∞
Total annual costs	∞	27,088	27,490	28,607	32,070	41,072	46,166	∞

a. Inspection of Table VII, results, and corresponding graph (Fig. 5) shows that total costs are a minimum at a reflux ratio of 1.5 that requires a column 6.12 ft. in diameter and containing 42 plates. The corresponding hourly requirements are 7,760 lb. of steam and 81,900 lb. of cooling water.

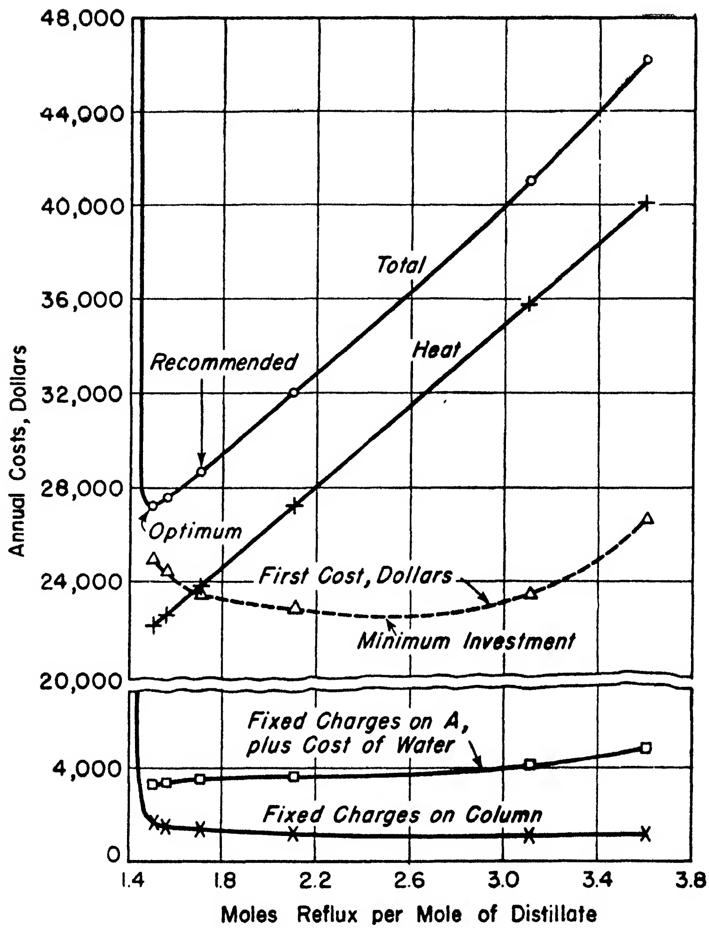


FIG. 5.—Optimum cost for rectification.

b. At the optimum reflux ratio the annual costs are as follows:

Item	Dollars per year	Per cent of total	Cents per gallon distillate
Steam	22,100	81.5	0.123
Water	1,107	4.1	0.006
Fixed charges on column	1,755	6.5	0.010
Fixed charges on HT surface	2,126	7.9	0.012
	27,088	100.0	0.151

The cost of shells for the heat exchangers, process and utility piping, instruments and accessories might cost an additional \$50,000, which would add 50,000(0.15) = \$7,500 to the annual fixed charges. The total investment would then be (1,755 + 2,126 + 7,500)/0.15 = \$75,800. Since the cross section of the column is 29.4 sq. ft. and there are 42 plates, the entire first cost, divided by the product of the cross section and the number of plates is 75,800/(29.4)(42) = \$61.3, which is of the usual magnitude for copper columns of this diameter and plate spacing.

c. The investment for column plus heat-transfer apparatus is a minimum (\$22,500) at a reflux ratio of 2.5. However, at this reflux ratio the annual costs would be \$35,600 compared with \$27,000 at the optimum reflux ratio of 1.5.

d. Since the curve of total annual cost vs. reflux ratio is flat near the optimum, by increasing the reflux ratio from 1.5 to 1.7 total annual cost is increased only \$519 and the original investment is decreased \$2,420. The corresponding column would have a diameter of 6.35 ft. and 31 plates, compared with 6.12 ft. and 42 plates, and would have the advantage of decreasing the cost of the building. The recommended ratio of reflux to distillate is 1.7, which is 20 per cent more than the minimum value corresponding to infinite number of plates.

Further refinements could be made in the design by solving for the optimum temperature of the feed entering the bottoms-feed exchanger (instead of arbitrarily selecting 166°F.) and by finding the best outlet temperatures of cooling water from both the condenser and the coolers. In designing the heat-transfer apparatus, it might be found possible to obtain somewhat higher coefficients of heat transfer than those assumed. None of these refinements will make any large percentage reduction in annual costs, which is primarily that of steam.

CHAPTER VIII

HEAT AND POWER

By Robert V. Kleinschmidt[1]

Practically all chemical reactions involve energy changes that may be considered as potential sources of power or that require a supply of power for their accomplishment. The two major forms of energy used in the chemical industry are heat and electric power. In a few cases light and biological energy are used, and some proposals to use mechanical wave motion in the "supersonic form" have been made.

Energy Sources.—There are four main sources of energy that may be utilized by a chemical industry:

1. Fuel—coal, oil, gas, wood.
2. Water (and wind) power.
3. Purchased electric power.
4. By-product heat and power from processes within the industry.

Electrical energy is the most valuable as well as normally the most expensive form of energy. It can be converted at high efficiency into heat, mechanical work, light, sound, or used directly in ionic reactions. Heat, on the other hand, is the cheapest and most generally available form of energy, but its conversion to other forms of energy is limited by complex thermodynamic relations and by the properties of materials for construction of power generating apparatus, boilers, engine cylinders and pistons, or turbine blades. In general, not more than 25 per cent of heat at temperatures above 1200°F. can be converted to power, while heat below 400°F. is practically worthless as a source of power. Special oils used as Diesel fuel may be used at a thermal efficiency as high as 35 per cent.

The cost of heat and power is one of the major items of expense in many chemical processes. In many cases a source of energy is the determining factor in plant location. The chemical industries around Niagara Falls, the steel industries of the Pittsburgh district, and the more recent grouping of industries in the Kanawha Valley of West

[1] Consulting Engineer; Professor, Harvard Graduate School of Engineering.

Virginia and around Anniston, Ala., are examples of this fact. A clear understanding of the relations of the various forms of energy is essential to a proper understanding of their relative value.

Heat.—Heat is obtained from

1. Combustion of fuels, mostly forms of carbon and hydrogen.
2. Waste heat of other chemical processes.
3. Exhaust steam from power generating equipment.
4. Natural sources such as the sun, water, or steam from the earth's heat.

In fact, all materials may be regarded as sources of low-temperature heat.

The chief primary industrial fuels in the United States are coal, fuel oil, and natural gas. Other less important fuels include wood, peat, shale, and certain industrial wastes such as petroleum coke. Radioactive or "fissionable" materials may have to be considered as possible fuels in the future, but at present they are to be regarded as expensive, highly concentrated forms of energy rather than as primary fuels.

In chemical industry, fuels occupy a position of far greater importance than in most industrial processes. They are not only a source of heat and power, but are a major raw material—the chief source of carbon, hydrogen, and hydrocarbons, and an important secondary source of sulphur and nitrogen compounds. Moreover, heat and electric power are often major cost items in chemical processes. Fuel supply and cost is therefore a major factor in determining chemical plant location and layout, and the proper handling of fuels is vital to economical operations.

Choice of Fuel.—The choice of a fuel is determined by

1. Availability.
2. Quality.
3. Cost.

Coal and fuel oil are available throughout the United States and at coastal points throughout the world, at prices that depend largely on the cost of transportation from producing areas. (Figure 1 from data of the U.S. Geological Survey, U.S. Dept. of The Interior, is a diagram of major coal, oil, and gas producing areas of the United States.) The producing areas for both coal and oil in the United States are so extensive that there is little reason for locating a chemical plant far from a source of supply. Next to location at "mine mouth," a location where water transportation is available is to be preferred.

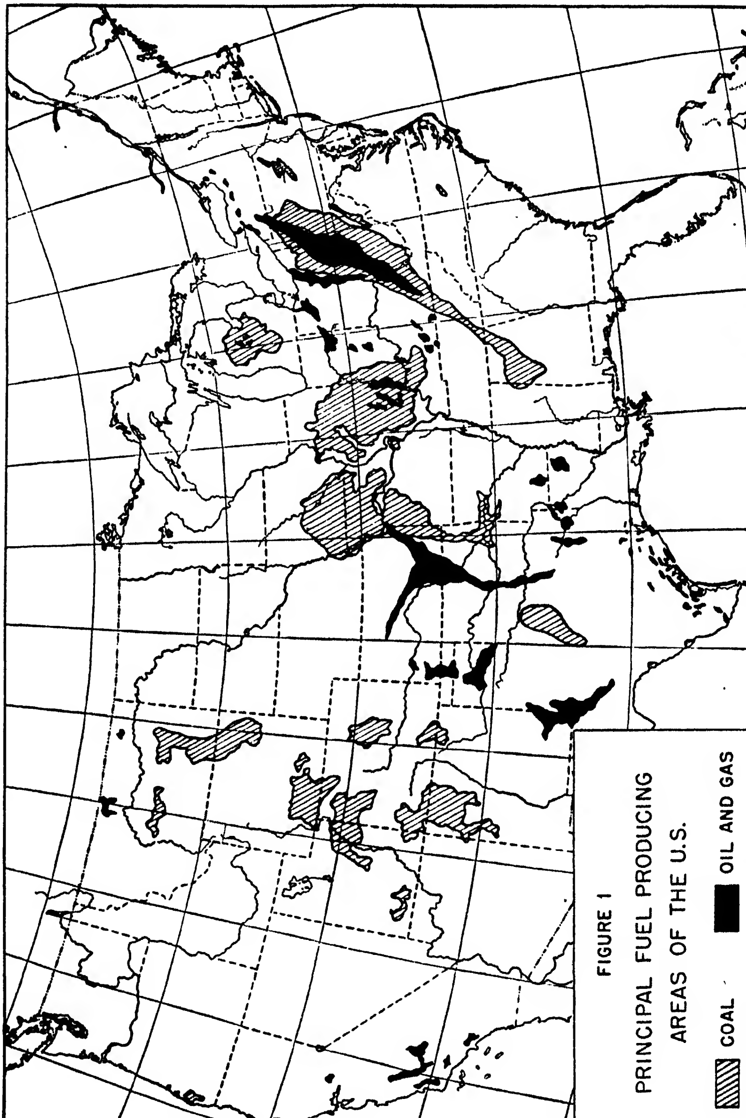


FIG. 1.—Principal fuel producing areas of the United States.

For production of heat and power there is available suitable equipment for handling almost any type of coal, oil, or gas, and the difficulties of handling poorer grades of coal are largely offset by lower cost.

The quality of coal is determined by

1. Ash content.
2. Ash fusion temperatures and composition.
3. Volatile matter.
4. Coking properties.
5. Sulphur content.
6. Fixed nitrogen.
7. Chlorine.
8. Heating value.

A complete analysis of the importance of these various factors under various conditions is far beyond the scope of this book. For power generation it may be said that low ash content is always desirable, and that high ash fusion temperature, a moderate volatile content, and low sulphur, nitrogen, and chlorine are desirable. For by-product coke production, high volatile, good coking properties, low sulphur, and high nitrogen may be desirable. There is a definite trend toward recovery of sulphur, either as oxide or as elemental sulphur, from coke-oven gas and flue gases. The significance of this trend is seen when it is realized that the total sulphur in coal mined in the United States is several times the total sulphur used. The sulphur in coal may vary from under 0.5 per cent to as much as 6 per cent with an average in the range of 1 to 2 per cent.

The quality of fuel oils is determined by

1. Viscosity and density.
2. Carbon-hydrogen ratio.
3. Distillation range (and flash point).
4. Sulphur content.
5. Water and ash content.
6. Heating value.

For special uses other properties are often specified such as octane or cetane numbers for engine fuels, pour point for heavy oils, and some form of carbon residue test. Sulphur in the cheaper fuel oils runs around 1 to 2 per cent, but the higher grade distillates may be obtained with sulphur as low as 0.02 per cent, or better.

Fuel Cost Factors.—Fuel prices tend to be competitive for power production purposes over wide areas, when all factors are considered. The special conditions of the chemical industry, however, tend to upset this balance in many cases. Thus, a penalty for high-sulphur coal may become an asset if sulphur recovery is practiced, while the extremely high-volatile coals which are "smoky" for power generation will give high by-product yields in a coke plant.

It costs as much to haul a ton of poor grade, high-ash coal as a ton of the best steam coal. Therefore, at distances from the mines where transportation is a large item in the delivered cost, the better grades of coal are most economical, while at the mine the reverse is usually true. It may be stated as a general principle that *near the source of supply, low-grade materials tend to be the most economical, while at a distance from the source, the highest grade material will be the cheapest.*

Thus far, only costs "delivered at the plant" have been considered. Since what is desired from a fuel is not a coal pile but heat, power, and chemical raw materials such as hydrogen, a comparison of various fuels must include the cost of storage, handling, and conversion to identical useful materials. In subsequent sections the conversion of fuels into heat at various temperature levels and into power is discussed.

Solid fuels are, in general, the cheapest to store in large quantities, especially where suitable ground area is available, but are more expensive to handle than liquid fuels. Gaseous fuels cannot be stored in any appreciable quantities and must practically be delivered as used. They require large piping and valves.

The following table shows the approximate B.t.u. stored per cubic foot of storage volume and per square foot of ground area under conditions of normal good practice.

SPACE REQUIRED FOR FUEL STORAGE

Fuel stored	B.t.u. stored per cu. ft.	B.t.u. stored on 1 sq. ft. of ground
Coal (bituminous)	750,000	9,000,000
Fuel oil	900,000	5,000,000
Natural gas (Holder)	1,000	50,000
(Hortonsphere)	5,000	75,000
City gas (540 B.t.u.)	500	25,000
Producer gas	100	3,000

Alternative Fuels.—In regions where competition between two fuels is intense it may often pay to select equipment for use of either fuel, so that advantage can be taken of temporary unbalance in prices or availability of supplies. Alternative fuel using equipment is almost always necessary when by-products are to be used as fuel, when the supply of by-products may bear little relation to fuel demand. It is also desirable to have available means for using oil or gas as standby fuel to care for overloads or other unusual operating conditions.

Utilization of Heat.—It must be remembered that heat becomes increasingly more difficult to produce, hence more expensive, the higher the temperature at which it is used. Heat from combustion of fuels is limited to about 3,500°F. to 4,000°F., the temperature at

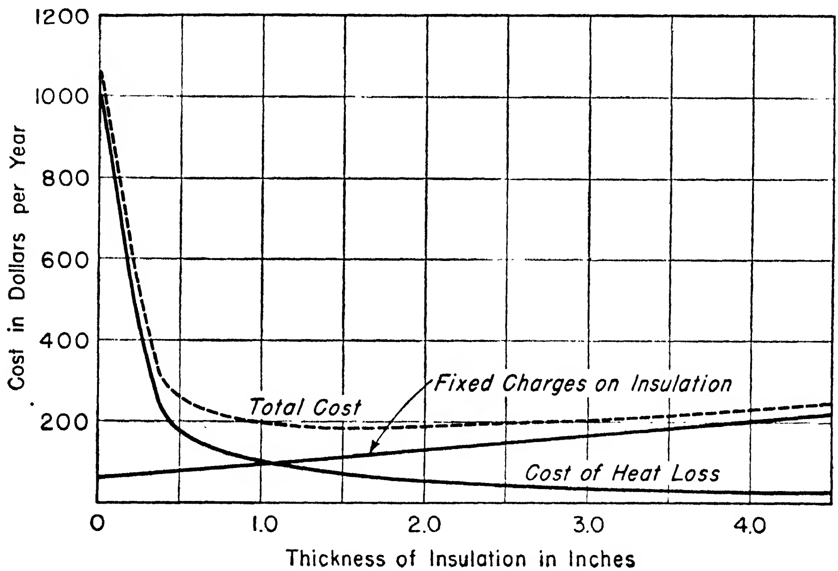


FIG. 2.—Heat loss vs. fixed charges on insulation.

which dissociation of CO_2 and H_2O becomes appreciable. At higher temperatures, heat is usually produced from electrical energy in an electric furnace. The value of heat energy, therefore, depends not only on the amount of heat but also on its temperature.

Heat is not easily insulated and its transfer and use are attended with considerable losses. The saving of heat by use of insulation is becoming more and more general, not only for steam and hot water pipes, but for buildings, tanks, furnaces, etc. The economical amount of insulation to use has been the subject of much study, and as better and cheaper insulating materials become available more heat will be saved. The most economical amount of insulation to use is that for which the fixed charges on the insulation plus the value of the heat lost, is a minimum. Other factors which may also influence the problem, are improved working conditions in hot weather and reduction of equipment capacity or even freezing up in cold weather. Figure 2 illustrates qualitatively the manner in which cost of lost heat and fixed charges on insulation may vary with the thickness of insulation.

A similar economic balance between cost of heat lost and charges on equipment to conserve it, occurs in the case of heat transfer equipment such as boilers and heat exchangers. The cost of heating surface is practically inversely proportional to the final temperature

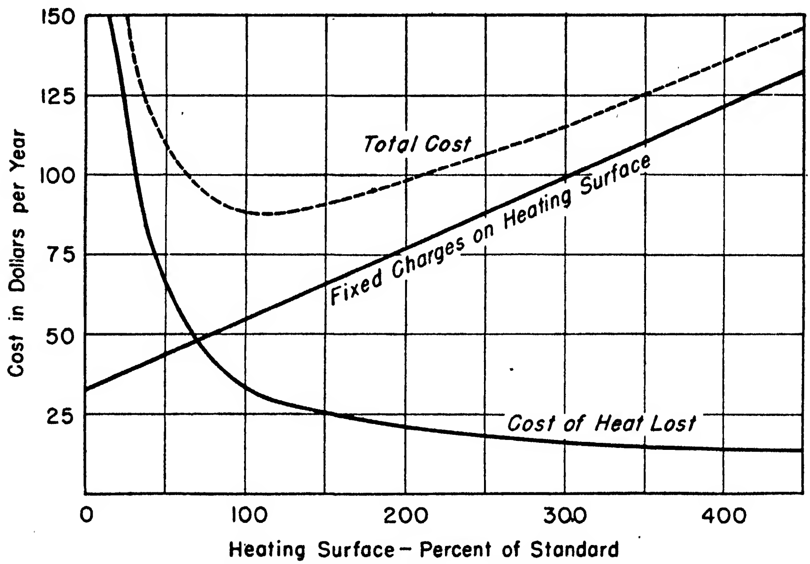


FIG. 3.—Heat loss vs. fixed charges on heat-recovery equipment.

difference between the combustion gases and the steam so that the incremental value of heat recovered decreases while the cost of equipment increases rapidly. Figure 3, which is of much the same form as Fig. 2, illustrates this point. The final utilization of heat from combustion is seldom over 70 per cent and is frequently much lower.

Conversion of Heat to Power.—Thermodynamics teaches that heat is not completely convertible into other forms of energy, the maximum amount that is convertible being given by Carnot's law, as

$$W = Q \frac{T_1 - T_2}{T_1}$$

where Q is the total quantity of heat which is at an absolute temperature of T_1, and T_2 is the lowest absolute temperature at which the heat not converted to work can be thrown away. The quantity W is called the "available energy." The conversion is analogous to water power where T_1 represents the elevation of the reservoir above the center of the earth, and T_2 represents the elevation of the tail-race that carries away the water after it has been used.

All other forms of energy, electrical, mechanical, light, radioactive, etc., tend to degenerate into heat and can be converted into heat at 100 per cent efficiency.

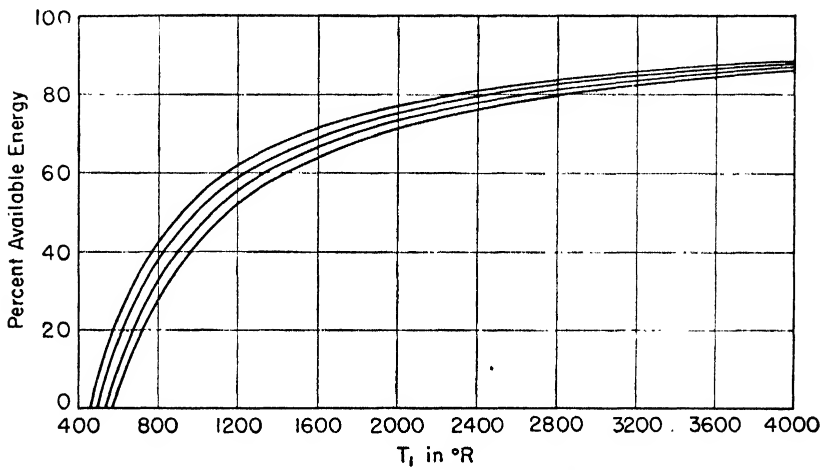


FIG. 4.—Available energy for heat at various temperatures.

The importance of Carnot's law in heat and power economics is that it furnishes us with a basis on which to evaluate heat at various temperatures, in terms of "available energy." Figure 4 shows the relative available energy above several base temperatures for heat at various temperatures.

Although Carnot's law and Fig. 4, give the theoretical basis for evaluation of heat in terms of available energy, under theoretically perfect conditions the values so obtained must in most cases be modified by other factors depending on actual plant conditions. These factors are

1. The efficiency of the available power generating equipment.
2. The actual marginal cost of power.
3. The investment costs and operating charges for converting heat into power.

These factors will be more fully considered after discussing the other forms of energy.

Mechanical work for driving all forms of moving machinery, such as pumps, stirrers, compressors, conveyors, machine tools, presses, etc., is usually obtained as primary power from steam or Diesel engines, or from water power; as secondary power it is obtained from electric motors. An important and growing field, in chemical industries especially, is the utilization of hot compressed gases from the process to furnish power in a gas turbine directly connected to a compressor furnishing air to the process. Because of the heavy machinery and high maintenance costs of mechanical power transmission and control, the direct use of mechanical power is now rare. The steam engine driving a line shaft and the water wheel driving millstones through wooden cogwheels are romantic but expensive. Available primary power is usually converted to electric power for distribution to electric motors. However, where appreciable amounts of power, (say, over 500 hp.) are required to drive a single compressor or pump, direct mechanical drive may save both installation and energy costs.

Electric power is the most valuable commonly used type of energy. Its value lies in the fact that it is very cheaply transmitted to considerable distances, is easily and accurately controlled, and is convertible at high efficiency to mechanical work, to heat at any required temperature, or to any other form of energy required. It is also used directly in electrochemical processes. Large amounts of power may be concentrated in a very small space.

The Cost of Energy.—The cost of any form of energy delivered to a process is made up of the following factors:

1. Energy cost. This corresponds to the "material" cost in a manufacturing process and may be in the form of fuel (chemical energy), water in an elevated flume or reservoir, or electric power from a public utility line.

2. Equipment costs. These are the fixed charges on boiler plant, fuel storage and handling equipment, engines, transmission lines, transformers, circuit breakers and switches, etc., required to generate, convert, control, and apply the power to the process machinery.

3. Operating and maintenance labor and materials.

4. Process costs chargeable to power and heat characteristics. These are often overlooked but may be of major importance. Thus, a failure of power supply may ruin a large amount of valuable material, quite out of proportion to the normal cost of power. Dust from a coal pile or fly ash from stacks may ruin thousands of dollars worth of

product or may necessitate extensive air-cleaning equipment, which might be avoided by a change to oil firing. Such costs should be properly charged to the power plant which necessitates them.

From the economic viewpoint these costs may all be classified under three types:

1. Fixed charges. Interest, depreciation, taxes, which depend primarily on the initial cost of the installation.

2. Semifixed charges, which vary only with large changes in the amount of power produced but not with hour-to-hour or day-to-day fluctuation. These include operating labor, maintenance, and some overhead and standby costs.

3. Proportional charges, which are primarily fuel, water, oil, etc.

Whether power is purchased from a power company or generated in the plant, these types of charges have to be met, and the problem of determining whether to purchase or generate power and the type of equipment to install depends on an evaluation of these costs under the particular conditions encountered.

In the case of water power, the costs are normally almost entirely fixed and semifixed charges. The water itself costs nothing, but the dams, penstocks, turbines, power house, and transmission lines may cost from $100 to $500 or more per kilowatt of capacity. The inaccessibility of many excellent water power sites from industrial centers makes extensive transmission lines necessary. Many chemical industries have, however, been grouped about such originally inaccessible sites, as for example, Shawinigan, and the T.V.A. developments.

Steam power plants use the cheapest generally available fuel—coal or heavy fuel oil—and reach their maximum economy in very large sizes. When operated to supply an industry operating on only one or two 8-hr. shifts, the standby losses from banked boilers and steam lines are high.

For smaller plants, below about 2,000 hp., the Diesel engine offsets a higher priced fuel and high maintenance costs by greater thermal efficiency and a more compact plant with few auxiliaries. Standby costs are also low in comparison with steam plants, and units can be started and brought to full load in a few minutes.

The gas turbine promises in the near future to furnish a moderate sized plant of 1,000 to 10,000 hp. with few auxiliaries, low maintenance, and thermal efficiency at least equal to the best steam plants.

It is difficult to obtain good representative figures for either operating costs or investment costs of power plants. The first cost of steam plants may fall in the range of $60 to $200 per kilowatt of output while Diesel plants will run somewhat higher, $75 to $300.

Diesel plants may easily have 40,000 hr. of full load life, while at lower loads the total output may be considerably greater. Steam plants may be figured on at least 150,000 hr. of life with reasonable maintenance. However, because of the rapid development of equipment, and the even more rapid change in chemical processes, obsolescence is likely to be the determining factor in plant life, so that in some cases, depreciation and obsolescence as high as 15 per cent for steam plants and 25 per cent for Diesels should be charged.

In order to determine the effect of fixed charges on the cost of power per kilowatt-hour, the total fixed charges per year or month must be divided by the total power developed during the same period.

Load Factor.—It is at this point that the effect of "load factor" in costs becomes apparent. The high cost of low load factors is clearly brought out in the structure of public utility power rates, discussed further on. It is equally important, although more often overlooked when power is generated at the plant.

Load factor is the ratio of the actual kilowatt-hours used during a given period, to the total kilowatt-hours that could have been generated if all available equipment had been used to full capacity. Chemical industries are particularly fortunate in frequently having opportunity for high load factors. Process characteristics which contribute to high load factor in power consumption are

1. Continuous operation 24 hr. per day and 7 days per week.
2. Continuous flow processes.
3. Steady production and stock-piling during slack sales periods.
4. A minimum of seasonal loads such as air conditioning or space heating.
5. Scheduling batch processes to operate in sequence.

The last factor mentioned above is one that is particularly important. Careless starting of several units simultaneously, which require heavy current for initial heating, may increase the maximum demand several fold and thereby may reduce the load factor to a fraction of that necessary.

Closely related to load factor in its effect on power costs is the effect of "power factor." Without going into electrical engineering details, power factor may be regarded as the ratio of the kilowatt hours actually used to the kilovolt-ampere (kva) hours generated in the equipment. All direct current processes have 100 per cent power factor, and alternating current heating and incandescent lighting is also at practically 100 per cent power factor. Induction motors have low power factors, and some a-c electrolytic processes also have low power factors. Synchronous motors can be made to "correct" or offset the low power factor of induction motors and should be used for large steady loads. Static condensers are also used for correction of power factor. The capacity and losses in generating equipment and transmission lines are a function of the kilovolt-ampere demand and not of the kilowatts of power used, so that a low power factor also reduces the maximum load factor of the system.

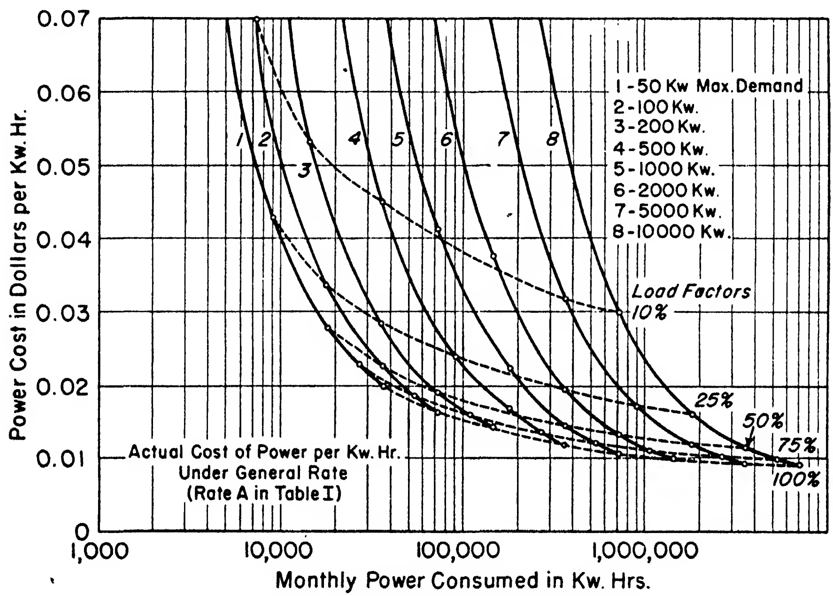


FIG. 5a.—Actual cost of power under rate *A*, Table I.

The Structure of Power Rates.—Public utility companies have given a great deal of thought to the development of rate structures that will penalize users having low "power factors" and "load factors." The simplest of these is the step rate frequently used for domestic service, in which the rate per kilowatt-hour is decreased in steps as the total power used per month increases. A more common rate for large consumers is the combined "demand" and energy rate in which there is a charge for each kilowatt of maximum peak demand, together with an "energy charge" for each kilowatt-hour used. Water-power companies, whose costs are almost entirely fixed charges, have often made rates, based entirely on connected load, of $20 to $50 per year per horsepower. Many companies in the Niagara Falls district formerly operated on such rates. Table I gives several typical rate schedules of one large public utility company. Figures 5*a* and 5*b* show the effect of demand and load factor on the actual cost per kilowatt-hour of power under rates *A* and *D* of Table I.

One of the major advantages that central station power companies have over individual power plants is that by diversifying their load they are able to get higher load factors, than can a factory operating only one 8-hr. shift. Chemical plants on the other hand usually have

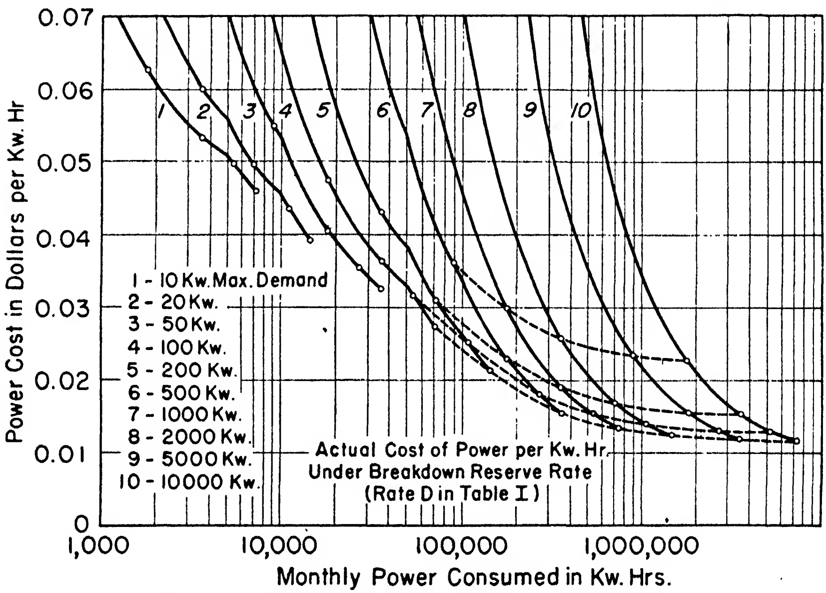


FIG. 5*b*.—Actual cost of power under rate *D*, Table I.

high load factors and are therefore prize customers of public utility companies.

Another feature that is, in a sense, the complement of high load factor is the ability of a chemical plant to use "off-peak" power in some cases. Whenever a process can be shut down for a short period without damage, either on a prearranged schedule or on short notice, there exists the possibility of obtaining power at only slightly above the "energy cost," from public utilities. Policies as to rates for such power differ among different companies, but the use of "off-peak" power should be considered wherever applicable, and the conditions under which it may be used should be thoroughly understood. Rate *C* in Table I is an example of such a rate.

Table I.—Typical Electric Rate Schedules of a Large Public Utility

A—General Rate

Monthly Demand Charge		Energy Charge	
First 3 kw	No charge	First 10 kw.-hr./month	9.0 cts./kw.-hr.
Next 12	$2.50/kw.	Next 70	5.5
Next 985	2.00	Next 720	5.0
Next 1,000	1.75	Next 5,200	4.0
Excess	1.50	Next 24,000	1.3
		Next 150,000	1.0
		Excess	0.7

B—Manufacturing (Demand over 40 kw.)("Combined Rate")

Monthly Demand Charge		Energy Charge	
First 50 kw	$2.00/kw.	First 1,600 kw.-hr./month	5.0 cts./kw.-hr.
Next 100	1.50	Next 4,400	4.0
Excess	1.00	Next 5,000	2.2
		Next 260,000	1.0
		Excess	0.5

C—Off-peak Manufacturing (over 200 kw. Demand)

Yearly Demand Charge		Energy Charge
For each kilowatt outside peak period (4 P.M. to 7 P.M., during November, December, and January)	$13.60	1.25 cts./kw.-hr.
For each kilowatt during peak periods	$23.60	

D—Breakdown Reserve (Connection for Plants Normally Making Their Own Power)

Monthly Demand Charge	Energy Charge	
$2.50/kw. connected load	First 1,000 kw.-hr./month	5.0 cts./kw.-hr.
	Next 4,000	4.5
	Next 5,000	3.5
	Next 40,000	2.5
	Next 50,000	1.0
	Excess	0.8

E—Wholesale Rate (a "Step-rate")

Monthly Consumption	Rate/kw.-hr.
First 1,250 kw.-hr.	5.0 cts.
Next 8,250	4.0
Next 12,500	3.0
Next 64,500	2.5
Excess	2.0

All public utility companies have certain periods of heavy demands for power. A black overcast will jump the lighting load 30 per cent in a few minutes, calling for thousands of kilowatts of extra capacity. In Boston there is a period just before Christmas when it is dark by

4:30 P.M. so that offices, stores, and factories as well as homes need full artificial light. At the same time the subway and trolley service is at a maximum, and just before the mills close a sharp peak of almost 20 per cent above normal maximum load occurs. To handle this peak, all available equipment must be used and if on such occasions more than one major generating unit is down for repairs, a serious

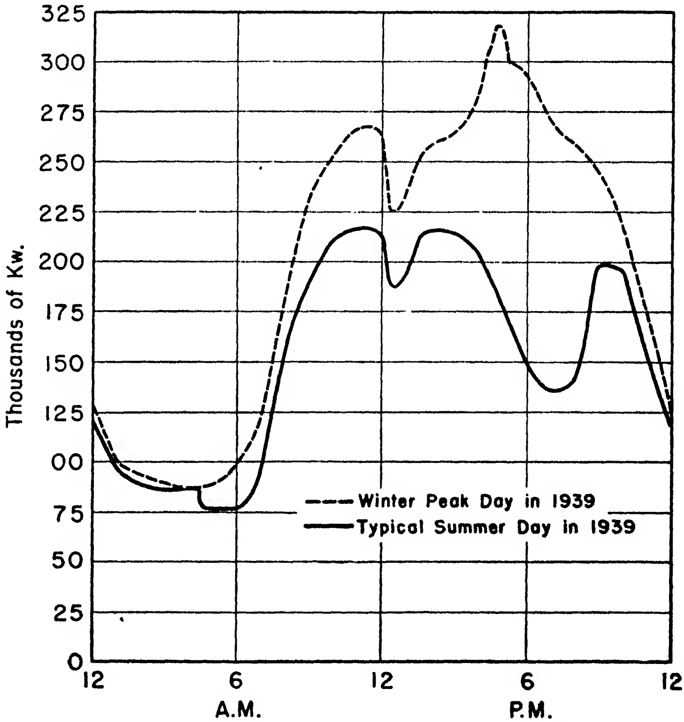


FIG. 6.—Typical system load curves for summer and winter peak days in 1939.

situation may develop. A thunderstorm in New York City some years ago shut down the entire system because standby generators could not be put into operation fast enough. If a large block of power could be cut off, even for half an hour, at such a time, large investment in equipment and cost of keeping excess boilers hot and ready would be saved. In many systems in addition to these severe peaks, there are regular "valleys" in the load curve. This is true daily from midnight to about 7:00 A.M. and on Sundays in many industrial and residential districts. Figure 6 shows typical system load curves for summer and winter peak days in 1939, for a large public utility system in the northeast.

A batch process that requires initial heating followed by a long slow "cook" can be fitted into such a load curve by starting after midnight each day. The use of electric current for water heating in a storage system can be arranged with a time switch to interrupt heating current at times of probable peak electrical load, and many companies make very favorable rates for such service.

Generated vs. Purchased Power.—A major problem which always faces the chemical plant engineer is whether it is better to purchase public utility power or to operate a private power plant to generate steam and electric power for the chemical plant. Such a study is very complex and is best handled by an experienced power engineer, but the basic factors on which the decision will be based should be understood by the chemical engineer, since factors that he might think entirely irrelevant may have an important bearing on the decision.

It has already been indicated that heat and power are to a certain extent interconvertible, that electric power can be converted into heat at any desired temperature with 100 per cent efficiency, and that a portion of heat can be converted into electric power, the amount depending on temperature conditions. The cost of generating power, therefore, is closely related to the use of heat in the plant.

In general, if considerable heat is used at temperatures in the region below 150°C, such as for water heating, drying, evaporating, space heating, etc., a considerable amount of power can be generated as by-product power, at very low fuel cost. The loss of heat in generating this power is equal to the electrical energy produced and, so far as plant economics goes, this is a case where power can be obtained from heat at 100 per cent efficiency. Allowing for some losses in piping and mechanical losses, it is fair to charge to power the fuel value of about 4,000 B.t.u. per kw.-hr. (theoretical is 3,412 B.t.u.) plus the cost of plant equipment and labor required to produce such power at the generator switchboard. Few public utilities can compete with such power, if it is available in sufficient quantity at the required times.

The by-product power available from a given demand for low-temperature heat depends on the maximum temperature of the power cycle, (boiler steam temperature in the case of a steam plant) and the temperature at which the heat is sent to process. Steam plants are widely used in chemical industry and are extremely well suited to by-product power recovery because of the flexibility of arrangement possible.

Whenever there is a substantial requirement for low pressure steam or hot water, the simultaneous production of power should be considered. The actual cost of a modern high-pressure, high-efficiency steam boiler plant is only slightly higher than for a low-pressure plant. The operating labor and maintenance may be no greater, or even less,

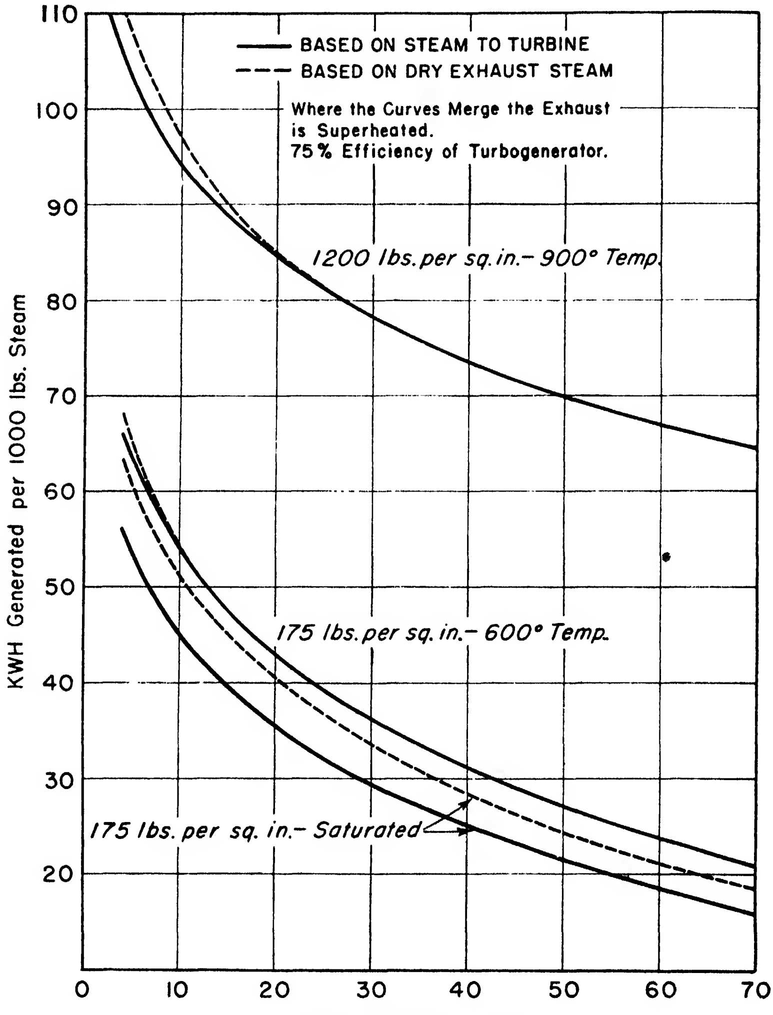


Fig. 7.—Power generated per 1,000 lb. of steam based on total steam to turbine and on dry exhaust steam.

and the fuel cost may well be less than for the average low-pressure plant. If pure feed water is available, this item will not increase very much, but if poor water only is available, extensive water treatment or even distillation may be necessary. The pressure and temperature conditions to be selected for the boiler plant will depend on the amount of power required relative to the steam consumed. Figure 7 shows the kilowatt-hours developed in a turbine per 1,000 lb. of total steam from the boiler supplied to the turbine throttle. The dotted curves show the same value per 1,000 lb. of dry exhaust steam sent to process at various back pressures. The curves show the marked effect of both boiler pressure, and the back pressure at which the process steam is used. It is obvious that every effort must be made to reduce the back pressure, if a large ratio of power to process steam is required.

If there is not enough power generated by process steam to supply the plant demand, any additional purchased power will tend to have a poor load factor, and will, therefore, be relatively expensive. Under these conditions, it will usually pay to put in additional condensing equipment to supply the entire load. In small and moderate-sized plants this is accomplished by the use of so-called "extraction" or "bleeder" turbines, or by a combination of noncondensing and condensing units, as best suits the steam and power load conditions of the particular plant.

Where some additional power is required, and especially where only a small lighting load is carried during the night, an auxiliary Diesel engine generator may be more economical than condensing steam equipment. Although there is a possibility of obtaining some waste heat from Diesel jacket water and exhaust heat exchangers, these sources of heat have not always been satisfactory due to high maintenance costs. The Diesel engine is best regarded as a unit for producing power only and is economical for small and moderate loads. Owing to the high first cost and fixed charges, it is most economical for loads having good load factors, say, above 30 per cent.

Whatever the type of equipment used, in evaluating the advantages of generating power in the plant, two items must be given special attention. These are the amount of standby equipment to be supplied and load matching.

Standby Equipment.—If the power and heat requirements of a process were constant and were known, and if the process operated continuously year in and year out, and if, further, equipment were available to operate continuously without shutdown for maintenance or repair, the selection of equipment would be easy and the cost a minimum. Since these conditions never apply, even in the most "continuous" processes, such as blast furnace and coke-oven operation, or catalytic synthesis, the question arises as to how much excess equipment must be provided. In selecting standby equipment not only must the general character of the load be considered but also the importance of full service under all conditions.

For full service under all conditions, such as is supplied by public utility systems, the rule usually followed is: There must be sufficient capacity so that any one unit or dependent group of units may be cut out at *any* time while the system continues to carry full peak load. Since at *some* time the largest unit in the system must be down for

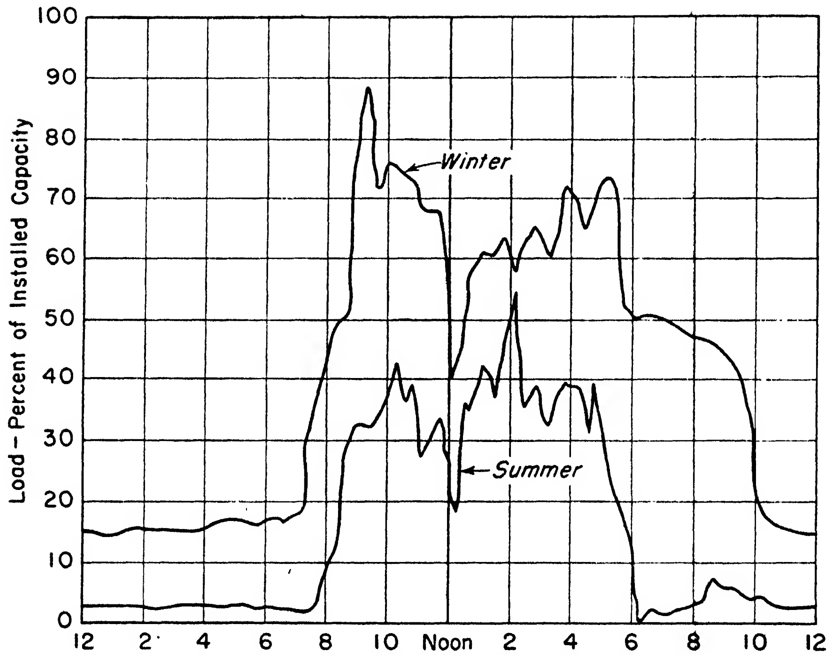


FIG. 8.—Load curves for pharmaceuticals plant.

overhaul, and the next largest unit *may* suffer a casualty, this means that the system must be able to carry full load with its two largest units out of commission, that it, the standby capacity is at least that of the two largest units of the system. This is a severe requirement and is one reason both for the fine record of dependability of central station power, and for the high percentage of total power cost which "demand" charges represent.

If routine maintenance can be scheduled during low-load periods, an equivalent reliability can be attained by making the standby capacity equal to the one largest unit in the plant. Even this is too severe a requirement for the average industrial plant since the largest unit may represent 50 per cent or more of the total plant capacity.

In a plant where there is good cooperation between the service and operating departments, it is possible to arrive at a reasonable figure for standby capacity by dividing all the uses into four categories.

1. Loads which cannot be cut off without serious loss (for example, most continuous processes).

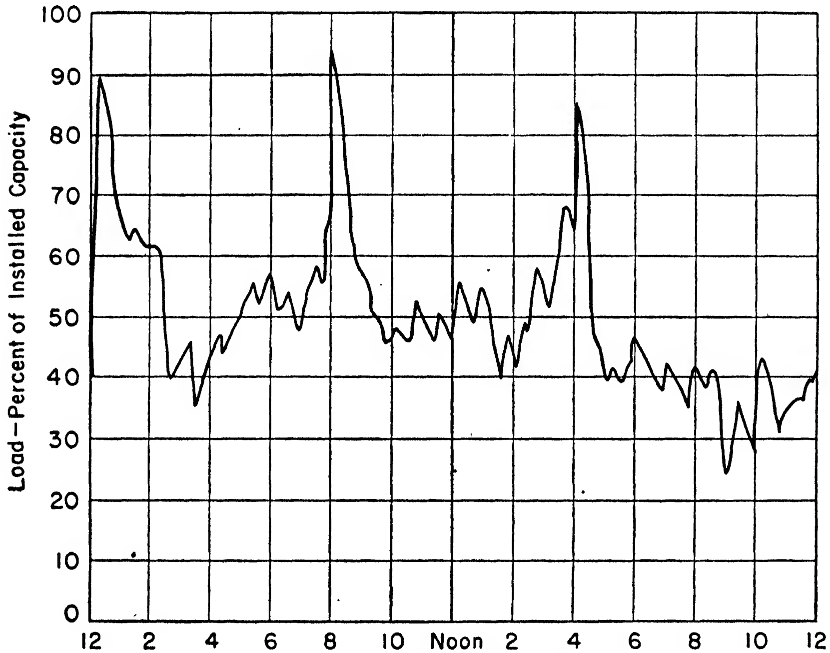


FIG. 9.—Load curve for soap plant.

2. Loads which cannot be cut off instantly but can be shut down within a certain time, T, (for example, short-time batch operations).

3. Loads which can be cut off instantly, for a length of time, T, but not for an indefinite period, (for example, packaging machines, processes involving perishable goods).

4. Loads which can be cut off instantly for an indefinite period.

The continuous load to be carried with one or two units off the line should then be figured as 100 per cent of either $(A + B)$ or $(A + C)$ whichever is greater.

The relation of the standby capacity to the selection of machine size is discussed later. It may be noted, however, that for figuring standby capacity maximum output of a machine is to be used regardless of economy, since standby operation is for such short periods (low load factor) that operating economy is sacrificed to reduce investment costs.

Load Matching.—Load matching is the process of adjusting the numbers and kind of power generating units in use to give the maximum economy of operation.

Figures 8, 9, and 10 show three typical industrial plant load curves under summer and winter conditions. Figure 8 is a plant manufac-

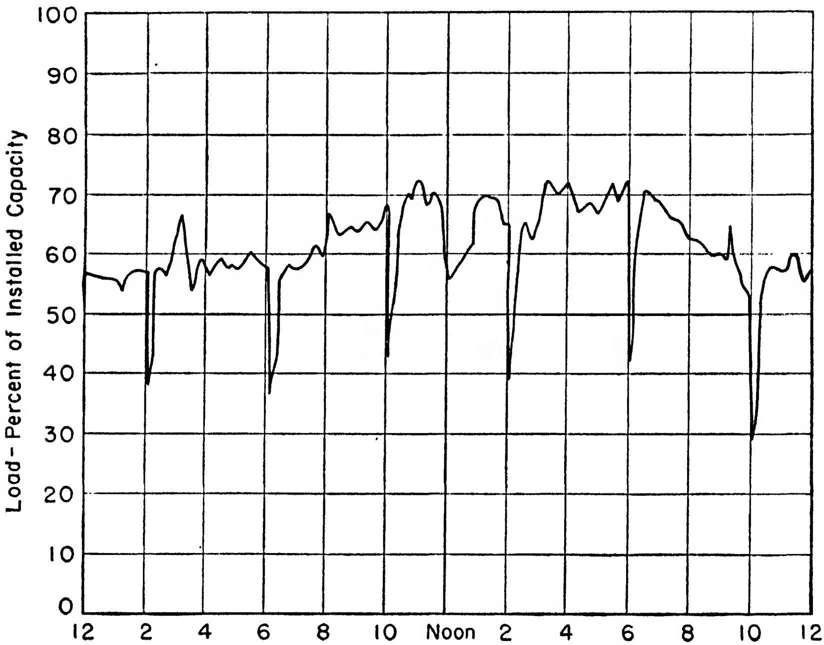


FIG. 10.—Load curve for blast-furnace plant.

turing pharmaceuticals, in which the loads are used in a large number of small operations such as mixing, grinding, and autoclaves. As will be seen by comparing winter and summer loads, there is a large heating and lighting load. Most departments are on a single shift.

The second (Fig. 9) is for a soap factory having a large variable process steam load and with a high continuous power load. The third (Fig. 10) is for a blast furnace with full continuous operation.

Figures 11, 12, and 13 give the fuel consumption for typical steam and Diesel plants, and for a recently developed gas turbine plant. The load curves given in Figs. 8, 9, and 10 and the efficiency curves given in Figs. 11, 12, and 13 indicate clearly the need for a careful study of load matching. The possibilities of economy by proper load matching are so complex as to warrant a lifetime of study by a spe-

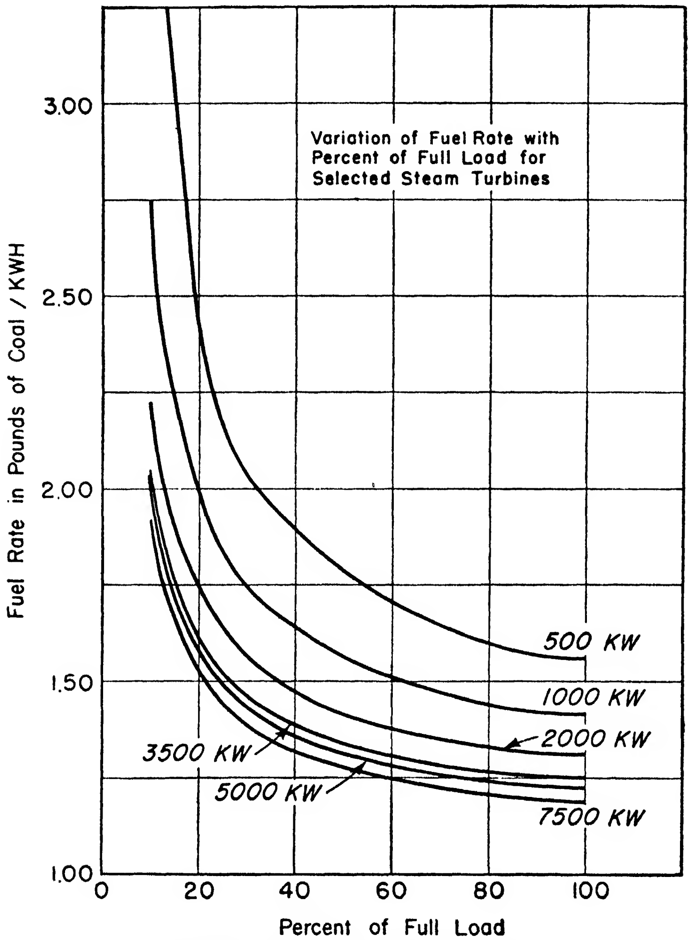


FIG. 11.—Variation of fuel rate for selected steam turbines.

cialist. Only the broadest general principles can be discussed here, based on the following axioms:

1. The maximum capacity of machines on the line must always be greater than the maximum anticipated load.

2. The combined fuel consumption of all machines should be a minimum.

3. The load conditions, should—as far as possible—be adjusted to operate at a minimum on the total power plant fuel-rate curve.

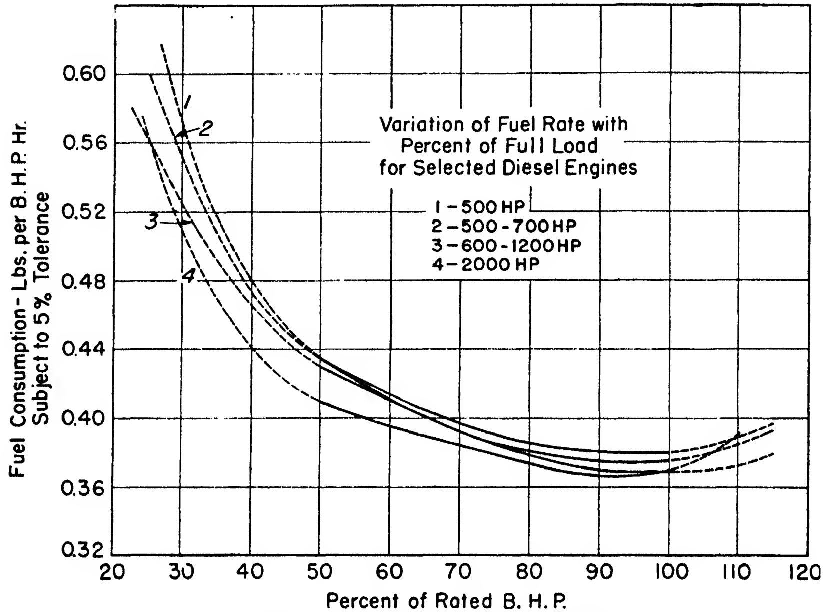


FIG. 12.—Variation of fuel rate for selected Diesel engines.

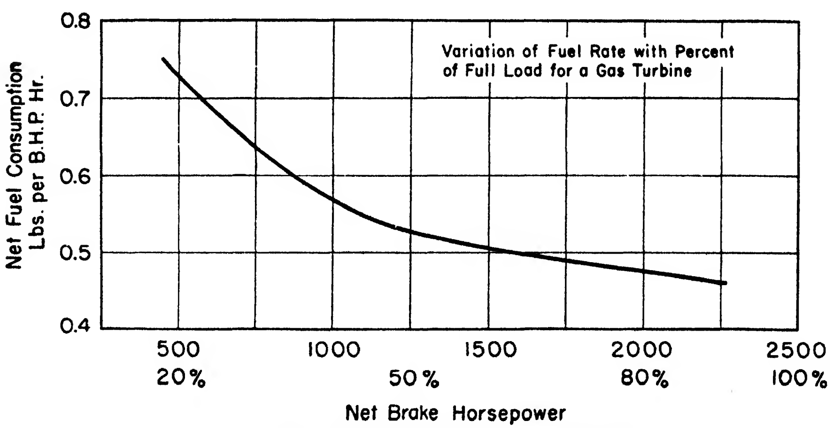


FIG. 13.—Variation of fuel rate for a gas turbine.

The total plant fuel-rate curve is a composite curve made up from the fuel-rate curves of the various generator units in the power plant, in such a way that it indicates the minimum over-all fuel rate (or cost) at which any given load can be generated (Fig. 14). Since the larger and more efficient units (at full load) have poor efficiency at part load, the efficiencies of the smaller units may determine the plant efficiency

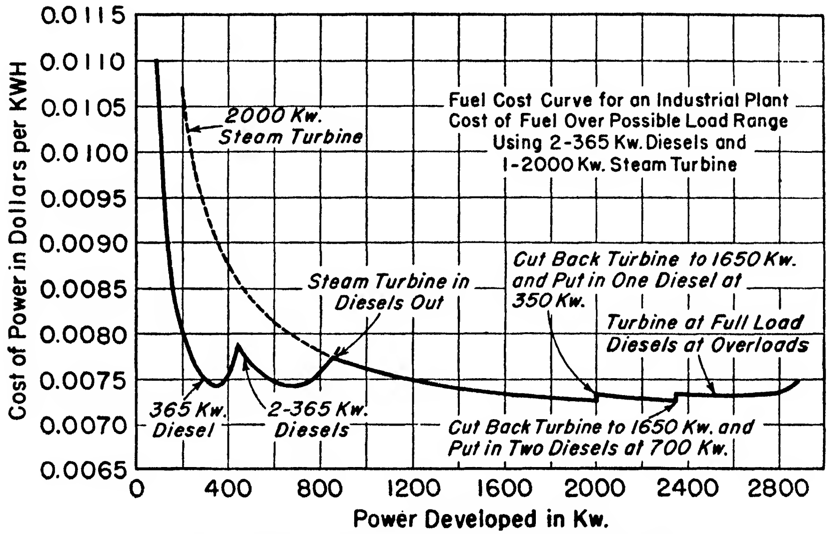


FIG. 14.—Over-all fuel-cost curve for an industrial plant.

curve at low loads, and will again show their influence at the highest loads when all available equipment is in use. The best plant efficiency will occur at or near full load on the most efficient unit.

CHAPTER IX

PLANT OPERATION AND CONTROL

BY J. L. BENNETT[1]

The chemical engineer in the chemical plant may be in an executive position or be actively engaged in supervising the operations.

The plant manager is directly responsible for the formulation of policies, for the conduct and performance of his staff, and the over-all results obtained. Since a proper environment is essential to the attainment of high standards of performance, the manager should strive to obtain a cooperative staff and to create working conditions that will develop and maintain a favorable atmosphere.

While it is advantageous for the manager to have a background of technical training and experience in chemical plant operations, it is vitally important that he have executive ability, characterized in part by the faculty for selection of competent assistants and supervisory personnel, and the establishment and maintenance of harmonious relations between and among all those working under his direction. Selection or retention of personnel not qualified for the work to which they are assigned tends to create an unfavorable atmosphere and to impair the morale of the organization.

Coordination of the work of the various departments is a function of general plant management and is essential to a smooth-working and efficient organization.

Staff meetings can be an effective means of improving relations between staff members. They afford an excellent opportunity for interchange of information of general and specific interest and coordination of their activities. Staff meetings may be conducted informally, but continued interest and good results are more easily obtained if such meetings are scheduled in advance and are conducted as an instrument of good management.

If the plant is one of several operated by a parent organization, the plant manager will usually report directly to the head of the operating department in the central office of the company. He will have the

[1] Manager, Chemical Operations, Explosives Department, Hercules Powder Co., Inc., Wilmington, Del.

support and guidance of the various divisions of the operating department and assistance from the engineering, purchasing, traffic and other departments as and when necessary, and will direct the contacts between the members of his staff and the corresponding departments of the central office.

Many millions of dollars are appropriated annually by the chemical industry for research and development to make more and better chemicals at lower cost for the pleasure, comfort, and convenience of man. That this money is well invested is evidenced by the vast number of new chemical products that become available and the constant effort to increase the volume of sales and lower the costs of production.

Through established channels, the staff and facilities of the central research laboratories of the company are available to the plant manager for consultation, advice, and assistance. He should encourage the members of his staff to take full advantage of the plant and central laboratories, the facilities of which are provided to aid the operating departments in the conduct and improvement of established processes and to help create new processes and new products.

Research and development work on the plant is usually under the general direction of the plant manager. Suggestions for investigation are appraised and if the work is approved, the problem is assigned to the plant technical department or referred to the appropriate department of the central office in the prescribed manner.

In chemical plants many of the operations involve the use of chemicals, pressures, temperatures, or procedures that make it mandatory to follow established practices in order to avoid injury to personnel or damage to equipment. Establishment and maintenance of safe operating practice is a prime responsibility of plant management. The safety engineer should have the active support of management and the active cooperation of his fellow workers.

Production and distribution of all forms of power, such as steam, electricity, compressed air, water, and the like, are usually under the direct supervision of the plant engineer. Likewise, the plant engineer is usually responsible for general plant maintenance and cooperates with the supervisors of manufacturing areas in decisions affecting the maintenance and improvement of equipment used in the operations.

Most of the technically trained men in the plant organization will be members of engineering, chemical, or other scientific societies. Association with other men of similar training is highly important in the continued professional development of persons engaged in work based on the natural sciences. The wise plant manager will encourage such associations and whenever practicable will provide opportunity for attendance at scientific society meetings. In the larger plants it may be advantageous to have an organization devoted to the study of the technical aspects of the plant activities. Such an organization should be fostered by the management, since its chief function would be to improve the safety, efficiency, and economy of the operations.

The general plant management is usually directly responsible for items of cost that are classed as "plant overhead" or "indirect expense." Such costs include operation of the general office, shops, laboratory, warehouses, transportation systems, sewers, roads, and other similar services.

Organization for Production.—Supervision of chemical plant production areas is generally entrusted to technically trained men, such as chemical engineers, who by their training and subsequent experience are not only competent to supervise the operations, but are also able to contribute materially to improvement of the processes. The rapid development of the chemical industry is due in no small part to the intelligent interest and deep-rooted urge of the operating men to get the work done with utmost safety, efficiency, and economy.

It should be understood that college training is not a basic requirement of a good supervisor. It is an advantage enjoyed by some, and the technically trained man generally has an advantage in comparison with the man who lacks such training. However, in many plants men without college training are advanced to responsible supervisory positions provided they possess the requisite ability. The executive management should be alert to discover and promote such men, and the chemical engineer should consider it his duty to assist them to the same extent that he would help fellow engineers. Failure to do so will result in weakened morale.

Organization for direct control of operations may be divided into three general types:

1. A straight-line organization in which the area supervisor is responsible for all phases of the operation, including labor and maintenance.

2. A modified or divided organization in which the area supervisor is responsible for all phases of operation and ordinary maintenance, but in which the services of the plant engineering department are used for the larger items of maintenance and replacement.

3. A modified organization in which the area supervisor is respon-

sible only for chemical efficiency and other groups are responsible for labor and maintenance.

There are many variations of these three general types of organization. Type 2 seems to be preferable, and it is particularly effective when there is real cooperation between the operating, the engineering, and the maintenance groups. The operating group receives advice and suggestions in conjunction with the repair and replacement work. However, since the costs of repairs and replacements are part of manufacturing cost for which the area supervisor is responsible, it is apparent that both groups should recognize that fact and should cooperate in the interest of lower costs of production.

The production area supervisor's duties and responsibilities may be divided into groups, such as

1. General supervision of the operations.
2. Training of assistant supervisors, foremen and operators.
3. Safety.

General supervision of an operation comprises the coordination of all elements to produce the desired effect. It will include a continued study of personnel relations and qualifications of the operating and maintenance men in relation to the work, chemical and mechanical efficiency, and all other factors that influence the safety of operation and cost.

While the plant manager will prescribe procedures for formal cooperation between departments and coordination of their activities, the operating supervisors should be alert to take advantage of the information and assistance available from the engineering department, laboratory, and other divisions of the plant organization.

Technically trained men are expected to conform to ethical practices. Chemical manufacturing processes are based on the natural sciences which deal with facts; and experience in the use of scientific data and factual information develops a fundamental honesty that tends to influence the attitudes and actions of the scientist and engineer. It is therefore to be expected that the technically trained man will be inherently honest in his work and will be unwilling to compromise with truth.

Mistakes and errors in judgment will be made in the supervision and operation of the chemical plant. A mistake should be promptly and frankly admitted. Discussion of the cause and effect of a mistake in a constructive manner will develop useful information and improve morale.

The area supervisor by precept and example should establish the pattern of performance for the area. He should maintain a firm but friendly attitude toward those working under his direction and should insist on the same attitude by his staff. His sincerity, loyalty, and integrity will have a marked effect on his associates, particularly the younger men. The early industrial experiences of the young engineer will have an important influence on his future. Experienced staff men should realize that an important part of their work is the development of assistants who are not only competent, but who are also thoroughly grounded in ethical practices.

The duties and responsibilities of each member of the staff should be specified and understood. Responsibility for performance should not be delegated unless a commensurate amount of authority is granted.

The area supervisor is generally responsible for the training of assistant supervisors, foremen, and operators. In larger plants it is practical to establish formal training courses, but experience on the job provides the best final training if the work is properly supervised. In the smaller plant the supervisor must arrange for the training with the operating group.

Foremen are selected from the operating personnel because of their experience and ability to develop and maintain good relations with the men working under their direction.

The initial training of a man assigned to the production area for supervisory duty is highly important, particularly if he is a new employee. It is preferable that his first contact in the area be with the area supervisor who should explain the general plan of training that will be followed. If the trainee is not familiar with the plant, he should be given some general information about the operation, raw materials used, and the products.

If the organization is large, the area supervisor may refer the trainee to one of his assistants who will elaborate on the training program and will give any instructions necessary about plant rules and regulations, particularly those associated with safety of personnel and equipment, and also with employee relations policy.

Sometimes the trainee is assigned to one of the supervisors to learn the job. There are many objections to this plan. In a short time, the trainee may be giving directions to operators who know far more about the work than he does. It is important that the trainee avoid any assumption of authority until it has been delegated to him.

A much better way to train the young chemical engineer is to assign him to a selected and experienced operator who will teach him the job just as if he were training a new operator. The average operator will be glad to help in the training of young engineers, as he knows that a competent supervisory staff of trained men is essential to safe and efficient operation.

The wise trainee will appreciate the efforts of the operator to give him the "know how" of the work and will be alert to take full advantage of the experience. Such direct association with the operators affords an opportunity to become well acquainted with them and to develop an *esprit de corps* that will be valuable when he is assigned to a supervisory position.

The supervisor who is handling the training should contact the trainee at intervals. He should encourage questions and should provide adequate answers. He might quote a portion of one of Kipling's poems:

> I keep six honest serving-men
> (They taught me all I knew);
> Their names are What and Why and When
> And How and Where and Who.

After a suitable period in the first training work, the trainee will be transferred to other operations under other operators. During these periods, the trainee should learn the actual operations and should become reasonably competent in them. He should become familiar with the equipment, the materials of construction, temperature and pressure conditions, and safety precautions. As an aid in the training program, it is often desirable for the area supervisor to have the trainee prepare a written report of each operation. It is sometimes helpful to have him obtain some data that may be desired.

In these early days of training, the potential supervisor has an excellent opportunity to cultivate and improve his ability to form accurate mental pictures of the equipment and process. The ability to visualize equipment and operating procedures quickly and accurately contributes to the development of imagination, an important forerunner of improvement.

While many young chemical engineers worked before college and during summer vacations, most of them are concerned about how to get along with the operating and maintenance men with whom they will be associated. This concern is easily understood and should be appreciated by the older and more experienced men.

The supervisor in a chemical plant, and particularly the young supervisor, should not confuse formal education with intelligence.

He should recognize that the average American workman is an intelligent person, even if he does not happen to have college training.

He should assume that the men working under his direction are just as interested in doing their work efficiently as he is in performing his duties properly. He should assume that adequately trained operators and repair men are competent to do their work properly and will do it properly if they have adequate facilities.

The average person is accustomed to give and to accept information and directions, and it is natural that the personnel of the chemical plant shall expect to receive directions and instructions about their work. This is just as true for the plant manager and his assistants as it is for the operators and their assistants. However, all men object to being "bossed," especially by younger men who are not so well informed as they might be. The supervisor can do much to create a friendly atmosphere with those working under his direction, and this can be accomplished without prejudice to his authority or responsibility.

While the general policy of the plant stems from the manager, it must be remembered that the contacts between management and men are through the individuals who are in the supervisory positions. Therefore, friendly relations between the supervisors and men is of prime importance to plant morale. Friendly relations are a product of straightforward contacts, considerate treatment, and a recognition of the importance of competent workmen. The manner in which directions are given or in which questions are answered is important. The men want to feel that they are integral parts of the organization, as indeed they are. They are prone to willingly accept directions given in a friendly manner as from one employee to another, but they will resent a discourteous or indifferent attitude by a supervisor.

The young supervisor can learn much from the older and experienced operators, and he will profit in many ways by consulting with them about the work. Experience is a great teacher, and a fund of valuable information can be gained in this way. If the young supervisor should question the value of the friendship of the operating or maintenance men, he should note the hearty greeting given some of the men who formerly worked on the plant when they return for a visit, and the satisfaction evidenced by the operators because they helped train them to be eligible for more important positions in the company management. It has been demonstrated many times that subordinate employees help the friendly and competent supervisor to more responsible positions, and foremen and supervisors are well advised to cultivate the friendship of the men working under their direction.

Competent staff men know that part of their advancement is due to the quality of the effort of the men working under their direction, and they are quick to acknowledge it. A production unit that is staffed with properly selected, well-trained, and experienced operators and foremen will require a minimum of direct and continuous supervision, and the supervisor who develops such an organization will have more time to devote to other phases of the work.

Satisfactory operation cannot be expected from poorly or partially trained men. The extent of the training necessary for good operation depends partly on the aptitude of the men for the work in question; partly on the simplicity or complexity of the work; and partly on the hazards that might develop from faulty operation. Training of men for operating positions like the training of young supervisors in the operating practices should be under the guidance of qualified operators. Intelligent and friendly interest in the progress of the training will be repaid not only by more efficient and economical operation, but also by an improvement in morale. Experienced men prefer to work with well-trained associates in whom they can have confidence.

Elements of Production Cost.—Cost of manufacture of any commodity may be divided into three major groups, such as

1. Direct cost of manufacture.
2. Indirect mill costs.
3. Company organization costs.

The direct cost of manufacture comprises the costs for which the area or production supervisor may be held responsible. They are

1. Operating labor.
2. Maintenance labor.
3. Maintenance materials.
4. Replacement.
5. Power
    Electricity
    Water
    Compressed air or vacuum.
6. Direct superintendence.
7. Chemical control.
8. Raw materials.

Operating labor is the cost of operators, helpers, etc., who actually perform the duties required to manufacture the product and to deliver it to storage or for shipment. Working foremen are included in this group.

Maintenance labor is the cost of labor required to repair the equipment provided to make the product, including buildings and other facilities directly involved in the manufacture or storage. This will include the cost of men assigned to preventive maintenance. It will also include charges made by the plant engineering department for repair services.

Maintenance materials includes all materials needed to repair buildings, equipment or other facilities provided to make the product.

Replacement covers the cost of making replacement of larger equipment worn out in the operation. This is essentially a repair charge but for convenience and cost study, such charges may be kept separate from ordinary repair charges.

Fuel covers the cost of any fuel used directly in the process.

Power covers the cost of all forms of power used in the operation, such as steam, electricity, water, compressed air, etc. In some cases where compressed air is an important raw material, such as in the oxidation of ammonia for the manufacture of nitric acid, the cost of such compressed air may be kept as a separate item.

Direct superintendence is the cost of all supervisors and foremen who supervise the operations but does not include working foremen.

Chemical control is the cost of chemists or technicians who make chemical analyses or other control tests not made by the operators or foremen. This may include a charge made by the plant laboratory for analytical or test work, if such costs are distributed by the laboratory.

Raw materials includes the cost of raw materials processed in the operation to make the finished product.

Sometimes a process involves the use of a secondary process of such importance that it is desirable to keep separate costs for it. Such costs may be collected on a separate cost sheet and transferred in total to the cost sheet of the main process as a separate item.

Each of the direct costs is usually carried through and reduced to cents per 100 lb. of product or dollars and cents per ton, depending on the value of the product.

The preparation of cost reports is discussed in another chapter. However, a simplified and convenient arrangement of direct operating cost data may be prepared as shown in Table I for the convenience and guidance of the area supervisor.

TABLE I.—ELEMENTS OF DIRECT MANUFACTURING COST

Item	Month of year		Year to date		Previous year
	4,127,435 lb.		49,214,712 lb.		50,782,658 lb.
	Total	Per 100 lb.	Total	Per 100 lb.	Per 100 lb.
Labor	$ 959.72	$0.02	$ 14,682.87	$0.03	$0.02
Repairs labor	1,295.93	0.03	12,154.63	0.02	0.03
Maintenance materials	2,266.77	0.06	10,906.60	0.02	0.05
Replacement	....	.....	....	.....	0.00
Miscellaneous expense	10.92	0.00	258.21	0.00	0.00
Power	6,309.67	0.15	59,511.74	0.12	0.11
Fuel	1,238.23	0.03	14,764.41	0.03	0.03
Chemical control	371.47	0.01	5,342.02	0.01	0.01
Direct superintendence	768.00	0.02	7,662.31	0.02	0.01
Total direct operating charges	$13,220.71	$0.32	$125,282.79	$0.25	$0.26
Cost of raw material	$18,579.07	$0.45	$215,283.20	$0.44	$0.45
Total direct cost of product	$31,799.78	$0.77	$340,565.99	$0.69	$0.71

It should be emphasized that the items shown in Table I comprise only the direct cost of manufacture, and that indirect mill cost must be added to obtain the total mill cost of production.

The indirect mill cost comprises items of a general nature, such as charges for service facilities, depreciation and obsolescence, property taxes and insurance, cost of paid vacations, and general plant administrative overhead.

Organization costs comprise the general administrative expenses of the company. They will generally include the cost of operating the central offices and research laboratories and the various departments that conduct the general business of the company and serve the production and selling organizations. The cost of pension plans is generally included in the category of general administrative expense and services.

Periodical Production Reports.—In addition to the cost sheets that reflect the over-all efficiency of the operation, it is necessary to prepare reports of the chemical operation at intervals, which are usually monthly. Preparation of the chemical reports requires that certain basic data be collected. These data may concern temperatures, pressures, percentages of undesired components in the product, or other information bearing on the quality of the finished product, idle times of the equipment, and the cause thereof. The report may show amounts of steam, electricity, etc., per unit of product.

The monthly chemical report will show all the data necessary to give an over-all picture of the chemical operation. It will show weight and average analysis of the raw materials used and of the finished product. The percentage of chemical efficiency will be shown when using 100.00 per cent as the theoretical yield. As a simple illustration, the oxidation of ammonia for the production of nitric acid theoretically requires 27.028 lb. NH_3 to make 100.00 lb. HNO_3. If the unit used 28.73 lb. NH_3, the percentage yield is obtained by dividing 27.028 by 28.73 to get 94.09 per cent, which is the actual yield of finished product from the raw material used.

Of course the management wants to know what became of the difference between the yield of 94.09 per cent and 100 per cent. In most chemical operations there are definite known losses such as unreacted raw materials, incomplete absorption, etc. It is frequently worthwhile to calculate a balance sheet somewhat as follows, using the oxidation of ammonia for the example and assuming 946,765 lb. NH_3 used:

TABLE II.—RAW MATERIAL BALANCE

	Pounds	Per cent
NH_3 equivalent of HNO_3 made	890,811	94.09
NH_3 loss in converters	38,817	4.10
NH_3 loss in unabsorbed NO_2	13,823	1.46
Total NH_3 accounted for	943,451	99.65
Unknown loss	3,314	0.35
Total NH_3 used	946,765	100.00

With such a balance sheet, the supervisors and management know the extent of each kind of loss and can decide how much effort should be spent to reduce it.

For control purposes, the weights of raw materials used and of finished product made may be obtained "as used" and "as made." However, for the monthly chemical and cost reports, the amount of raw materials used and finished product made should be accurately determined by the "difference in inventory" method.

To illustrate:

TABLE III.—RAW MATERIAL INVENTORY BALANCE

	Pounds
Raw Material Used:	
Stock of raw material first of month	110,460
Received or purchased	480,900
Total to account for	591,360
Stock end of month	89,400
Used	501,960
Finished Product Made:	
Stock end of month	640,860
Sold or delivered	1,238,840
Total accounted for	1,879,700
Stock first of month	538,920
Made	1,340,780

No matter what the sum of the daily reports shows, the "difference in inventory" definitely and surely shows the amounts that have been used or made. While the area supervisors are responsible for the monthly inventories, it is good practice for management to have a complete audit made of all stocks at least once each year.

For study of the chemical efficiency of an operation, it is necessary to make allowance for losses of raw materials when such losses are not associated directly with the chemical operation. For instance, the loss of a liquid raw material from a leak in a storage tank should be deducted from the "used" figure obtained by the "difference in inventory method" in order to obtain the amount of raw material actually used in the operation. However, the value of such material lost is included in the cost report, accompanied by appropriate explanatory note.

The monthly cost and chemical reports comprise a record of the results of the operation for the period. They are basic requirements for any intelligent study of operation.

The plant manager may be informed of many details of the operation and maintenance of operating areas and other departments of the plant through informal reports submitted monthly by the area supervisors or department heads. Such reports should be arranged in suitable sequence, should be written concisely and clearly, and should be free from trivial matters. Information of current interest or that might be of value later, explanations of changes in procedures or equipment, and general discussion of plans for the future may be included in the monthly reports.

In addition to the periodic reports, supervisors will be required to prepare special reports dealing with various phases of the operation and equipment. Requests for such reports should clearly state the information desired and the reason therefor so that the person addressed will be in a favorable position to make an intelligent study and a suitably comprehensive report. Plant management will do well if it rejects poorly prepared reports and insists that they be written in logical sequence, clearly, concisely, and with well-considered conclusions.

Other types of reports of the process are prepared by operators and foremen for routine control purposes. These reports are usually of temporary value but are essential for efficient operation. The data and information collected on such reports should be evaluated at intervals, for it is a waste of time and money to collect information that serves no useful purpose. Conversely, information or data that is important for record or statistical purposes should be accurate and reliable.

If there are two or more similar operations of the same company located in different parts of the country, a distinct advantage results from an interchange of information. This may be through the central office of the company, by direct communication between the plants, or by a combination of the two methods. Such interchange of information may include summaries of the chemical and cost reports and the monthly supervisors' reports to the plant managers.

Process Improvements.—Supervisors are needed to insure safety and continuity of operations, to direct changes in procedure or rate of production, and to make certain that the product fully meets the established specifications. Few operating procedures and little equipment remain static in the chemical plant. The history of all chemical processes is one of improvement. Costs are lowered, yields are increased, better equipment developed, and techniques simplified. Continued improvement is aided by an accurate record of the conditions and equipment for good operation, and a record of the reasons for and results obtained by alteration of process or equipment.

Many changes have their inception in suggestions made by the supervisors and operators. Suggestions should be sought and passed on to those who are responsible for the operation. It is important that these suggestions be evaluated carefully and that the decisions be made known to the persons making them. If a suggestion is rejected, the reasons for the rejection should also be made known.

It is highly important that credit be given where credit is due. It is claimed that President Lincoln said, "You can fool some of the people all the time and all the people some of the time, but you can't fool all the people all the time." That statement applies to the chemical plant staff. A supervisor may take credit for another's idea once or more, but eventually not only will his subordinates know of his sharp practice, but his superiors will know it also. Of course, a responsible engineer will avoid any suspicion of such unethical practice and will not condone it in others. Frank and open discussion of the work and proper credit for suggestions will induce a corresponding frankness, develop important information, and create an atmosphere that is conducive to efficient operation.

Progress in the development of our chemical processes and plant facilities and the continued effort by management to reduce costs of production make it necessary for the operating staff to learn more and more about the work. It is particularly important for the young supervisor to realize that no matter how much he knows about the plant and his work, there will always be something new to learn.

He should not be hesitant to admit that he does not have the immediate answers to all of the multiplicity of questions that are asked about the work. Such questions should be an incentive to increase his knowledge. Senior supervisors frequently ask questions to stimulate interest in the work and to learn something of the progress of the younger man.

Whenever practical, written operating procedures should be prepared and posted along with any regulations that are imposed to promote the safety of men and equipment. A log book is valuable for the transfer of pertinent information from one shift crew to another, or to the foremen. In some plants the log books are also used by the foremen and supervisors to record over their signatures, any directions they wish to issue. This practice reduces the possibility of misunderstanding.

Preparation of periodic chemical reports has been discussed earlier in this chapter. The yields established by these reports are a measure of the losses that occur. Experience and study of the factors influencing yield eventually bring it to a figure that, for all practical purposes, may be considered normal for the process. However, it is natural for alert supervisors to strive for improvement on past practice. This effort is more likely to be successful if the operators are given sufficient information and their assistance is solicited. It should be recognized that a high level of performance in the chemical plant can be obtained only by the active interest and support of the men who actually do the work.

When unduly low yields are shown by the chemical reports, accuracy of inventories, raw materials received, and product delivered should be verified. If the low yield persists, a careful examination of every phase of the operation is indicated.

While it is very interesting to obtain the highest possible yield and worthwhile to know how to obtain it, there are some cases where lowest manufacturing cost is not associated with the highest possible yield. It is frequently true that the increased yield will cost more than it is worth. It should be remembered that changes in cost of raw materials and value of finished products may justify changes in yield.

Supervisors are generally expected to assist in the improvement of operating procedures, equipment, and cost. One of the most fruitful efforts is in the direction of increased production from a given unit with a resulting decrease in capital cost and in operating cost per unit of production. Sometimes this is simply the result of eliminating "bottle necks" and in other cases the removal of such limitations requires the installation of additional or auxiliary equipment in order to take advantage of the information. However, the cost of the additional equipment may not be justified unless the increased production is needed.

In the late 1920's, when synthetic ammonia became available in quantity in the United States, the pressure process for the oxidation of ammonia was developed and was put into operation. The bubbler cap absorption towers were 64 in. in diameter and 40 ft. high. Heat of reaction was removed by several external shell and tube coolers. The gas and liquid were withdrawn from the tower sections, were passed through the coolers and were returned to the next sections. Operating data soon established that the towers had a substantially greater capacity than the 10 tons HNO_3 per 24 hr. that was conservatively estimated from the development work. One limitation after another was located and removed as production demands increased so that today, towers of the same 64-in. diameter by 40 ft. high will produce up to 60 tons HNO_3 per 24 hr., or an increase of 500 per cent.

Improvements such as this are expedited by the intelligent cooperation of the operating supervisors. They will not be satisfied until they know what limits the through-put. However, they will be very careful that their quest for knowledge does not cause them to introduce a hazard to the operation. No change should be made in a chemical operation or the equipment used therefor, until after careful consideration by those who are competent to make or authorize such alterations. It is always advisable to appraise the proposed change to insure that the advantages to be gained are not offset by some obscure adverse effect or hazard.

Even with the best equipment, capable supervision, and competent operators, troubles of various kinds will develop. Some operating troubles occur without any apparent reason, but it is obvious they are due to some change in one or more of the operating conditions. Adverse operating conditions may result from one of the following causes:

1. Man failure.
2. Equipment failure.
3. Variations in raw materials.

The search for the cause of trouble begins with a check of each step of the operation followed by a careful examination of the raw materials and equipment. It should be remembered that if a process has once been conducted with satisfactory results, the same results can be obtained again if the cause of the trouble is discovered and corrected.

Operating difficulties caused by failure of the operators to do the work properly can be reduced by better training methods, by selection of personnel who are better adapted to the work, or by better supervision. Many chemical plant operations do not require arduous work, but many of them do involve the use of very expensive and complicated equipment.

In the chemical manufacturing plant, the charges for maintenance and replacement may be an important factor in the cost of the finished product. However, a general high level of maintenance usually results in safer working conditions and more favorable costs.

Since continuity of production favors a more uniform product at lower cost, forced shutdowns for repairs are to be avoided as much as possible. Study of the cause and frequency of failure of equipment will often permit minor repairs at the proper time, and such minor repairs may postpone or avoid a major repair job. Such preventive maintenance can effectively reduce failure of equipment. This practice requires continued inspection of the equipment and prompt adjustment or repair while the objectionable condition is of minor importance. It is obvious that best results will be obtained by men who are interested in preventive maintenance and who are competent to do such work. It is also obvious that close cooperation between the operator and maintenance man is essential. Repeated failure of any part of the equipment may be the reason for a major change in the design or the simple substitution of a different metal or alloy.

The value of preventive maintenance is rapidly being recognized throughout the chemical industry.

In some processes shutdowns for repairs or cleaning are scheduled in advance. Preparation for such idle periods includes the listing of any repair work or alterations needed to place the unit in first class condition. This practice will reduce the number of costly forced shutdowns that frequently occur at the most inopportune times.

An important factor in good maintenance at low cost and minimum interference with production is the availability of spare parts for essential repairs, particularly those of special design that cannot be procured without delay. Conversely, an excess supply of spare equipment should be avoided in order to guard against excessive investment and also because some parts may be rendered obsolete by changes in design.

Operating troubles due to objectionable variations in raw materials are generally caused by failure to appreciate the effect of such variations on the operation or may be due to acceptance of materials that do not comply with specifications. It is obvious that neither of these conditions should be allowed to persist.

Raw materials are usually purchased on specification, and the price is likely to vary according to purity, screen size, or other items included in the specification. In some cases the original specifications established for the materials to be processed are proven to be more rigid than is necessary. In other cases where the quality of the raw material influences operating conditions or the quality of the finished product, it is possible to impose a more rigid specification even at a higher purchase price and yet have a lower manufacturing cost and a better product. The plant or central office purchasing department should be consulted whenever a change in specifications is indicated, as they are responsible for the procurement of suitable materials at lowest cost.

Since the cost of raw materials is an important item of cost of the finished product, and since there may be a choice of suitable materials, the cost conscious management and purchasing department will maintain a constant check on the relative prices of the alternative materials or ingredients.

Other Economies in Production.—Changes in plant equipment may be made to improve safety, to increase production, or to reduce cost. A request for the money to make alterations or additions that are expected to reduce operating charges should be made with full knowledge of the facts on which the savings are based.

In the pressure process of ammonia oxidation to make nitric acid, air for the reaction is supplied at 120 lb. gauge pressure. The spent gas may leave the oxidation tower at 90 lb. and may be exhausted to atmosphere.

At some plants, where the cost of power is high enough, this waste gas is heated in shell and tube exchangers by the hot gas from the converters and is passed through the power end of air compressors, thus saving above 40 per cent of the power that would otherwise be required by the compressors. Calculation of the savings to be gained by the investment in the equipment must be based on the actual net reduction in costs. For instance, if the air compressors are driven by steam that costs 40 cts. per 1,000 lb. including fuel cost of 25 cts. and the plant has ample installed boiler capacity, it is obvious that the net saving should not be based on steam at 40 cts. per 1,000 lb. but should be based on steam at near 25 cts. per 1,000 lb. as that will represent the actual cost of power that will be saved.

Another illustration may be of interest. Most modern contact sulphuric acid plants include steam boiler units to recover the surplus heat of combustion of the sulphur. The investment in the boiler equipment can be easily justified by the value of steam generated in the larger units. However, if the unit is small and the cost of steam from the power house is low, the value of steam made in the sulphuric plant may not make a satisfactory return on the investment in the boiler equipment.

The foregoing illustrations direct attention to the necessity of sound appraisal of data and information in the preparation of a construction project that is based on savings to be made as a result of the investment. Similar analysis is indicated for other investigations looking toward lower costs of operation.

The cost of electric power usually varies with the "demand" or peak load for a short interval, which may be as low as 5 minutes. A study of the power data will reveal the time and cause of the peak loads, and measures can be taken to reduce them. Some loads may be transferred from day to nighttime operation with a corresponding increase in load factor and reduction in cost.

Sometimes clear thinking will solve a vexing problem, such as the following: a water pump in an isolated location may tend to freeze when not in service in cold weather. If the pump house is well-insulated and an electric power line is close by, an automatically controlled electric heater may give trouble-free operation at a tolerable cost.

It is sometimes economical to return steam condensate to the power house for re-use as boiler feed water. This is particularly true if the distance is not too great, or if the boiler water requires extensive treatment. Nct only is pure water salvaged, but also a high percentage of the heat content of the condensate is recovered. The power engineer is conscious of the fact that hot water discharged from a steam trap has a heat content corresponding to water at the temperature of the steam in the equipment. The chemical engineer using the steam in operations should remember that all forms of power, such as steam, electricity, compressed air, and water may comprise an important part of production costs. He should impress that fact on those using them and should see that undue waste is avoided.

If an operation uses sufficient steam or electricity to warrant the investment in meters, the data may be used effectively to reduce consumption and waste.

Scientific Control of Operations.—Scientific control of the chemical operation is initiated by the technical staff of the plant or parent organization. Extensive research, development, and pilot plant operation usually precedes design and construction of the production unit. Research and development demonstrate the feasibility of the process and the pilot plant and semiworks operations are employed to give reasonable assurance that the process will be practical and can be conducted at a fair profit when transferred to plant scale equipment. Such investigations are needed to establish suitable materials of construction, rates of reactions, optimum temperature and pressure conditions, and many other factors that should be known in advance in order that equipment of suitable capacity may be designed in accordance with good engineering practice and suitably arranged for safe, convenient, and economical operation and repair.

The quality of information supplied for conducting a chemical process may be a measure of the quality of the work obtained. Plant management should not expect good results from an operation unless the supervisors are fortified with all essential information pertaining to the process. Likewise, no supervisor should expect efficient operation of the production unit unless the operators are provided with information and directions needed for efficient operation.

Chemical plant operations should be conducted according to procedures established by the technical staff of the company. Tentative methods for the works scale process are formulated during the pilot plant and semiworks scale operation and are critically appraised and revised before being approved for initial operation of the plant equipment. It is usually impossible to predict accurately the behavior of chemicals and equipment involved in plant scale operation and to anticipate all the possible variations.

However, careful control and experience with the process eventually furnish information for a set of operating procedures, which are still subject to alteration as further experience may dictate.

This implies that the operating department will have a manual of operations that explains the chemical reactions involved, equipment used, temperature and pressure limitations, and an outline of acceptable methods of operation. All manuals should include directions and procedures to be followed in case of abnormal conditions or emergencies. They should be specific in regard to precautions necessary for guarding the safety of men and equipment, and particularly so if any possible additional hazards may arise from abnormal conditions. It is therefore apparent that the manual and detailed directions for conducting the chemical process should be revised as changes in methods or equipment are approved and adopted.

An authentic manual is valuable in the training of supervisors and foremen and for the preparation of written directions to be posted in the buildings for guidance of operators. For the batch-type operation, a detailed stepwise procedure is often of value.

A new process should be placed in operation under the direction of the technical staff who developed the process or who are thoroughly familiar with it. Carefulness will be the watchword to insure that all goes well. Essential data will be collected to supplement the information obtained from the semiworks operation and to establish the approximate limitations of the equipment and quality of the product. Initial operations under the guidance of the technical staff provides the opportunity to transfer the "know-how" to the operating men. The technical staff men should be certain they have transmitted all pertinent information, and the operating men should be sure they thoroughly understand the entire process before the technical staff is withdrawn.

Instrumentation.—Efficient and convenient operation of modern chemical plants depends to a major extent on the use of a wide variety of indicating, recording, and control instruments. New methods and new equipment for the automatic control of a variety of processes are continually being developed. The importance of adequate instrumentation is so well recognized by the management of some of the larger plants that technically trained men are assigned to the study and evaluation of instruments for indicating and recording useful information and for automatic or semiautomatic control of processes.

Even though an automatic control may not immediately permit a reduction in operating labor, it may be instrumental in maintaining a far greater degree of uniformity than can be realized by manual control. A reduction in the amount of work required of the operator will permit insistence on performance of a higher quality. The present-day chemical plant operator is readily interested in the use of control instruments and will make effective use of any that are placed at his disposal.

Of course, the function and value of all instruments should be understood and appreciated by the operators, but they should also understand that instruments are of value only as long as they are reliable. All instruments should be checked and tested at stated intervals, and whenever their accuracy is questioned. It is obvious that operators cannot work to best advantage unless control instruments are maintained in a dependable condition.

Cooperation and coordination are key words in the successful operation of the chemical manufacturing plant. The competent and experienced plant manager will lead the way in cooperation with and among his assistants and department supervisors. He will direct the coordination between the operating, the engineering, and the maintenance departments, the laboratory, and service divisions. Since safety is of paramount importance in the chemical plant, the manager will continue to emphasize the value of safe practices. The other members of the plant staff will loyally support the plant management and the company in efforts to manufacture chemical products with greater safety, of higher quality, and at lower cost.

CHAPTER X

COST ACCOUNTING

By Chas. R. Schwartz[1]

The successful company in the chemical industry, as in any other industry, should know with reasonable accuracy the profit that each of its products, or at least each group of similar products, is contributing to the whole. The successful company may frequently find it expedient to continue the sale of a product that contributes no profit, but it does not do so in ignorance of the fact and for no purpose. Obviously, a successful company is one that through the years earns a satisfactory return for its owners. This can only be accomplished with certainty when receipts from the sale of products exceed the costs incurred in manufacture and distribution.

Cost accounting is the defining, classifying, recording, and analyzing of expenditures and income so that management may know the relative profit position of each product produced. The results are obtained as a record of past performance, but their historical value is often of least importance to management. It is the future with which successful management must concern itself. Cost accounting records are therefore of prime importance in preparing sound and practical standards, budgets, or goals. They are the only sound basis for revising selling prices. They supply statistical data to guide research into practical channels, to insure compliance with government controls and tax laws, to reward employees for exceptional service, and to chart the course for expansion.

It is important that the chemical engineer in industry understand the principles and conventions used in cost accounting. He will sooner or later come into contact with the cost accountant. If he does not understand the language of accounting, his contacts with management will leave him mystified. Terms such as "return on investment," "obsolescence allowance," "marginal cost," "accrual," and "working capital" are in constant use. It often comes as a discouraging shock to the otherwise competent chemical engineer when he learns that one

[1] Manager, Control Division, Ammonia Department, E. I. du Pont de Nemours & Company, Wilmington 98, Del.

of his experimental developments is of no commercial interest because its estimated cost and required investment is prohibitively high.

It is the purpose of this chapter to acquaint the chemical engineer with the terms and the procedures commonly used in cost accounting.

Cost Systems.—All cost accounting systems are an integral part, but only a part, of a complete accounting system. The latter involves records for controlling financial transactions not related to cost of manufacture and distribution, such as investment of excess cash in securities, raising funds for expanded operations, payment of dividends, preparation of financial statements, and computation of income taxes. The cost accounting system is used in conjunction with these other financial records and must be consistent therewith. Manufacturing costs may be based either on actual expenditures or on "standard costs."

An "actual" cost system, as the name implies, is a consistent, classified record of actual expenditures incurred for labor, ingredients, power, etc. By necessity the actual cost, whenever possible, is computed after the fact. However, even in actual cost systems, certain items of cost such as real estate taxes, manufacturing taxes, and advertising, are estimated in advance of expenditure and are charged into cost as accruals in anticipation of the actual expenditure.

A "standard" cost system on the other hand is based on predetermined costs for each level of production using practicable obtainable yields. Standards based on experience are set for both quantity and unit value of each element of cost. Illustrative items might be man-hours required per unit of production and average rate of pay per man-hour, or number of pounds (gallons or other units) of a raw material required for each unit of finished product and a selected cost per unit of such material. Standard cost systems require an accompanying record of actual costs but not in the same elaborate detail as in the actual cost system. The records of actual costs that accompany the standards are used to measure the efficiency of manufacturing operations by means of "variances," or differences. Only such detail of actual cost is kept as is needed to make the desired comparisons with the standard cost. Efficiency or inefficiency is disclosed by these comparisons of standard man-hours, cost per man-hour, quantity of raw materials, power, etc., with the actual cost incurred for the same items. Differences between standard and actual cost must, of course, be carried through the books of account. These differences are usually totalized and credited or are charged directly to profit and loss.

No matter whether the cost system selected by a company is an "actual" cost or whether it is a "standard" cost, the detail may be kept on a job (or batch) or on a process basis.

In the job cost method, costs are accumulated for each job, or batch, produced. This is possible only when each job or batch, as well as each element of cost, is physically identifiable.

In the chemical industry, where production is so frequently continuous, the process cost method is most commonly used. Here each element of cost is accumulated for a definite period, usually the calendar month. The accumulated cost is then applied to the total quantity of material produced during the period. Each product cost statement may include data on many unit operations, such as preheating, reacting, cooling, compressing, centrifuging, and drying, for which individual cost detail is not often important. The labor, power, etc., required is usually totalized for the series of operations over the period involved.

By-product Costing.—The chemical industry, particularly, is confronted with the difficult problem of by-product costing. In many processes there is obtained not only a single primary product, but also other less important products. The manufacture of coke from coal is a familiar example of the production of by-products, such as tar, benzol, naphthalene, and ammonia. In various distillations products are often obtained that were not the primary objective of the operation. It is these secondary products that are usually referred to as "by-products." There is no problem in costing unless the by-products are saleable or useable on the plant in other operations.

By-products, when sold or used, are commonly costed in either of two ways. First, and particularly if the by-products are relatively of small value, the easiest method is to credit the operation producing the by-product with the net amount realized on its sale. This amount is the sales value less freight, selling expense, and any other distributive cost and less the entire cost of recovering, purifying, and packaging it for shipment, if these latter costs have not already been charged to the operation. If the by-product is used on the plant, the operation using it is charged either at an arbitrary value (if there is no market), or at its replacement value (if it is obtainable by open market purchase). A second method in costing by-products treats them as a regular product and assigns to them proper portions of each applicable cost element. In deciding the proportions of each cost element to apply to each of the jointly produced products, the accountant needs sound chemical and engineering guidance.

Like all other costs, the results of these methods of by-product costing are of more use when the judgment is soundly in accordance with the chemical engineering relationships and when care has been expended to measure reliably the quantities and rates used in the costing.

PREPARATION OF A COST STATEMENT

Within any of these general systems of cost accounting, many details are required to develop a useful cost statement. For any established chemical manufacturing company certain expenses are incurred daily, which must be analyzed and allocated. Such expenditures may be segregated into the following general classifications:

Mill or factory costs.

Selling costs.

Management or administrative costs.

Technical and research costs.

Transportation of product to customer costs (distribution costs).

The total of all such costs assigned or allocated to any one product may be called the "cost of sales" of that product.

Mill or Factory Cost.—The largest item of cost making up the cost of sales of a product is usually the mill or factory cost. Expenses making up this cost are usually classified as

1. *Ingredients.*—Materials directly entering into the manufacture of each product.

2. *Operating Labor.*—Salaries and wages of all operating employes who are directly assigned to work on the production of each product.

3. *Repairs Labor.*—Salaries and wages of all employes who are directly assigned for various periods of time to repair or maintain the facilities used.

4. *Repairs Material.*—Material used in the repair and maintenance work done by the labor expended in item 3 above.

5. *Operating Supplies.*—Supplies used in normal operation of the facilities, such as lubricants, housekeeping supplies, wiping cloths, and janitor supplies.

6. *Direct Supervision and Clerical.*—Salaries of all direct supervisory employes (excluding maintenance supervision) and salaries and wages of any clerical help assigned directly to these supervisors for recording production data.

7. *Maintenance Overhead.*—Salaries of all supervisory employes responsible for repair and maintenance work.

8. *Services or Utilities.*—Electricity, gas, steam, water, etc., used directly in the manufacture of each product.

9. *Works Laboratory.*—Direct cost of analyzing samples of products in order to control quality.

10. *Depreciation.*—Allowance for wear, tear, and obsolescence on buildings and equipment used in the production of each product.

11. *Property Taxes and Insurance.*—Taxes on real estate and improvements, and premiums for property insurance against fire, explosion, and other accidents.

12. *Container Costs.*—Cost of drums, cans, cylinders, barrels, carboys, etc.

13. *Salaries and Wages Overhead.*—All direct expenses incurred whenever salaries and wages are paid, such as federal old age benefits, unemployment compensation, company employee benefits (pension plans, personal injury insurance premiums, vacation allowance, group life insurance premiums, disability payments, etc.).

14. *General Plant Overhead.*—Expenses of a general nature not directly applicable to any specific product, such as the cost of providing plant management, general plant accounting office, patrol and protection forces, hospital and medical service, fire protection, canteen, or restaurant services, personnel and employment office, shipping office, storeroom, automobile service, and telephone and telegraph service.

The foregoing costs or expenses are incurred either by direct expenditure of cash (for purchase of raw materials or for payment of salaries and wages) or by book entries, sometimes called "accruals," to set aside from profits certain estimated costs such as plant depreciation. The usual flow of accounting papers covering cost entries is shown in Fig. 1, and a typical cost sheet for chemical operations is shown in Table I.

Other Breakdown of Mill Cost.—When packaging and shipping expenses are of major importance and in instances where a manufactured product is used in other manufacturing operations on the plant and also is sold as such, a further breakdown of costs is sometimes necessary. For this purpose, mill cost is usually segregated by the same captions shown previously into the following classifications:

Bulk cost.

Packaged cost—including containers and cost of putting material in containers.

Shipping cost—including cost of loading packaged product in box cars, trucks, barges or marine vessels, and loading bulk product in tank cars or tank trucks.

When the product is packaged in many different sizes of containers, particularly in small sizes, the packaging and shipping cost may be greater than the total bulk cost of manufacture.

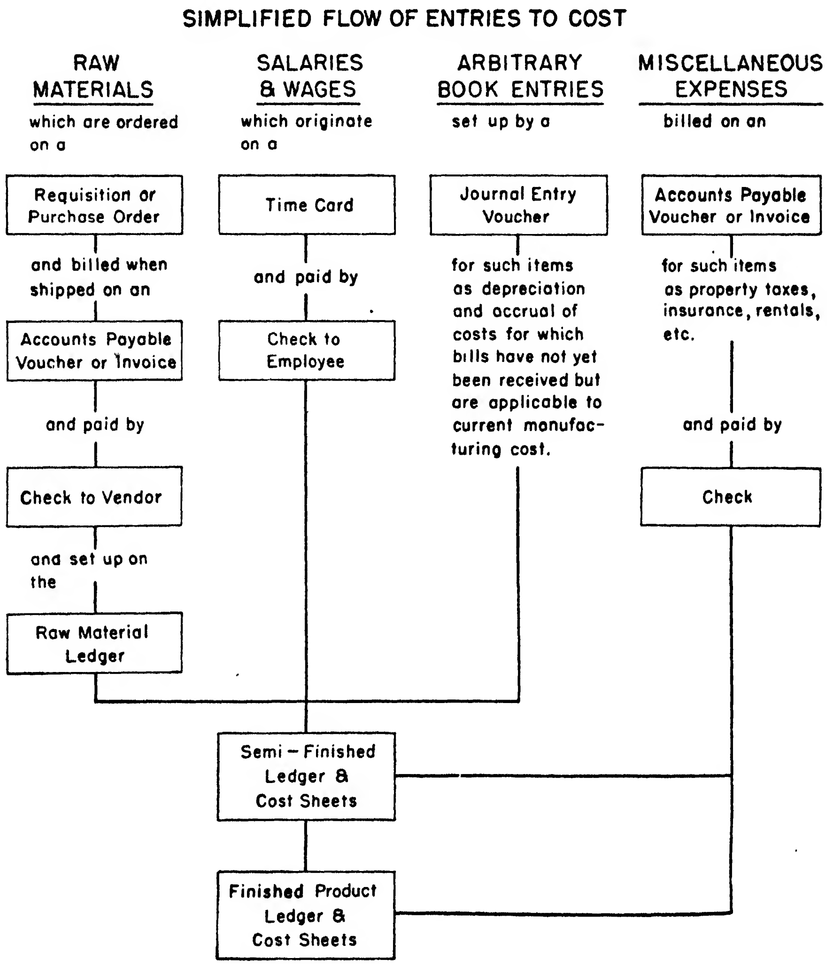


FIG. 1.—Simplified flow of entries to cost.

Distribution of General Items of Expense in Mill Cost.—The cost accountant always strives to apply cost directly to the product or operation to which it should be allocated. Ingredients and direct labor present no problem in allocation of cost; however, general services and overhead that benefit all operations are always subject to many points of view as to proper allocation. If the position of each product

TABLE I.—TYPICAL PROCESS COST SHEET

__________Works Month of December, 19__ Operation__________

This month actual					Goal*			Item	Year to date				
Per unit quantity	Quantity	Unit price	Value	Cost per unit	Per unit quantity	Value	Cost per unit		Per unit quantity	Quantity	Unit price	Value	Cost per unit
.0417	206,670	.5050	104,370	.0211	.0400	.5050	.0202	Raw material *A*, lb.	.0434	2,438,300	.5001	1,219,400	.0217
.0205	101,600	.6800	69,090	.0139	.0180	.6800	.0122	*B*, lb.	.0198	1,112,400	.6769	753,000	.0134
.0147	72,850	.4375	31,870	.0064	.0135	.4375	.0059	*C*, gal.	.0149	839,300	.4352	365,300	.0065
.0222	110,000	.9425	103,670	.0209	.0200	.9425	.0188	*D*, lb.	.0217	1,219,200	.9356	1.140,700	.0203
			309,000	.0623			.0571	Ingredient cost				3,478,400	.0619
.0123	60,960	1.4500	88,390	.0178	.0120	1.4500	.0174	Operating labor, man-hr.	.0127	713,103	1.4500	1,034,000	.0184
.0098	48,570	1.5500	75,280	.0152	.0090	1.5500	.0140	Repairs labor, man-hr.	.0103	576,451	1.5500	893,500	.0159
			54,530	.0110			.0105	Repairs material				618,100	.0110
			1,000	.0002			.0002	Operating supplies				11,200	.0002
			20,800	.0042			.0041	Direct supervision and clerical				236,000	.0042
			12,390	.0025			.0023	Maintenance-overhead				134,900	.0024
.0072	35,680	.3627	12,940	.0026	.0070	.3627	.0025	Steam, M lb.	.0072	406,960	.3634	147,900	.0026
.0130	64,430	.0052	340	.0001	.0125	.0052	.0001	Electric, kw.-hr.	.0127	715,700	.0052	3,720	.0001
.0290	143,725	.0064	920	.0002	.0275	.0064	.0002	Raw water, M gal.	.0298	1,676,450	.0062	10,450	.0002
.0004	2,000	.0732	150	.0000	.0004	.0732	.0000	Filtered water, M gal.	.0004	21,460	.0736	1,580	.0000
			18,350	.0037			.0032	Works laboratory				196,700	.0035
			117,460	.0237			.0236	Depreciation				1,382,400	.0246
			2,970	.0006			.0006	Property taxes and insurance				33,700	.0006
			23,890	.0048			.0046	Salaries and wages overhead				267,300	.0048
			3,010	.0006			.0005	General plant overhead				33,900	.0006
			8,900	.0018			.0018	Containers				101,200	.0018
			441,320	.0890			.0856	Manufacturing cost				5.106.550	.0909
			750,320	.1513			.1427	Total mill cost				8.584,950	.1528
.2685	1,330,850	.0350	46,580	.0094	.3000	.0350	.0105	By-product sold, lb.	2532	14.288.600	.0350	500,100	.0089
			703,740	.1419			.1322	Net mill cost				8.084.850	.1439
	4,956,000							Production, lb.		56,194.000			

* Goal figures should always be attainable results for quantity produced in current month.

in the analysis of over-all profits is desired, every dollar spent in the manufacture of a product must be allocated.

The breakdown of general overhead is not difficult. All that is required is an agreement by management of a common denominator as a basis of each item of overhead. Thus, cost of fire protection can be distributed according to the value of plant investment utilized by each product; hospital expense can be distributed according to the number of employees assigned to each product; employment office can be distributed according to the number of employees hired each month by operations to which they were assigned, and so on.

Expediency in bookkeeping work, however, often calls for a compromise because an elaborate allocation system covering the many general items would require more man-hours of work than would be justified in such a refinement. The usual compromise is a segregation of such general items in two categories, one more or less related to employees and the other to investment, thus reducing allocation work to not more than two breakdowns. Even more general is a collection of all general overhead into one account, which might be called "general plant overhead" with only one distribution to products based on either total dollars of direct salaries and wages charged to each product, or on total man-hours charged to each product.

Other Mill Cost Items.—Sometimes a plant may be rented rather than owned. In this case the line "depreciation" on the cost statement reads "rent" and represents an allocation of rental payments by products.

In other instances the company may be employing a process protected by a patent owned by another company or individual for which a royalty must be paid, usually on the basis of units manufactured. Such payments are usually shown as "royalty" on the cost sheet for the operation involved.

Selling Expense.—Selling expenses include all cost of selling the product—salesmen's salaries, advertising, traveling expense, market analysis, branch office expense, commissions, telephone and telegraph, etc. Again direct allocation of such expenses is made insofar as practicable, and general expenses are apportioned on some common basis such as dollars of sales value or unit of weight of products sold.

Management or Administrative Expense.—The salaries and expenses of general officers of the company are usually bookkept separately in an account known as "management" or "administrative expense" and include all items of expense for which management is solely responsible. Salaries and expenses of company officers, general accounting work on published statements, institutional advertising, legal counsel, auditors' fees, etc., are examples of items of over-all general expense usually classified as management or administrative expense. The apportionment of these items to products can sometimes be on some direct basis but usually is based on sales value of each product or investment utilized by each product, and sometimes even on a weighted factor that takes both sales value and manufacturing investment into consideration.

Technical and Research Expense.—Experimental work expense includes all expenditures for chemists, chemical engineers, mechanical engineers, metallurgists, etc., who devote their time to process improvements, new products, searching for new applications of existing products, fundamental research, and other technical problems. The cost of such work is usually kept by projects to which all expenses on related work or a specific study are charged. If the work is in connection with an existing product, the costs accumulated under the project involved are charged directly to such product. Cost of work on new products or on fundamental research studies is allocated on a common basis such as sales value to existing products, or sometimes is not apportioned at all but grouped in an "unallocated experimental expense" account.

Transportation of Product to Customer Expense.—Transportation costs include all costs incurred in physically moving the product to customers. Such expenses are freight, barging, warehouse rental and handling, delivery trucks, etc. Most of these items are easily identifiable as to product involved and present no problems in allocation.

Profit or Earnings by Products.—With all costs broken down by products, the position of each product and of each group of related products can be ascertained. Sales for any desired period have been recapitulated by products. Operative earnings, or profit before taxes on income, is prepared in somewhat the form shown in Table II.

With the analysis of operative earnings, where *each item of cost is applied to a product*, management is informed as to the profit position of *each* product and is enabled to take any necessary action by reducing selling prices where profits permit or possibly by discontinuing the manufacture and sale of unprofitable products where, after detailed study, reduction of any one or all of the costs seems unlikely.

A statement such as the foregoing is only a record of past performance and is merely a medium for management judgment, but without such a detailed analysis as a starting point, any decision of management as to price policy can be based only on guesses.

TABLE II.—STATEMENT OF OPERATIVE EARNINGS BEFORE TAXES ON INCOME
Year Ending December, 19—

Product	Unit of weight	Sales			Freight and delivery		Mill cost		Selling expense		Administrative		Technical expense		Profit		
		Quantity	Dollars	Per unit	Dollars	Per unit	Dollars	Per unit	Dollars	Per unit	Dollars	Per unit	Dollars	Per unit	Dollars	Per unit	Per cent profit to sales
A	Pounds	10,272,000	3,081,600	.3000	22,600	.0022	2,252,600	2193	95,500	0093	38,000	0037	1,000	.0001	671,900	.0654	21.8
B	Tons	43,300	3,719,500	85.90	303,100	7.00	2,385,800	55 10	69,300	1 60	125,600	2.90	37,700	87	798,000	18.43	21.4
C	Gallons	7,300,000	5,168,400	.7080	335,100	.0459	4,277,800	.5860	262,800	.0360	103,700	.0142	15,300	0021	173,700	.0238	3.4
Total group *X*	......	.. .. ..	11,969,500	.. . .	660,800	. . .	8,916,200	.... .	427,600		267,300	... .	54,000	. .	1,643,600	.... .	13 7

INVESTMENT

No analysis of profits is complete, nor does such an analysis have any meaning, until it is related to the investment required to produce the profit stated. In the final analysis, the management and owners of the company are interested solely in the return on investment realized. Profit divided by investment gives this percentage. A product yielding a comparatively high and otherwise satisfactory percentage of profit on sales dollars may require such a large manufacturing investment that it contributes little to the over-all return on investment and is therefore not as satisfactory a product as one with a lower percentage of profit on dollar sales but requiring such a small investment that the resulting return on investment is higher.

Investment is generally broken down into two general categories—working capital and permanent investment.

Working capital, or liquid assets, consist of

1. *Cash.*—Dollars which must be reserved in bank for payment of operating expenses such as salaries, wages, purchase of raw materials, etc., as distinguished from cash held to pay dividends or temporarily held awaiting investment in securities.

2. *Accounts Receivable.*—Average outstanding amounts collectible from customers on invoices rendered them but not yet due according to sales terms.

3. *Raw Materials Inventory.*—Average dollars tied up in stocks of raw materials required in manufacture.

4. *Semifinished Inventory.*—Average dollar value of semifinished product on hand.

5. *Finished Product Inventory.*—Average dollar value of finished product inventories held in reserve to meet fluctuating sales demands or as insurance against plant shut-down.

Each of these items making up working capital must be apportioned to each product in order to complete the study of profit and of return on investment position for each product. Arbitrary allocation is not necessary, as each item can be directly or indirectly applied to each product. That portion of cash held for payment of operating expense can be apportioned to products on the basis of one month's cost of sales; accounts receivable directly on the basis of outstanding receivables by products; raw materials and semifinished products on the basis of consumption; and finished product directly to the product.

Permanent investment, or fixed investment, consists of

1. *Plant Investment.*—Total investment in manufacturing facilities required to produce a product.

2. *Plant Real Estate.*—Real estate on which the plant is located.

3. *Transportation Facilities.*—Trucks, tank cars, barges, ships, etc., owned by the company and used in the delivery of product.

4. *General.*—All other permanent investment, such as management

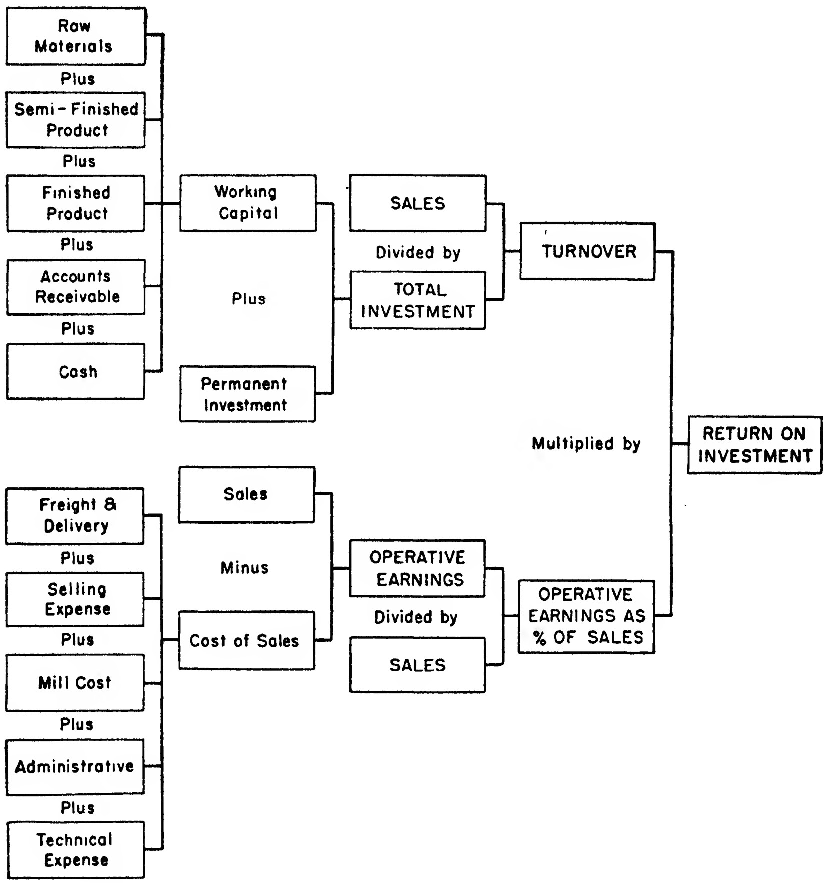


FIG. 2.—Relationship of factors affecting return on investment.

office buildings, owned warehouses or branch office buildings, furniture & fixtures, etc.

Permanent investment must also be apportioned to each product. Plant investment, usually the largest portion of the total, can be for the most part directly applied to the product benefiting. It should be noted here that all plant investment in any way utilized or applicable in the manufacture of the product must be apportioned and

TABLE III.—ANALYSIS OF OPERATIVE INVESTMENT FOR YEAR ENDING DECEMBER 19—

Product	Quantity produced	Unit	Working capital											
			Cash		Accounts receivable		Raw materials		Semifinished		Finished product		Total	
			Dollars	Unit	Dollars	Unit	Dollars	Unit	Dollars	Unit	Dollars	Unit	Dollars	Unit
A	10,272,000	Pounds	207,500	.0202	78,100	.0076	244,500	.0238	35,900	.0035	139,700	.0136	705,700	.0687
B	44,270	Tons	264,300	5.97	166,900	3.77	84,600	1.91	55,300	1.25	73,900	1.67	645,000	14.57
C	7,215,000	Gallons	436,500	.0605	289,300	.0401	486,300	.0674	153,700	.0213	1,168,100	.1619	2,533,900	.3512
			908,300		534,300		815,400		244,900		1,381,700		3,884,600	

Product	Quantity produced	Unit	Permanent investment										Total investment	
			Plants		Plant real estate		Transportation equipment		General		Total			
			Dollars	Unit	Dollars	Unit	Dollars	Unit	Dollars	Unit	Dollars	Unit	Dollars	Unit
A	10,272,000	Pounds	2,711,800	.2640	6,200	.0006	4,100	.0004	5,100	.0005	2,727,200	.2655	3,432,900	.3342
B	44,270	Tons	5,782,100	130.61	33,200	.75	367,000	8.29	27,000	.61	6,209,300	140.26	6,854,300	154.83
C	7,215,000	Gallons	317,500	.0440	2,200	.0003	....	.....	1,400	.0002	321,100	.0445	2,855,000	.3957
			8,811,400		41,600		371,100		33,500		9,257,600		13,142,200	

included in the total plant investment assigned to the product. Hence, a portion of investment in steam, power, and other services must be apportioned according to the use of such services in the production. If a product is both sold as such and is used on the plant in a derivative, its investment must be apportioned so as to apply the proper portion to the derivative. All general facilities such as main office, roadways, club house, etc., must be apportioned to all products on some rational basis such as direct manufacturing investment. Thus, when all plant investment has been properly allocated to products, the result for each product will be the total plant investment including services and general facilities related to its manufacture.

Tank cars often are used for only one product and can be directly applied, or if not, can be apportioned according to use. Other items of a general use can be apportioned in several ways, one of which would be based on the investment that already has been directly applied.

With a complete apportionment of investment, a statement similar to Table III can be prepared.

For the over-all analysis of profit and investment, all the basic data are known, and a statement similar to Table IV can be prepared for management. This is shown diagrammatically in Fig. 2.

Table IV.—Analysis of Operative Earnings and Investment
Year Ending December, 19__

Product	Sales	Profit	Per cent profit on sales	Investment	Per cent return on investment	Per cent turnover of investment
A	$ 3,081,600	$ 671,900	21.8	$ 3,432,900	19.6	89.8
B	3,719,500	798,000	21.4	6,704,200	11.9	55.5
C	5,168,400	173,700	3.4	2,888,600	6.0	178.9
	$11,969,500	$1,643,600	13.7	$13,025,700	12.6	91.9

It must be emphasized again that these statements are not an end in themselves, but without them management can only guess the "why" of good or bad results of past performance. Only with a breakdown by products can management isolate the products requiring attention. There will always be enough guessing in predicting the future without adding unnecessary uncertainty about past performances that can so simply be made a matter of easily interpreted cost, investment, and earnings records.

Thus far federal taxes on income have not been mentioned. The calculation of such taxes is a specialized and complicated accounting procedure, which will not be dealt with here. Needless to say, such taxes must be considered an item of cost of conducting a business and deducted from operative earnings before determining the dollars earned for distribution of profit to the owners of the business.

If it is desired to know the profit position after income taxes for each product—taxes are a large item of expense that must always be considered—the total tax payment applicable to operative earnings may be prorated over such earnings. Application of taxes to individual products does not, however, change the relative position established for each product before such application.

Plant Investment Records.—Because plant investment is usually the largest class of permanent investment, a working knowledge of how records are maintained for this investment is necessary for the technical man interested in the economics of chemical manufacture.

To be useful, plant investment records must be set up in sufficient detail to make easily available the book value of all equipment used in a specific process or operation. Since individual pieces of equipment are often moved from one process to another, each individual piece must be set up separately for identification.

In the chemical industry, a plant usually consists of a number of buildings each of which houses one or only a few major processes involving either one product or a group of closely related products. For bookkeeping purposes these buildings are identified by account numbers, which are sometimes referred to as "building numbers." In addition to manufacturing buildings, a plant may also include storage tanks, a warehouse, plant office building, cafeteria, and, if a large plant, a hospital, fire house, and other service buildings. Each of these buildings is assigned an account number so that an index of plant investment might appear as follows:

Building (or Account) No. 1. Alcohol.
2. Sulphuric Acid.
3. Formaldehyde.
4. Nitric Acid.
5. Experimental Laboratory.
6. Main Office.
7. Cafeteria and Club House.
8. Steam.
9. Water Purification.
10. Storage Tanks.
11. Roads.
12. Power House.

Where appropriate, each of these accounts (or building) numbers may be broken down between buildings proper and equipment. The building detail can include the foundations; superstructure consisting of flooring, stairways, walls, roof; lighting; heating; plumbing; fire protection; and sewers. The records should carry adequate descriptions and measurements.

Each piece of equipment with related accessories within each building is then set up separately showing full description, value, serial number, and any other information relative to identification. Equipment will include separators, centrifuges, coolers, motors, preheaters, condensers, converters, calandrias, vaporizers, evaporators, etc. As a further detail, the value of each piece of equipment may be broken down into (1) bare equipment value, consisting of the actual purchase price plus freight, and (2) installation costs, including necessary foundations. Illustrative detail records for plant investment are shown in Table V.

As alterations, removal of equipment, new installations, replacement of equipment, etc., occur, proper adjustment of the plant investment records is made to reflect current conditions. Repairs cost and small alterations not increasing the value of equipment or materially prolonging the life are not charged to the investment account but are charged to mill cost as "repairs." Larger replacements and alterations, which increase the equipment value and sometimes useful life, are charged to the plant investment account, and at the same time the items being replaced are removed from the records and charged to the depreciation reserve.

The plant investment account is usually intended to show the original cost of equipment in use. It does not give the present replacement value of the plant. With cycles of inflation and deflation the construction index is ever changing. In using permanent investment figures as experience on which to base judgment, the book values must be adjusted to current replacement values if the difference is great. This may be done in elaborate detail, piece by piece, or as is often the case by approximate adjustment of average construction index at time of installation to current construction index. A record of past and current construction indexes is published monthly by McGraw-Hill in *Engineering News-Record.*

DEPRECIATION

Depreciation has always been a perplexing subject, and many volumes have been devoted to this one important problem. In general, the whole problem of depreciation is an attempt to anticipate complete lack of usefulness of permanent investment. If a converter costing $10,100 falls apart exactly 10 years after purchase and at that

TABLE V

Building Detail

Plant______ Building No.______ Title______ Building______

Project No.	Date	Description	Detail	Total
100	Jan. 31, 1940	Four-bay building 60 × 90 × 40 ft. reinforced concrete foundation with walls of 8 in. brick 9 ft. high, first floor surmounted by corrugated asbestos on steel framing	$15,000	$15,000
122	Oct. 31, 1946	One-bay addition 60 × 20 × 40 ft. same as above	6,000	21,000
		etc.		

Equipment Detail

Plant______ Building No.______ Title______ Process______ Equipment______

Project No.	Date	Description	Detail	Total
706	June 30, 1944	Three 12 in. O.D. × 12 ft. long scrubbers with ⅛ in. thick shell and heads including ceramic ring packing and steel supports, per dwg. G-624 (E.P. No. 41-42-43)	$3,043	
		Struthers Wells 12 in. O.D. × 12 in. long scrubber shell and heads ⅛ in. thick stainless steel construction, per dwg. G-624 (E.P. No. 44)	1,336	
		Horizontal storage tank 4 ft. O.D. × 5 ft. long on straight shell × ¼ in. thick shell and heads, per dwg. G-618 (E.P. No. 41-A)	2,454	
		One 5 ft. I.D. × 8 ft. long × ¼ in. thick aluminum tank, per dwg. G-647 (E.P. No. 36)	923	$7,756
822	Apr. 30, 1946	Two Toledo model 31-0220 hopper-type scales with cabinet type dials, capacity 1-1,000 lb.	1,400	
		One size No. 1 one-ton capacity geared pneumatic hoist with I-beam trolley mounting, lift height 30 ft., full chains 26 ft. long including air hose	435	9,591
		etc.		

time has a salvage value of $100, its useful life has been estimated accurately if exactly $10,000, or $1,000 in each of the 10 years of its use, has been withheld from profits and set aside in the depreciation reserve.

There are many reasons for retirement of investment, the wearing out factor as in the case of the converter just cited being merely one. It should be noted that the Internal Revenue Code defines depreciation as, *A reasonable allowance for the exhaustion, wear and tear of property used in the trade or business, including a reasonable allowance for obsolescence.* Particularly in the chemical industry, obsolescence is often a greater determining factor in the useful life of the equipment used in a given process than the probable physical life of such equipment. There are four major causes for obsolescence that must be considered along with wear and tear in determining the probable periodic loss of value of investment:

1. *Process or Chemical Obsolescence.*—Retirement resulting from an improvement in the chemical process making the older process too costly or inefficient.

2. *Engineering or Mechanical Obsolescence.*—Retirement resulting from a major mechanical improvement in the equipment making the older equipment too costly to continue to operate.

3. *Expansion or Capacity Obsolescence.*—Retirement caused by a major growth in the market for a product resulting in abandonment of small manufacturing units and substitution of larger and more economical units.

4. *Product Obsolescence.*—Retirement caused by loss of sales market because of development of new and cheaper substitutes.

The problem of depreciation, then, is to estimate the probable useful or economic life of investment and to charge cost and to set aside in a reserve periodically such amounts that, when they are added to the salvage value, equal the original cost of the investment on retirement.

There are several recognized methods of apportioning this loss of value over the life of the investment. Three of the more generally used methods are described here.

Straight-line Method.—The simplest and most commonly used method is the straight-line method, in which an equal amount is set aside in each accounting period, usually monthly. Thus, if the useful life is estimated to be 10 years, a monthly set-aside is made equal to $\frac{1}{120}$ of the original cost minus estimated salvage value.

Unit of Production or Use Method.—When physical exhaustion rather than obsolescence is the determining factor in loss of useful life, use rather than time is sometimes the more accurate method for providing for loss in value. Machines, operated at varying number of shifts from time to time can be cited as an example adaptable to this method where hours operated is the basis of determining loss of value. However, a better example of practical application of this method is the company depending on natural resources, such as mineral deposits, oil and gas resources, and standing timber. Here, the rate of exhaustion of the natural resources is the more accurate method for evaluating loss of value.

Declining Balance Method.—In this method, the rate is so developed that when applied to the net value, or original cost of the investment minus accumulated depreciation already set aside, the investment less its salvage value is fully depreciated over its estimated useful life. Since the rate must be higher than that used in the straight-line method, this method is the more conservative in that the first year's depreciation set-aside is the heaviest and the last is the smallest. Often a piece of equipment actually becomes less productive in somewhat this pattern. Another point in favor of this method is that since maintenance and upkeep costs increase as equipment becomes older, this method tends to equalize the sum of the two over the life of the equipment. A formula for developing this rate is:

$$\text{Rate} = 1 - \sqrt[x]{\frac{\text{salvage or scrap value}}{\text{original cost}}}$$

where x = years of expected life.

In setting depreciation rates every qualified person in the organization should be consulted. Hence, the sales manager should be consulted for product and capacity obsolescence, the research director for process obsolescence, the chief engineer for wear and tear, and so on. Sometimes, the result of such careful study will be a rate higher than allowed by the Bureau of Internal Revenue. In such instances, prudent business men will, for their own cost records, use the higher rate, substituting the lower rate only in tax return calculations.

Depreciation rates should be reviewed annually and corrections made when changed conditions materially affect the economic life of any investment.

A few examples of estimated average life recognized by the Bureau of Internal Revenue for the chemical industry are shown in Table VI.

Table VI.—Estimated Average Life of Chemical Equipment

	Years
Divisions:	
Acids	15
Atmospheric nitrogen	15
Alkaline products	22
Aniline dyes	20
Carbide and carbon products	15
Carbonic gas products	16
Chromium products	15
Coal-tar products	20
Electrochemicals	17
Oxygen products	18
Pharmaceuticals	20
Soap	20
Items:	
Acetic Acid	
Blow cases, cast iron and copper	3
Columns, fractionating	8
Condensers—Copper	10
Duriron	14
Lead	6
Motors	14
Pipes—Aluminum	3
Glass	5
Acid	
Copper	10
Rubber	8
Water	10
Pots	17
Pumps, vacuum	7
Receivers, acid (stoneware)	14
Scrubbers (stoneware)	14
Receivers, acid, for product (stoneware)	20
Stills—Cast iron	12
Refining, copper	14
Refining, heating coil	3
Tanks, storage—Steel	12
Wood	25
Carbide and Carbon Products	
Absorbers	10
Bagging machines	14
Barrels, tilting and tumbling	8
Breakers	12
Briquetting machines	18
Buckets, charging	8
Cells, chlorine	6
Charging machines	12
Chlorinators	12

TABLE VI.—ESTIMATED AVERAGE LIFE OF CHEMICAL EQUIPMENT.—(*Continued*)

Items:	Years
Coke quenchers	15
Columns	8
Columns, ammonia	6
Concentrators (hydraulic type)	12
Condensers (closed type)	17
Containers, copper	9
Coolers, after, fore, and inter	17
Coolers	10
Crushers, gyratory, jaw and roll	12
Digesters	10
Dryers (rotary and tunnel types)	25
Evaporators	17
Fillers, bag	14
Furnaces—Electric, carbide and metallurgical	20
Gas for heat treating, torching and branding	8
Preheating and welding	12
Generators, acetylene	12
Grinders	12
Holders, gas	25
Hydrators	12
Hydrolyzers	7
Incinerators	22
Kettles—Melting	6
Nitrating	6
Reducing	6
Salt	6
Steam jacketed	6
Kilns—Calcinating	22
Rotary	22
Vertical	28
Ladles	22
Mills	12
Mills, stamp	12
Mixers	12
Ovens, coke	17
Oxygen manifolds	20
Pans—Melting	6
Nitrating	6
Reducing	6
Steam jacketed	6
Preheaters	9
Precipitators	18
Press, filter	17
Pulverizers	12
Purifiers	18
Receivers, copper	9

TABLE VI.—ESTIMATED AVERAGE LIFE OF CHEMICAL EQUIPMENT.—(*Continued*)

Items:	Years
Retorts	22
Saturators	12
Screens	12
Sifters	12
Stills (closed type)	17
Thickeners	17
Towers—Acid and reaction	5
Cooling	7

A complete list of acceptable rates for tax purposes is published in *Bulletin F*, U.S. Treasury Department, Bureau of Internal Revenue, for sale by Superintendent of Documents, Washington, D.C., price 15 cts.

Only seldom are individual pieces of equipment depreciated on a unit basis. More common is the application of a "composite" or weighted average rate to plant areas, processes, or products. Frequently, one composite rate is developed for an entire plant where no one process is subject to extreme obsolescence and where all processes are generally thought to have approximately the same over-all useful life. Over-all composite rates are useful in averaging offsetting errors in judgment as to the length of useful life.

COST AND INVESTMENT ESTIMATING

Every chemical engineer will be confronted sometime with the problem of determining the financial aspect of a new product. He will want to know how much it will cost to produce, to sell, and to distribute the product; how much investment in plant and working capital will be required; and approximately how much the product will have to sell for to earn a satisfactory return on the investment. If a reasonable return is not indicated, more experimental work must be carried on until a lower manufacturing cost or saving in required investment is realized, or if this is not possible, the work must be abandoned. Knowledge of how such estimates are made is therefore essential.

Most estimating is based on factors developed from historical data prepared in the regular cost accounting of the business. Average labor rates per hour, average cost of supervision per dollar of operating labor, average overhead rates, cost per unit of steam, water, and other services, etc., can be obtained from actual costs, modified where necessary for known or anticipated changes in such costs. Therefore, the chemical engineer should have available for ready reference, up-to-date factors for every item of cost and investment practicable. These factors should be issued by the cost accountant at frequent intervals.

TABLE VII.—MILL COST ESTIMATE

______________Works

Product________________________________ Computed for______________

Quantity__________ ________ ____________ Computed by________Date____

No. of Units Unit Period of time Approved by________Date____

Cost elements	Unit	Per unit quantity	Quantity	Unit price	Value	Cost per unit	Remarks-factors derivations
Ingredients...............	......						Here all ingredients are listed separately with expected quantities used for each for unit of product. Anticipated cost per unit of ingredient should be obtained from the cost accountant or purchasing agent
Direct supervision.........	......						Experience factor applied to "Operating labor"
Operating labor...........	Man-hr.						Estimated man-hours required with current average rate per hour
Repairs labor.......... ..	Man-hr.						
Maintenance overhead.....	......						Experience factor applied to "Repairs labor"
Salaries and labor overhead.	......						Experience factor for Social Security and other employee benefits as applied to Direct supervision, Operating labor, and Repairs labor
General plant overhead...	......						Experience factor applied to "Direct supervision," "Operating" and "Repairs labor"
Materials and supplies.. ..	......						Best estimate
Raw water................	M gal.						Estimated quantities of services required together with average costs per unit as supplied by the cost accountant
Filtered water............	M gal.						
Steam....................	M lb.						
Electric..................	Kw.-hr.						
Works laboratory..........	......						Best estimate based on anticipated control work required
Depreciation..............	......						Applicable rate applied to direct plant investment
Property taxes and insurance	......						Experience factor applied to direct plant investment or "Depreciation"
Bulk cost..............							
Packaging cost...........	......						Should be calculated in detail if of sufficient magnitude in same manner as above
Shipping cost............	......						
Mill cost...............							

Printed forms are indispensable for estimating both for orderly work and as a safeguard that no item is unintentionally forgotten. Suggested forms are therefore shown. Thus, Table VII is suggested for mill cost estimates, possible bases for factors being indicated where applicable; Table VIII is designed to assist in estimating investment; and Table IX is a summary form for estimating earnings and returns.

TABLE VIII.—INVESTMENT FOR RETURN

____________Works

Product____________________Computed for________________

Quantity________ ____ ________ Computed by________Date____

No. of Units Unit Period of Time Approved by________Date____

Working Capital

Account	Basis of calculation	Dollars	Dollars per unit
Cash	One month's cost of sales		
Accounts receivable	Based on credit terms, for example, one month's sales for 30-day terms		
Inventory—raw materials Inventory—semifinished product	List average inventory of all major raw materials and semifinished products used in manufacture of product		
Inventory—finished product	Expected inventory of finished product		
Total working capital			

Permanent Investment

Account	Quantity	Factor	Dollars	Dollars per unit
Plants—Detail	Each major piece of new equipment should be listed with estimated installed cost based on similar installations as recorded on investment ledgers corrected to current construction index. Portion of existing manufacturing investment to be used in the process should also be listed			
General facilities	Experience factors applied to new direct investment detailed above			
Water Steam Electricity	Quantity of services required applied to per unit investment factor supplied by cost accountant			
Total rolled-up plant investment				
Transportation equipment	Estimate of cost of tank cars, trucks, etc., if applicable			
Real estate	Factor as applied to total plant investment			
Total permanent investment				
Total investment for return				

TABLE IX.—EARNINGS AND RETURNS

	________ Works
Product________________	Computed for________
Quantity________ ________ ________	Computed by________ Date________
No. of Units Unit Period of Time	Approved by________ Date________

Gross Receipts

Type	Quantity	Dollars	Dollars per unit
Domestic sales........... ..			
Export sales............. .			
Total gross receipts. . . .			

Cost of Sales

Item of cost	Basis of calculation	Dollars	Dollars per unit
Freight and delivery..	See detail discussion		
Mill cost.....................	See detail Table VII		
Selling expense.........	See detail discussion		
Management—administrative.	See detail discussion		
Direct research..	Provision for continuing experimental cost if applicable		
Special costs or credits........	Such as royalties, etc.		
Total cost of sales........ .			

Operative Earnings

Earnings and federal taxes on income	Dollars	Dollars per unit
Gross receipts, less cost of sales............		
Less: federal taxes on income.............		
Net operative earnings......................		

Return on Investment

Total investment for return $ ____(Table VIII)____ Per unit $ ____(Table VIII)____

Earnings required to give a return of:	Before federal taxes on income		After federal taxes on income	
	Dollars	Dollars per unit	Dollars	Dollars per unit
______%				
______%				
______%				
______%				
______%				

TABLE IX.—EARNINGS AND RETURNS.—(*Continued*)
Variations of Net Returns with Selling Prices

Assumed selling prices	Unit	Shipping terms	Return on investment	
			Before taxes	After taxes
			%	%
			%	%
			%	%
			%	%
			%	%

Other Items of Cost of Sales.—Freight and delivery costs must be included when the product is to be delivered to customers. Actual freight rates applied to estimated quantities to typical destinations is the safest and easiest method of estimating delivery costs when these costs are expected to be high. If the product is to be warehoused, estimates of such costs must be roughly approximated, based on expected rent per square foot of space utilized and handling charges. Warehousing charges vary widely by location and, if a new location is contemplated, quotations should be obtained if quantities involved warrant.

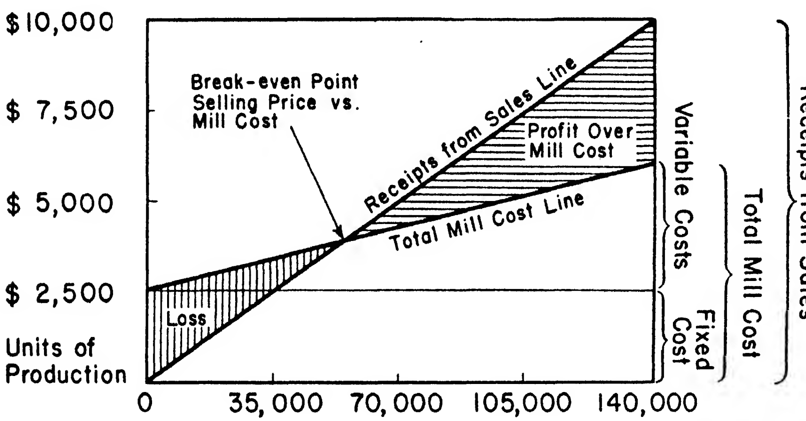
Selling expenses should be carefully considered. If the product is to be sold by an existing sales force merely as an addition to products already handled in volume, an experience factor per dollar of sales or per unit of product may be applied. However, if the product is entirely new to the field, as many chemical developments are, special consideration should be given to probable high advertising costs, customer technical assistance in use of the product, and larger than normal general selling costs for specialized salesmen's salaries and expenses. Any special commission arrangement with salesmen or agents should be included.

Management or administrative costs may be provided for by application of an experience factor based on dollar sales value or other denominator used in actual distribution of this item of cost.

FIXED AND VARIABLE COSTS

In the foregoing section concerning cost estimating, it was assumed that all costs were based on a definite assumed quantity of product. However, in any plant, manufacturing cost per unit depends largely on the percentage of capacity operated. Frequently larger capacity is installed than is immediately required. Because initial mill cost then will not be as low as expected at capacity and also because of the usual fluctuating sales demand for most products, it is frequently desired to know the cost at various production levels.

These data may be computed by analyzing costs for fixed and variable items. Fixed costs are those that do not vary with production, in fact, may continue if there is no production at all. These items depend



Percent of Capacity	0%	25%	50%	75%	100%
Mill Cost Per Unit		9.7¢	6.1¢	4.9¢	4.3¢
Margin between Selling Price and Mill Cost Per Unit.		(2.6¢)	1.0¢	2.2¢	2.8¢

FIG. 3.—Break-even chart.

on the operation but will always include such expenses as depreciation, plant taxes, and property insurance. Fixed charges may also include a part of direct supervision. Conversely, variable costs include all costs that vary with production such as ingredients, services, etc.

Study of applicable costs for the operation will develop data which can be plotted for ready reference in a suggested form as shown in Fig. 3. This chart may also be modified and made more useful by including all items of cost of sales in addition to mill cost.

CHAPTER XI

MARKET DEVELOPMENT AND RESEARCH

PART 1. MARKET DEVELOPMENT

By Chaplin Tyler

In this discussion, market development is assumed to be the function that comprises the creation of outlets for products through applied science. Thus, market development is distinguished from sales expansion through increased staff, employment of better salesmen or better management, or opening up new territory.

The starting point in any market development program is organization. Whether the organization comprises one man or a large group is immaterial, but it is essential that personnel designated should not be expected to handle market development as a side-line effort. Market development requires undivided attention and a favorable atmosphere. Like the research chemist in the laboratory, the market development man must penetrate deeply into the nature of things, and he must have patience. He must have technical ability, analytical ability, and imagination. He must be able to visualize new business and then be able to transform the vision into results. This is not to convey the impression that market development requires a higher order of ability than direct salesmanship. But a different kind of ability is required, and a different administrative viewpoint is required. Market development is relatively a long-range effort, and results may not be secured in a year, two years, or even more.

Considering the technical aspects of market development, as well as the commercial aspects, such effort can be supervised either by the research department or by the sales department. Both kinds of supervision are operable, though experience shows that the outside contact work, which is so essential in market development, in general, is better carried out under sales department supervision.

Market development problems originate in various ways, as for example the following:

1. *A desire to find new uses for existing products.* Thus, every producer of such staple chemicals as sulphuric acid, ammonia, methanol, caustic soda, and silicate of soda is interested in achieving increased

sales through new uses. Usually additional volume can be produced at an attractive "marginal cost," thus increasing the over-all profit, which at best is never large on such staple chemicals. Furthermore, certain existing outlets may diminish in volume or disappear entirely. Thus, market development is justified merely as a form of business insurance.

2. *A desire to find uses for new products.* Few indeed are the new products which are introduced without reasonable assurance of some definite outlet, if not outside the company, then within the company. But rarely is the initial volume of the new product so large that low costs are achieved; thus additional volume is much desired. For example, the initial production of anhydrous ammonia by the du Pont Company was intended primarily for use within the company, specifically for oxidation to nitric acid and for other chemical purposes. Eventually, consumption resulting from new uses made possible a much increased output with consequent reduction in cost and price.

3. *A desire to balance an operation by developing outlets for secondary products.* At one time the demand for caustic soda considerably outstripped that for chlorine, throwing a surplus of chlorine on the market. Uses for chlorine were developed with such success that chlorine has become a major commodity in its own right.

4. *A desire to satisfy a specific demand on the part of another industry.* At times a customer will submit a problem, the solution of which may involve a new use for an existing product, or will require that a new product be produced. These are special cases, often handled by binding the prospective customer to a requirements contract during such period as may be necessary to assure reasonable amortization of plant investment.

The first step in market development is to secure an abundance of working information concerning the product. This means acquiring an exact, comprehensive, thorough knowledge. Such knowledge is the foundation of market development.

Usually the description of the product should exceed the scope and detail of handbook data. Moreover, it is not always advisable to use handbook data in the description of the commercial product. The published data may not be correct; and if correct, may not apply to the particular commercial product. For example, when a solvent is offered to the trade, the actual boiling range should be stated, rather than boiling point or boiling range data from a handbook. Likewise, the trade will be interested in such data as specific gravity, vapor pressure, and viscosity over a considerable range of temperature; heats of vaporization; miscibilities with common liquids; solubilities of various solids; limits of various impurities; flash point, explosive limits with air; toxicity; shipping regulations, and shipping containers.

The second step is to correlate the properties of the product with uses, securing such patent protection as seems desirable before offering the material or a particular application to the trade. Following are examples in which properties have been correlated with new uses:

1. Methanol has low molecular weight, is completely miscible with water, and its water solutions have low viscosity, high specific heat, and are relatively inert to metals, rubber, and oils. The refined synthetic methanol, therefore, is well adapted for use in automotive antifreeze compositions.

2. A synthetic wax having an extremely high melting point is useful in raising the melting point of candles.

3. Ammonia, being readily handled as a gas, is an excellent neutralizing agent for the acids which form on the condensing side of petroleum-distillation equipment.

4. Urea is rich in nitrogen, is soluble in water, yet does not leach readily from the soil. It is nontoxic to plants and animals. Moreover, the reaction of urea in the soil is virtually neutral as compared with the strongly alkaline reaction of nitrate of soda, or the strongly acid reaction of sulphate of ammonia. Urea, therefore, is well adapted for plant food use.

5. Certain high-boiling monohydric alcohols are extremely surface active in aqueous systems. Accordingly, these alcohols are useful as foam inhibitors.

The third step is to test the proposed uses in the laboratory, taking care, however, to simulate operating conditions as well as possible. In this step, a large proportion of suggested uses will be found impractical. The promising uses will be investigated further—on a semiworks or "wash-tub" scale, as distinguished from the test-tube scale.

The fourth step is to induce someone in the trade with whom friendly relations have been established, to test the proposed use in the factory. This step, however, should not be undertaken until the outlook for success is fairly certain or—to state it another way—that, in the event of failure, the chances are slight that serious damage will result.

The fifth and last step is to prepare an operating manual containing all information needed by the trade and by the technical sales representative. The new product, or the new application of the old product is then on a commercial basis.

When the market development is based on a new product, extreme care is required to ensure that the product can be reproduced with reasonable uniformity. It is axiomatic that, in many operations, a particular impurity is not so harmful as are variations in purity. This means that the production staff must appreciate fully the nature of the market development problem. It is particularly important that the commercial stock be as good in quality as the sample material, or better. Much market development fails because the initial effort is not followed through with the type of service that the trade has a right to expect. It is astonishing how many new products are put out before a thorough knowledge of properties is in hand, or before the seller is prepared to supply trial material and to assist the trade technically.

Technical Publicity.—When a product, process, or application has been developed to the point where it is ready for market, a publicity plan should be formulated. Publicity may be regarded as the first step in selling; paid advertising, the second step; and personal salesmanship, the third and final step.

It is generally agreed among technical men that the first step in the publicity should be a presentation of the development in the technical press or before a technical society. There are several reasons for this procedure. First, a new industrial product, process, or application usually must be approved by technical representatives of the buyer; second, even if the product is to be marketed direct to the general public, the marketing campaign is much strengthened if based on publication satisfactory to the profession or trade; third, at least one professional society (American Institute of Chemical Engineers) requires in its code of ethics that initial disclosures be made to a technical audience.

As an example, assume that a company has developed a synthetic resin. The process has been worked out in the laboratory and on a semiworks scale. A full-scale process and plant design have been projected. Cost estimates have been made for various outputs. Important physical and chemical properties have been determined. Patents have been secured or applied for, covering various compositions of matter, methods of making the product, novel features of apparatus, and such uses as seem to have potential importance. A trade-mark has been selected and registered. Prices have been figured. A quantity of the material, in various forms and grades, is available for sample distribution.

The company is now ready to make an announcement. This takes the form of a paper for publication in a medium of recognized standing; or better yet, a paper for presentation before a technical society, with simultaneous release for publication. For obvious reasons, the paper should be signed by the person or persons closely identified with the development.

If the development looks as though it would be limited to a few important but unspectacular industrial uses, no attempt at general publicity should be made. For instance, if the resin is to be used in a protective coating for storage tanks, it is of little or no interest to the general public, at least in advance of some tremendously wide use. On the other hand, if the resin is to be used in safety glass, in aircraft or in finishes for automobiles, then the man in the street is concerned and therefore is interested. He would like to read about it in his newspaper and news magazine. For this purpose, a press release is prepared, embodying the important elements of general interest. It is publishable as soon as the basic paper has been published or presented, not before.

The basic paper and general publicity may then be followed up by such secondary efforts as distribution of reprints of the basic paper; preparation of direct-mail advertising, pamphlets, and periodical advertising copy; and preparation of further articles in the technical and trade press, featuring some special property or application of the product.

By this time, if the publicity has been at all successful, inquiries from prospective users and others should be in hand. These inquiries will call for samples, further technical details, and further details of marketing, such as price, delivery, and grades. This brings up for discussion an important point: when practicable, the announcement of the new development should be deferred until the company is prepared to follow through properly with the inquiries. Otherwise the trade, as well as the public, is likely to believe it has been deceived; that the publicity was merely for the sake of publicity—in brief, a stunt. It cannot be stressed too strongly that, in the long run, the publicity cannot be better than the underlying product.

It should be emphasized also that the planning, preparation, and distribution of the publicity are technical matters to be entrusted only to qualified persons. Today, among media for technical publicity—properly interpreted—there are not only newspapers and news magazines, but popular science publications, motion picture shorts and newsreels, radio, exhibits, and expositions. The larger newspapers and press associations are staffed to interpret science and technology. The public wants, and is getting, news of science and of new products.

Technical Advertising.—Broadly defined, any printed, spoken, or exhibited notice of a subject is publicity. This would include advertising. In this discussion, however, an arbitrary distinction is drawn: When the publicity is secured by purchase, it is called advertising. A distinction also can be drawn on an editorial basis: when the subject of the publicity is novel and of interest to the public, or to an important group of the public, it is considered "news." Accordingly, an editor might print it as part of the news or editorial content of his paper. Once it has been printed, however, it is no longer news, and any restatement would be secured only in the advertising (purchased) content of the paper. For instance, assume that a rayon yarn has been developed from cornstalk cellulose, instead of from wood pulp or cotton linters cellulose. This would be news, and an article announcing the development would be printed by a large number—probably a majority—of the country's important newspapers, news magazines, and chemical journals. The rayon manufacturer wanting to keep the subject alive would do so by releasing additional information and by repeating the published information in purchased space. In brief, he would follow up the news with a campaign of paid advertising.

Realizing this distinction between advertising and news, the seeker of publicity habitually will not attempt to secure "free advertising." In fact, no editor worthy of the title will accord it.

The technique of advertising is, moreover, different from the technique of news presentation. Thus, the advertising message may pointedly direct attention toward a specific product in order to solicit custom.

There is further opportunity for the technical writer in such work as preparing product bulletins, operating manuals, catalogues, and sales letters. In all these things, high standards of scientific accuracy are essential. There is no reason why technical advertising cannot have "sales appeal" and yet be accurate and informative.

Advertising reaches many readers who may have missed the previous publicity, or it may serve to impress a message upon a reader through frequent repetition. While it is not the job of the market development staff to prepare the advertising, or the publicity, these service agencies cannot be expected to function effectively unless they have help. Practically every case of poor advertising and publicity relating to new products or new applications can be traced to lack of coordination among the departments involved. Of what use is expensive and complex organization machinery unless it is operated properly?

Some years ago the du Pont Company began manufacture of a synthetic wax. The introductory publicity and advertising were conducted on a modest scale because there was no immediate expectation of large outlets. However, more than one hundred inquiries were received within a month, which is sufficient evidence that publicity and advertising will "pull" if the message is interesting, well-placed, and timely, even though the publicity may consist of only a few paragraphs, followed by several hundred dollars worth of paid advertising. To be exact, the out-of-pocket cost per inquiry received during the initial period of sales development was about three dollars.

Follow-up Is Important.—Analysis of these inquiries showed that most of them should be followed up by supplying a small sample and a memorandum of properties, suggested uses, and price schedule. In every case an individual letter was dictated, no matter how remote appeared the chances of making a sale. In these cases in which a favorable response was received from the follow-up by mail, or in which the inquiry appeared to represent an attractive outlet regardless of the response, personal calls were made. The proportion of these "live" prospects was about 20 per cent of the total inquiries.

Several interesting things will develop from the personal follow-up. In some cases the market development representative will discern immediately that no further contact is indicated, as for example, because the prospective customer is operating a "shoe-string" business and is unable or unwilling to give evidence of financial responsibility. In other cases it will be found that despite the prospective customer's verdict that the product is "uninteresting" or "out of line in price," this verdict was reached after only cursory examination.

New products are generally referred to the "research department," which, in some companies, may be little more than imaginary. In such circumstances the development representative must decide whether to accept the verdict as a convenient means of avoiding further expense, or to render such technical assistance as he can in an attempt to demonstrate the fitness of the product.

In relatively few cases, the potential volume is sufficiently large to warrant technical assistance not only by consultation with the prospective customer, but experimentally in the seller's laboratory. The best-laid plans for market development cannot anticipate all possible uses for a product; neither can these unforeseen uses be demonstrated without experimental work.

If the prospective customer is sufficiently interested, he may undertake such experimental work himself; and if he is at all competent in his field, he should be able to arrive at a verdict more quickly than an investigator who is not versed in the many practical aspects of the particular industry. Also, experimental work done by the prospective customer may lead to patentable results, which, of course, can be significant as a competitive factor. In any event, the market development man cannot hope to become a research jack-of-all trades and thus submit to the prospective customer the answer to all and sundry problems. But at least he should offer the best possible product at a reasonable price, at the same time giving an accurate account of all known physical and chemical properties.

Correlation of Properties and Uses.—As pointed out earlier, like products suggest like uses; therein lies a practical approach to market development. For example, outlets for the synthetic wax mentioned previously were developed in part by such an approach. Investigation of waxes already on the market disclosed that there were a number of principal uses, as for example, in polishes, paper coatings, dielectric systems, candles, carbon paper, and cosmetics. It then became a simple matter to compile a list of manufacturers in these groups, thereby creating a basis for direct-by-mail approach. This was desirable, because not all potential users of a product can be reached through journal publicity and advertising.

Suppose, however, that the problem is to develop new uses for a product that has no close counterpart, as for example, anhydrous ammonia. Liquid ammonia has been on the market so many years that it might be supposed that all conceivable uses have been developed. However, new facts about ammonia are being turned up continually, and even though these facts are widely published, practical application may not follow just as a matter of course. Furthermore, practical application of old, well-known facts may not be induced until the price of the product is reduced substantially. Thus, liquid ammonia in tank cars at 3 cts. per pound is an entirely different material from the economic viewpoint than ammonia in cylinders at 30 cts. a pound, which was the price in 1925.

In the foregoing example, a continuing market development effort was justified, because the volume of existing ammonia sales was large, thus enabling considerable expenditures to be made without seriously affecting current profits. Also, because commercial ammonia is a definite chemical compound of high purity, a study of its properties was indicated as a guide to possible outlets. Thus, ammonia can be considered (1) a low-cost alkali, since only 17 lb. of ammonia are equivalent to 40 lb. of caustic soda, or to 53 lb. of soda ash; (2) the most concentrated form of fixed nitrogen, being 82 per cent nitrogen; (3) an efficient refrigerant; (4) an economical source of hydrogen gas, because when dissociated 30 lb. of ammonia will yield 1,000 cu. ft. of catalytically pure hydrogen; (5) a possible medium for a variety of reactions, which, with modern equipment, are readily carried out under pressure; and (6) an unusual solvent of possible use in purification processes.

Similarly, any product can be considered in the light of its properties, in order to approach the market development problem in a scientific manner. If, like ammonia, the product is a definite compound, various chemical reactions likewise should be explored.

Another aspect of market development is the hazard relating to the handling of certain products by the customer. Of course, insofar as hazards are definitely established, safety measures or regulations have been promulgated. But regarding toxicity in particular, chemical developments are coming along so rapidly that it is difficult for toxicological science to keep up to date. Because of this situation, producers of new products, and those seeking to extend the use of existing products, should proceed cautiously.

PART 2. MARKET RESEARCH

By Richard M. Lawrence[1]

In addition to answering the primary questions: "How much could we sell?" and "How much could we get for it?", it is the function of market research to provide company management with information and recommendations on many problems related to the broader province of economic and commercial research.

Gains in scientific and technical knowledge are usually permanent, whereas information of an economic and commercial nature must be constantly renewed to be of value. Contrast, for example, the permanency of data on reaction rates and solubility with the relatively short useful life of information on costs, prices, freight rates, tariffs, taxes, labor rates, and many other factors which shape the size and character of markets. Moreover, scientific and technological facts can be determined by experiment, while most of those pertaining to markets cannot be so determined.

Business decisions can only rarely be made in the light of all pertinent facts, but, other things being equal, those based on the most facts and the newest facts are most likely to be correct.

It is a well-established principle that the best managed research

[1] Development Department, Monsanto Chemical Company, St. Louis, Mo.

comprises a succession of "crucial experiments," a negative answer to any one of which automatically bars further exploration of barren territory. As many of these crucial determinations are in its domain, market research should precede as well as parallel the major projects of technical research.

Scope of Market Research.—In a market survey of a selected chemical, the market research man is essentially studying supply and demand and costs and prices, with particular reference to his company's actual or potential competitive position. His job is like putting together the pieces of a picture puzzle. It may be impossible to get all the pieces, as many may be the well-guarded property of other companies. However, if he can get enough, he can determine the general outlines of the picture with fair assurance. In arriving at these outlines, statistics usually play a major part, but other types of information provide the coloring, the highlights and shadows, that make for a more complete and accurate portrayal.

In the main, chemical market research work deals with the chemical process industries, as it is these industries that comprise the principal primary markets of chemical manufacturers, although it is also true that almost every industry is a consumer of chemicals in some degree. As pointed out in Chap. I, the process industries include, in addition to chemical manufacturing itself such industries as ceramics and glass, cement, coke, drugs and cosmetics, explosives, fertilizer, leather, oils and fats, paint, plastics, petroleum refining, pulp and paper, rayon, rubber, soap, sugar refining and textile finishing.

Evaluation of chemical markets also involves other industries which provide the end-use consumption of chemicals. While relatively few chemicals as such are sold to or even seen by the general public, it is what the consuming public buys (for example, shoes) that generates the demand for chemical process products (leather, rubber) and activates their demand for chemicals (bichromates, carbon black, etc.). Raw material studies often reach still further back into the basic data of mineral and agricultural production.

The chemical market research man therefore has an extraordinary range of interests, expressed in his demands for data on almost every type of industry and operation. To illustrate, a chemical company may be interested in sources of fluorine-bearing minerals for use in the manufacture of refrigerants and may estimate the market for its products in terms of the output of mechanical refrigerators and the floor space of frozen food locker installations. It may also be interested in trends in air conditioning. It is interested in the brewing industry, which uses its by-product hydrofluosilicic acid as a disinfectant. In addition, the company may produce anhydrous hydrofluoric acid, used in an alkylation process for aviation gasoline, and other fluorine products, for which insecticide outlets are important.

Also, the particular types of functional data required, as contrasted with industry and regional data, are extremely varied. A product study may involve data on capacity, production, consumption, stocks, imports, exports, international trade, price structure, costs, tariffs, taxes, index numbers, conversion factors, foreign exchange, freight rates, specifications, legal restrictions, containers, names of producers, trade names, labor rates, and other matters. Products and industries may be measured in terms of quantities, values, prices, number of employees, equipment installed, power consumption, and other significant data.

In studies of individual companies, information usually must be developed on ownership, key personnel, corporate affiliations, plant locations, lines of products, manufacturing facilities and processes, disposition of by-products and waste products, financial standing, customer industries and companies, market areas, potential developments, competitive situation with reference to other companies, imports, and substitute products.

The Market Survey.—The market survey, which describes the changing picture of the competitive situation, primarily involves a study of consumption, which can be expressed by the equation:

$$C = P + I - E \pm \Delta S$$

in which C = consumption, P = production, I = imports, E = exports, and ΔS = the change in stocks. The last-named item must often be omitted because data may be unavailable; if a period of years is considered, the error in the estimate of consumption is minimized.

When the consumption cannot be estimated directly from published data, the investigator has ample opportunity to demonstrate his resourcefulness. For example, one procedure is to list all known uses of the commodity, after which the consumption is calculated by applying a factor for each use. As with engineering estimates the method depends, of course, upon the validity of the underlying data and assumptions. Thus if the output of a certain plastic is 100 million pounds per year, and the consumption of plasticizer is 0.3 lb. per pound of plastic, then it follows that the industry consumes 30 million pounds of plasticizer. Such consumption factors are obtainable by reference to the literature, or by "sampling" some friendly company in the trade.

Or the quantity of ester glycerin used in ester gum (essentially glyceryl abietate) may be estimated as 10 per cent of the tonnage of rosin which the Department of Agriculture reports for this use. For alkyd resins, the glycerin consumption is about 20 per cent of the output of such products. But the market survey is hardly begun when the total United States consumption has been estimated. A new producer should not expect to capture the entire market. The real interest centers in an estimate of the probable participation in the market. Analyses showing consumption by grades, by uses, by geographic areas (or freight territories), by industries, by individual consumers, and by seasons of the year are much more revealing than is a statement of total consumption. In markets nearer to plants of competitors, there is a disadvantage as to freights. If some consumers take their requirements in a few months of the year, the manufacturer must provide storage for large stocks.

When the foregoing factors have been considered carefully, the variation from total consumption may be tremendous. When assembled, the different elements of information yield only a historical picture of the market. In this picture, the trends are as important as the magnitudes in indicating the developing situations that are ahead. Analysis and interpretation of adequate market data yield forecasts, which are the final objective of market research. If properly made, these forecasts contribute importantly to effective planning of company budgets and schedules for purchasing, production, shipping, selling, and advertising. Projected still further ahead, they are the basis for long-range planning.

The many opportunities for measuring the flow of materials related to a product being surveyed are indicated in the accompanying chart by Clark[1] (Fig. 1). For example, when figures on the product itself are unavailable, the volume may be measured, or at least indicated, by the volume of a by-product or an end-use.

Condensed Outline.—A brief outline of the essentials of a market survey is that of Clark,[1] which covers the following facts for a product X:

1. Number of consumers (and list by name).
2. Location of plants (see Fig. 2).
3. Total consumption of product X.
4. Price paid for product X.

[1] "Chemical Market Research," *Chem. & Eng. News*, December 25, 1946, pp. 3318–3322.

5. Present supplier (s) of product *X*.
6. Economic trend of the consuming industry.
7. Technological trend in use of product *X*.
8. Competitive status of various consumers in the industry.

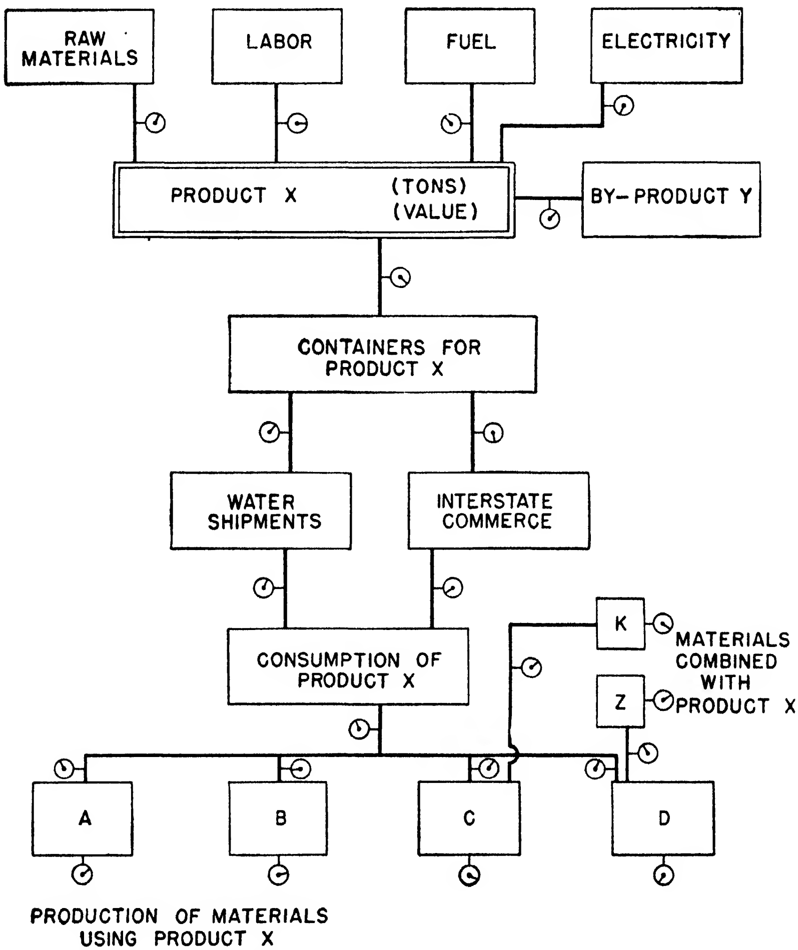


FIG. 1.—Measuring the flow of product *X*. (*From Melvin E. Clark.*)

The foregoing data on each of the markets for *X* are combined to give the composite picture of the market, in which the company's actual or potential position must then be delineated.

Forecasting Method.—Using market data of the latest available

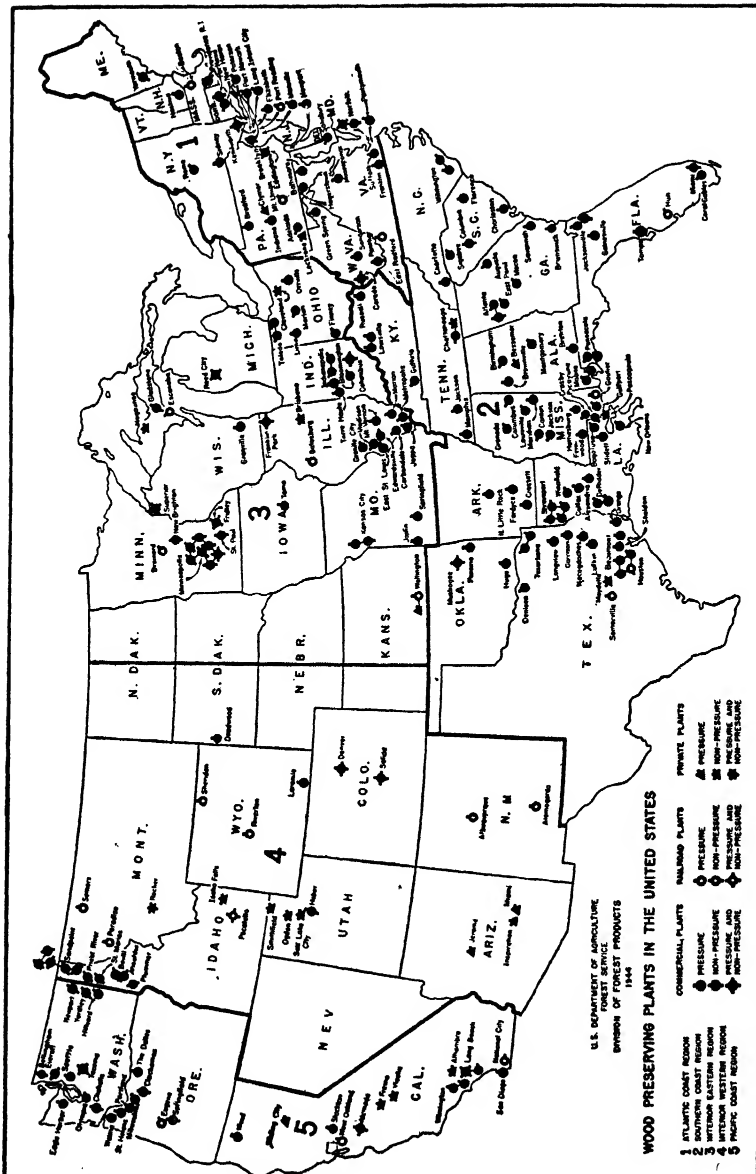


FIG. 2.—Industry maps indicate customers for chemicals and equipment. Trade directories and government sources list locations, capacities, and names of companies.

year as a "bench-mark," the forecasting method of Clark[1] utilizes factors representing both economic and technological trends. For example, if a rubber company plans to make 15 per cent more tires in the coming years, and larger sizes representing 8 per cent greater tonnage, the economic growth factor and the technological change factor are 1.15 and 1.08, respectively. If substitute products are expected to replace 5 per cent of some chemical raw material (product *X*), the factor for technological change must then be multiplied by 0.95. Thus, $T.C. = 1.00 \times 1.08 \times 0.95 = 1.026$.

The table of consumption by uses is constructed as follows:

PRODUCT *X*—CONSUMPTION BY USES

Use classification	Number of units used in base year	Growth factor	Factor of technological change	Estimated consumption for year 19__
A	100	1.00	1.00	100
B	200	1.00	0.90	180
C	300	1.00	1.40	420
D	400	0.80	1.00	320
E	500	1.20	1.00	600
F	600	1.10	1.10	726
Totals	2,100			2,346

Comprehensive Outline.—In order that essential factors in the market survey may not be overlooked, a fairly comprehensive procedure is outlined below. Naturally the topics studied and the relative emphasis will vary greatly with products, industries, companies, and geographic areas involved. However, a standard outline is a constant aid, even to the experienced investigator.

MARKET SURVEY OUTLINE[2]

1. Description of product:
   a. Physical and chemical properties.
   b. Physiological action.
   c. Shipping classification.
2. Standard specifications:
   a. Definition of grades.
   b. Limits of impurities and of physical properties, for example, specific gravity, color.
   c. Packing specifications.
   d. Possibility of improving quality.

[1] Clark, *loc. cit.*

[2] Includes material adapted from outlines of Chaplin Tyler, R. L. Dodge, and C. W. Berl.

3. Consuming industries:
   a. Uses and methods of use.
   b. Total consumption and value.
   c. Breakdown of total consumption (see Fig. 3).
      (1) By industries.
      (2) By geographic divisions.
      (3) By companies.
   d. Exports.
   e. Possibility of developing new uses.
   f. Use of product by own company.
4. Buying habits of consuming industries:
   a. Contract and spot sales.
   b. Sales methods now in use; need for technical service.
   c. Possible substitutes and market conditions governing choice.
   d. Seasonal or fluctuating demand.
   e. Wide market or restricted to few consumers.
5. Production statistics:
   a. Domestic production and trend of production.
   b. World production, and production by specified countries.
   c. Production by principal individual producers.
   d. Imports for consumption.
   e. Stocks on hand.
6. Prices:
   a. Price structure.
   b. Price history.
   c. Factors influencing price, for example, raw materials, substitute products, etc.
7. Transportation and storage:
   a. Freight rates on principal movements of raw materials and finished products.
   b. Storage of raw materials and finished products.
8. Competitive situation:
   a. Principal competitors, their location, and capacity.
   b. Nearby markets.
   c. Imports, and dependence of domestic industry on tariff protection.
   d. Interprocess competition.
   e. Intercommodity competition (see Fig. 4).
9. Comparison of manufacturing processes:
   a. Raw materials: sources, reserves, availability.
   b. Fuel and power.
   c. Labor.
   d. Capital investment.
   e. Yields.
   f. Costs of production.
   g. Importance of co-products and by-products.
   h. Health hazards.
10. Probable future markets:
    a. Trend of consumption.
    b. Trend of prices.
11. Patent situation and other legal restrictions on manufacture, sale, and use.

See also:

Check Sheet, "Production and Marketing of a New Product," *Chem. Met. Eng.*, editorial supplement, February, 1936.

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Davies, R. L., and G. T. Collins: "Expansion Research by the Pattern System," *Chem. Ind.*, June, 1945, pp. 949–953.

"An Outline for Making Surveys," Economic Series No. 34, (1944) Bureau of Foreign and Domestic Commerce, price 10 cts.

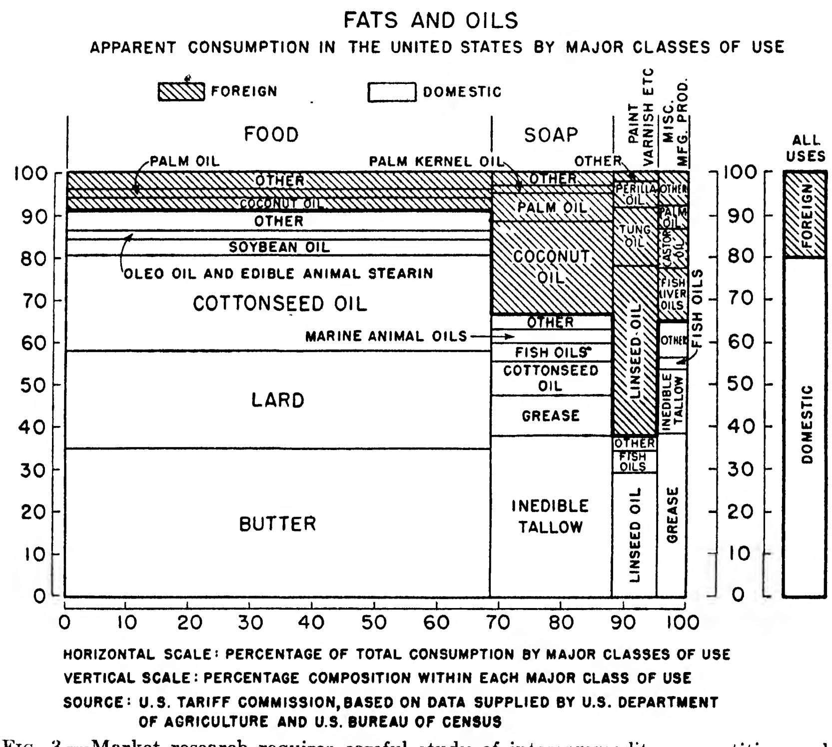

Fig. 3.—Market research requires careful study of intercommodity competition and foreign competition.

SOURCES OF MARKET RESEARCH INFORMATION

Just as "a man's judgment is no better than his information," there is no substitute for ample data and a large number of information sources. With a variety of sources at his command, the market researcher can proceed rapidly and effectively to the terminal problems of analysis, interpretation, and presentation.

Since many important chemicals are produced by relatively few

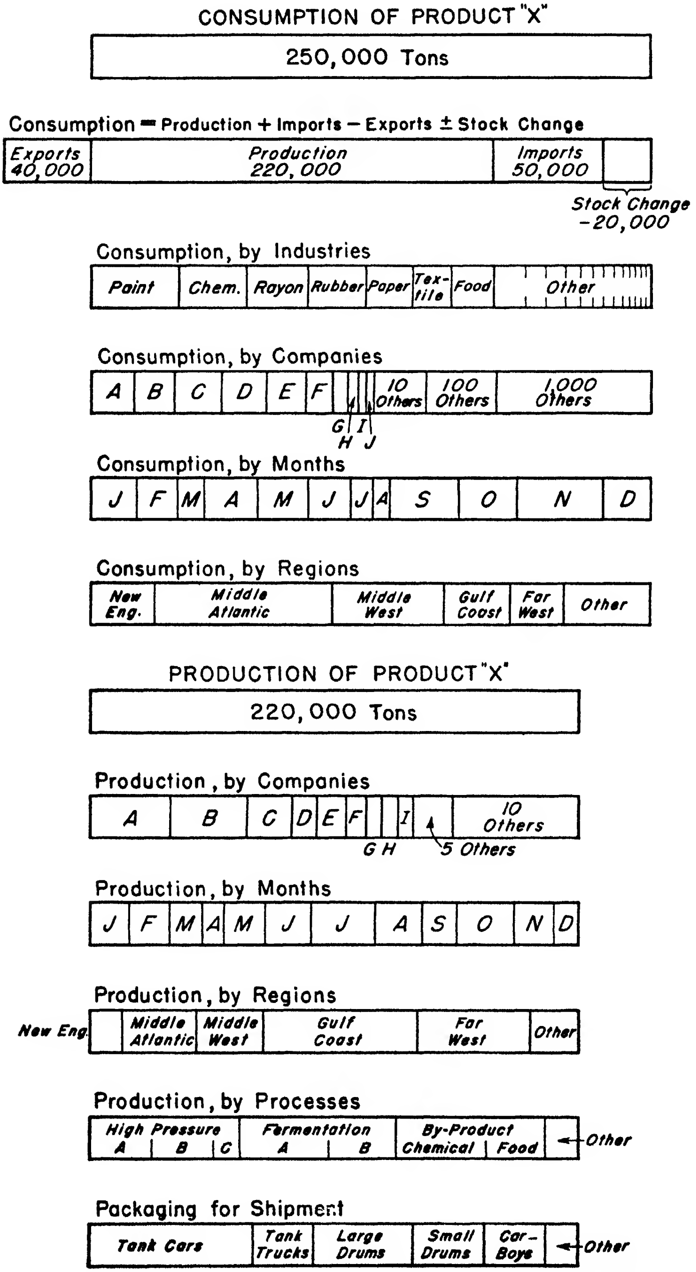

FIG. 4.—Graphical analysis of production and consumption of product *X*.

companies, statistics of the output of such products are confidential and are not published. Figures on chemical consumption are scarce and must be estimated by indirect means. Because of these inherent characteristics, data must be drawn from a great diversity of sources, analyzed with caution and interpreted with care to report fairly the contingencies and limitations surrounding the different factors described. The guiding principle is to make a large amount of information available for practical use.

Many Sources Needed.—Working knowledge of a great many sources of information is a major element in effective market research. In addition to obvious savings in time realized by prompt access to authoritative commercial information, using a variety of sources often permits checking the reliability of data or gaining better insight into the qualifications with which it must be used. If final production figures are not available for a given year, other sources may yield preliminary figures or estimates, or data from which the market researcher can develop his own estimates. For example, in addition to the several sources of information on ammonium sulphate, records and forecasts of steel production can be used to estimate coke-oven activity and by-product ammonium sulphate production.

The chemical market researcher begins with the available sources of information in his own company—the sales department, the purchasing department, the traffic department, and other eyes and ears of the organization. Information from internal sources is supplemented by correspondence and field work with suppliers, customers, government bureaus, trade associations, business paper editors, universities, public utilities, and other contacts. Much of the basic information of chemical market research, however, is scattered through many literature sources, the principal ones of which are listed at the end of this chapter.

Although governmental bureaus are the major sources of published market research data, there are also dozens of private sources such as trade journals, yearbooks, and directories of many industries. Individual companies are sources of corporate reports, catalogues, data sheets, and price lists. Chambers of commerce and public utilities publish regional surveys; specialized firms supply financial advisory services, credit reports, and mailing lists.

Types of Information.—In contrast with data on production, prices, imports, and exports, data on consumption of chemicals are relatively rare. Examples are creosote used in lumber-preserving and Census of Manufactures data on materials used by certain industries. Among the best of all are the War Production Board's published reports on allocations, and the end-use statistical releases of the Bureau of Census, which amplify them.

The most complete statistics, which indicate the ideal, are those on alcohol, published by the U.S. Treasury Department. These figures show production by states, by processes, by raw materials, and they show consumption by formula, by use, and by states. A number of states publish figures on farm consumption of fertilizer in elaborate detail, by counties, and by products.

A good government survey on a product may have cost $20,000 and may be available for 25 cts. It is obviously important that no such valuable sources be overlooked, and they must be ordered promptly before they get out of print. Although market research data sources become out of date rapidly, many of the old reports are valuable for providing background and methods of analysis. The literature of chemical market research is becoming steadily more abundant, a trend that will doubtless continue.

The Governmental Sources of Basic Data.—For basic statistics of the chemical and allied industries, the major publications are those of the Bureau of Census, which cover all manufactures; those of the U.S. Tariff Commission, which cover synthetic organics in great detail; and those of the Bureau of Mines, which cover minerals and metals and a number of related chemicals. Statistics of imports and exports are published in the Bureau of Census' detailed annual, "Foreign Commerce and Navigation of the United States" and in monthly publications.

The most important statistical development of recent years was the cooperative issuance of detailed monthly figures by the War Production Board, the Bureau of Census, the U.S. Tariff Commission and the Bureau of Mines. These "Facts for Industry" series, which began in 1944, now present production data for more than 100 products of interest to the chemical and process industries.

Other series of basic figures concerning the chemical and process industries are published in the U.S. Department of Agriculture's comprehensive annual volume, "Agricultural Statistics," special reports (naval stores, wood preservatives, fertilizers, etc.), and monthly publications. Series of commodity figures of narrower scope are regularly published by the U.S. Treasury Department and other governmental units.

The U.S. Department of Labor issues detailed figures on wages, hours, employment, living costs, and prices. Other figures are published irregularly in the special studies of a number of government departments.

Practically all foreign countries publish statistics of imports and exports. The leading industrial nations publish production statistics, though usually in far less detail than those of the U.S. Government.

In a few cases, state bureaus issue statistics of interest to the chemical industry such as data on fertilizer consumption and mineral production. University bureaus of business research, chambers of commerce, and state bureaus often issue directories of manufacturers and other reports on industry and business.

Statistical Summaries and Reviews.—Many of the more important statistics of United States production and foreign trade are regularly republished in the monthly "Survey of Current Business," the quarterly "Crops and Markets," and the annual "Statistical Abstract of the United States." The Manufacturing Chemists' Association issued "Chemical Facts and Figures" in 1940, with all important chemical statistical series for several prior years, and a comprehensive revision was released in February, 1947.

Periodicals and special reports containing analyses, interpretations, and reviews—many including special statistics not elsewhere published—are issued at frequent intervals by the Bureau of Foreign and Domestic Commerce, the Bureau of Mines, and the U.S. Tariff Commission—for example, "Domestic Commerce Monthly" and "Industrial Reference Service" of the Bureau of Foreign and Domestic Commerce, and the "Chemical Nitrogen" survey of the U.S. Tariff Commission.

Other Published Sources.—*Chemical Engineering* and *Chemical Industries* magazines publish monthly statistical sections, and leading trade journals in other fields usually republish government statistics in regular or annual issues and yearbooks. These are usually supplemented with trade estimates and reviews.

Many trade associations publish their own and government statistics on production, imports, exports, and prices. Examples are the American Petroleum Institute, the National Fertilizer Association, and the National Paint, Varnish, and Lacquer Association.

Various figures and background information are published in industrial directories, financial advisory services, company prospectuses, corporate reports to stockholders, manufacturers' catalogue and technical data sheets, regional industrial surveys, and credit reports.

Indexes to Sources.—In contrast with the technical and scientific literature, which is superbly covered by *Chemical Abstracts*, the literature of chemical market research is poorly indexed, and relatively little study has been devoted to the subject. The codification of its literature is a major step in the advance of an emerging profession, and this step has not yet been taken in chemical market research. It has been proposed that the Chemical Unit of the Bureau of Foreign and Domestic Commerce start an index and abstract service in this field.

Market Research Sources, a series of reports issued by the Bureau of Foreign and Domestic Commerce (8th ed., 1940), describes the activities and provides a detailed checklist of publications of federal, state, and local government agencies, also colleges, publishing houses, chambers of commerce, trade associations, and other commercial organizations.

Also noteworthy are the numerous publications of the Special Libraries Association, which effectively promote their aim of "Putting Knowledge to Work." The Association's reports on sources include *Guides to Business Facts and Figures* (1937), *Handbook of Commercial, Financial, and Information Services* (1944), and *Directories for the Business Man* (1938).

A market research library should have the catalogue of all government bureaus and should receive their announcements and checklists. Selected checklists of recent government documents are usually available also in the trade journals.

Information by Special Arrangement.—The Washington bureaus have in their files vast quantities of information from which they have published selected material believed to be of greatest importance to industry and government. Obviously they cannot publish everything. This leaves a great deal of information in their files, much of which is not confidential and may be obtained through correspondence or interviews.

It is also possible to obtain from the Bureau of Census, for a moderate fee, copies of nonconfidential tabulations, which might, for example, have been subtotals on their work sheets for figures that went into the grand totals published. They can also arrange to select groups of their punch cards on a certain industry or a certain area and run them through their machines to give totals which are of value for studying special problems.

The Bureau of Foreign and Domestic Commerce, "The Businessman's Bureau," compiles many special reports in response to inquiries. U.S. Department of Commerce offices in principal cities assist in getting information from Washington and from representatives abroad. Staffs of the Bureau of Mines and U.S. Department of Agriculture also make many special tabulations as a service to industry.

The Securities & Exchange Commission has in its files data on thousands of companies, which may be consulted, tabulated, or photocopied. Records cover financial reports, history and business, management, labor relations, production, sales, recent additions to plant and property, and intercompany affiliations.

Government bureaus welcome visitors to their large and specialized libraries.

MARKET RESEARCH ORGANIZATION

The primary responsibility of chemical market research is to study markets and market conditions and to continuously portray the competitive situation and the company's position therein—the actual position of established products and the potential positions of new and established products. It heightens the effectiveness of the sales department and is a major function of the development department in launching new products or promoting new uses for established products.

The term "market research" often connotes "marketing research" in which case it involves studies of all of the mechanisms of distribution by which the bulk product is packaged, labeled, stored, advertised, financed, sold, shipped, and serviced. Market research sometimes covers also the supply and price problems of the purchasing department. In a still broader sense, market research may at times be synonymous with commercial research, business research, and economic research.

Types of Personnel.—The director of chemical market research must be a broad-gauge individual, with technical background, economic understanding, numerous contacts in industry and government, and a grasp of the possibilities and limitations of market research techniques. He must possess a thorough knowledge of company organization, maintain close relationships with key personnel, and be able to contribute effectively to conference discussions. He must be versatile enough to conduct surveys appropriate to problems of varying magnitude and intricacy. He must have judgment in the amount of effort to be spent on preliminary, progress, and final reports.

In addition to clerical and stenographic services, a large department will include such specialists as statisticians and chart makers, field workers, and report writers. In small departments, each man carries on several or all requisite duties. In large departments, it is possible for individuals to specialize in problems incident to certain industries. Such individuals may be drawn from the ranks of the product departments and may later return thereto. In some companies, the market research department is utilized in part as a training ground to give promising employees an "executive's-eye" picture of company problems.

Because the chemical industry is one in which alternate products and alternate processes are powerful forces, both actual and potential, the director of chemical market research and key members of his staff must have well-rounded training and experience in the industry.

Training.—The universities do not offer curricula especially designed to equip graduates for chemical market research. However, courses in chemistry and chemical engineering may be supplemented by courses in business organization and management, economics, statistics, use of the library, and report writing. Extracurricular activities, such as debating, student publications, and general committee work also are valuable.

Position in the Company Organization.—As is common with an emerging professional specialty, there is no standard form of market research department and no uniformly accepted position in company organization. In most company organizations the functions are widely scattered, but such "playing by ear" frequently results in harmonious teamwork, producing effective results. There is a definite trend, however, toward the establishment of individual departments in which all or most of the market research functions are centralized.

Chemical market research is commonly a unit of either sales departments or of technical research and development departments. Some believe it can prosper under a research-minded sales director or a sales-minded research director.

The position of the market research department must be such that it can be a well-informed and independent advisory unit. In general, therefore, the closer it is to management and management problems, the better.

When market research problems involve highly specialized techniques or require a large number of field workers, the supplementary services of consulting organizations may be utilized on an intermittent or continuous basis.

Market research accounts for only a few tenths of one per cent of the income of typical chemical companies, and is undoubtedly equivalent to less than 10 per cent of the budgets for technical research. Both are growing rapidly. With the inevitable postwar return to a buyers' market, competition will accelerate the growth of chemical market research. It will also draw more tightly its many ties with technical research and with sales.

Professional Organizations.—The Chemical Market Research Association, founded in 1940, unites some 125 members drawn from more than 70 companies, in a study of their numerous professional problems. Members, who have important responsibilities in market, economic, and commercial research are drawn from all branches of the chemical and allied industries.

Association meetings have comprised addresses on market research techniques, the status of chemical-producing and chemical-consuming industries, and relations with the several government bureaus with which members are closely concerned. This Association has not only contributed importantly to promoting the professional background and skills of its members, but has also achieved recognition of chemical market research as an important instrument of management.

In a broader and less specialized field, the American Marketing Association is the leading professional organization, covering marketing problems of both consumer products and industrial products.

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GENERAL

Weekly (*W*), Monthly (*M*), Quarterly (Q), and Annual (*A*) publications. If price is given for government documents, order from Superintendent of Documents, Washington 25, D. C., otherwise from the Bureau.

Industrial Marketing magazine. Market Data Book Number (*A*). Statistical summaries and reviews of 85 industrial markets; data on trade journals, trade directories, buyers' guides, catalogue files and similar business reference publications.

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Price List 36—Government Periodicals.

Price List 53—Maps.

Price List 58—Mines, explosives, fuel, gas, gasoline, petroleum, minerals.

Price List 70—Census Statistics of population, manufactures, agriculture, occupations.

U.S. Government Publications. Monthly Catalogue, $2.25 per year.

Selected U.S. Government Publications (semimonthly).

U.S. DEPARTMENT OF COMMERCE

Bureau of Foreign and Domestic Commerce

The Businessman's Bureau (1944). (See also HAHN, A. R.: "The Bureau of Foreign and Domestic Commerce—How It Can Help You," *Sales Management*, September, November, 1943.)

Business Service Check List (*W*). $1.00 per year. Full list of current documents, with convenient order form.

Survey of Current Business (*M*). $3.00 per year. Includes principal figures for the basic industries and trade of the United States, showing comparative changes in production, prices, sales, stocks, distribution, employment, and other factors of business conditions. List of hundreds of sources presented in the supplement, which is normally issued annually.

Domestic Commerce (*M*). $2.00 per year.

Foreign Commerce Weekly. $6.00 per year.

Foreign Commerce News (*W*).

Regional Commerce Bulletin (*W*).

Industry Reports (*M*). Free:

Chemicals and Allied Products.

Drugs and Pharmaceuticals.

Fats and Oils.

Leather.

Pulp and Paper.

Sugar, Molasses, and Confectionery.

Inquiry Reference Service (Synopses of Information). Free.

Industrial Reference Service:

Volume I—14 reports. (Suspended, December, 1941).

Volume III (Publication resumed, 1945)—available in parts covering selected services and commodities. Topical reports and synopses of information.

Part 2: "Chemicals, Drugs and Pharmaceuticals." $2.00 per year, or 5 cts. per report if ordered singly.

Part 5: "Foodstuffs, Fats and Oils."

International Reference Service:

Volume II (Publication resumed, 1945). $2.00 per year, 5 cts. per report if ordered singly. Reports on foreign markets for hundreds of products.

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Rubber: History, production and manufacture, Trade Promotion Series No. 209 (1940). 10 cts.

Bureau of Census

Census of Manufactures (1939):

Vol. 1. General Reports, statistics by subjects.

Vol. 2. (two parts) Reports by Industries.

Vol. 3. Reports by States and Cities.

Catalogues and Indexes:

"Facts for Industry." List of Publications.

U.S. Foreign Trade Statistical Publications:

1. Reports covering calendar years 1941–1944.
2. Monthly reports starting with statistics for January, 1945.

Statistical Abstract of the United States (*A*). $1.75. Contains condensed tables of the statistics collected by government agencies on all forms of activity and progress in the United States.

Facts for Industry Report Series:

Data on production, consumption, stocks, shipments, etc. Most series start with 1941 or 1942. All are free on request.

Chemicals and Allied Fields:

Series No.	
6-2	Chemicals—Synthetic Organic (Order from U.S. Tariff Commission (*M*)).
6-3	Chemicals (selected products of mines, coke ovens and smelters) (*M*).
6-8	End-Use Patterns of Principal Chemicals in the War Program.
M13B	Softwood Plywood (*M*).
M14A	Pulp, Paper, and Paperboard (*M*).
M14C	Census of Pulp Mills and of Paper and Paper-board Mills (*A*).
M15F	Pyroxylin Coated Fabrics and Paper (*M*).
M17-1	Animal and Vegetable Fats and Oils (*M*).
M17-2	Animal and Vegetable Fats and Oils (Q).
M17-3	Cottonseed Products (*M*).
M17-5	Animal and Vegetable Fats and Oils (*A*).
M19A	Chemicals (inorganic) (*M*).
M19A.1-05	Sulphuric acid, statistics and map.
M19D	Superphosphate (*M*).
M19H	Plastics and Synthetic Resins (*M*).
M19J	Paint, Varnish, Lacquer, and Fillers (*M*).
M19K	Plastic-Texture paints, Cold-water paints, and calcimines (*M*).
M19L	Lacquer Sales (Q).
M19M-1	Gelatin (*M*).
M19M-2	Glue and Bone Black (*M*).
M26D	Asphalt and Tar Roofing and Siding Products (*M*).
50-3	Fabricated Metal Products (*M*) Shipments and orders for about 200 classes, including chemical manufacturing equipment.
M75B	Porcelain Enameled Metal Products (*M*).
M77C	Glass Containers (*M*).

Foreign Trade Report Series:

The following periodicals each comprise 12 monthly issues and a yearly issue (single issue prices marked *y*). Yearly subscription prices (13 issues) are marked *s*.

Order by number from the Bureau of Census, with checks payable to Treasurer of the United States. Following titles are abbreviated:

FT-100 Imports. Commodity totals. \$.10*y*; \$1.25*s*.
FT-110 Imports. Commodities, by countries. \$1.45*y*; \$3.50*s*.
FT-120 Imports. Countries, by commodities. \$1.45*y*; \$3.50*s*.
FT-400 Imports. Commodity totals. \$.10*y*; \$1.25*s*.
FT-410 Exports. Commodities, by countries. \$1.50*y*; \$12*s*.
FT-420 Exports. Countries, by commodities. \$1.35*y*; \$11*s*.
FT-800 U.S. Trade with territories and possessions. \$.10*y*; \$1.25*s*.
Foreign Commerce & Navigation of the U.S. Annual volume.

U.S. DEPARTMENT OF AGRICULTURE

List of Available Publications of the U.S. Department of Agriculture (Misc. Pub. 60).
Bureau of Agricultural Economics. Reports and Publications 1944, and supplements (*M*).
Agricultural Statistics (*A*). Comprehensive volume with detailed figures on crops, also data on derived products like vegetable oils and oleomargarine. Statistics on fertilizer and liming materials, data on payments under various control programs.
Naval Stores Report (Q).
Crops and Markets (*M*).
The Fats & Oils Situation (*M*).
The World Sugar Situation (*A*).
Quantity of Wood Treated and Preservatives Used in the United States (*A*).
Agricultural Outlook Charts (*A*).

U.S. DEPARTMENT OF INTERIOR

Bureau of Mines

List of publications of the Bureau of Mines; monthly supplements.
Minerals Yearbook (*A*). Comprehensively covers production of mines, smelters and secondary sources, consumption, prices, foreign trade, inter-commodity competition, and technological developments.
Production of Explosives in the U.S. (*A*).
Weekly Coal Reports.
Monthly Reports (production, shipments, stocks, etc.):
Crude Refinery Report.
International Coal Trade.
International Petroleum Trade.
Mineral Trade Notes.
Cement Report.
Coke Reports (including by-products).
Petroleum Statements.
Natural Gasoline.
and other metals and minerals.
Annual Reports:
Petroleum statements.
Directory of By-product Coke Plants in the United States.
Information Circulars:
7124 Directory of Petroleum Refineries (1940).

7126 Directory of Natural Gasoline Plants (1940).
7062 Marketing of Salt (1939).
7117 The Potash Situation (1940).
7149 Marketing of Barite (1941).
7169 Limestone and Dolomite in the Chemical and Processing Industries (1941).
7196 Crude-Oil and Gasoline Pipe Lines in the United States, May 1, 1941 (1941).
7197 Chalk and Whiting (1942).
7200 Strontium Minerals (1942).
7212 Sodium Carbonate (1942).
7217 Marketing Mineral Pigments (1942).
7225 Marketing Lithium Minerals (1942).
7226 High-Grade Dolomite Deposits in the United States (1942).
7233 Monazite Sand (1943).
7247 Economic Considerations in the Recovery of Magnesia from Dolomite (1943).
7263 Industrial Insulation with Mineral Products (1943).
7266 Graphite (1944).
7269 Marketing Magnesite and Allied Products (1944).
7320 Trends in Consumption and Prices of Chemical Raw Materials and Fertilizers (1945).

U.S. Department of Labor

Bureau of Labor Statistics

Selected List of Publications of the Bureau of Labor Statistics (1941) and Supplement (1943).
Publications of the Department of Labor (1946).
Monthly Labor Review. Presents principal series of labor statistics and discusses developments.
BLS Chart Series (semi-annual) covers principal series of labor statistics.
Handbook of Labor Statistics (1941) Bulletin 694:
Volume I. All topics except wages. $1.00.
Volume II. Wages and wage regulation. 45 cts. General summaries of all major statistical series and digests of reports.
Mimeographed Releases (*M*):
Employment and Payrolls.
Hours and Earnings.
Labor Turnover.
Average Wholesale Prices and Index Numbers of Individual Commodities (also annual).
Index Numbers of Wholesale Prices by Groups of Commodities (Mimeo. Tabulation 14,235).

U.S. Treasury Department

Statistics on Alcohol (*A*) and Comparative Statistics on Domestic Alcohol (*M*). Data on production, consumption, stocks, raw materials consumed; details by states.
Uses of Specially Denatured Alcohol (*A*).

Formulae for Completely and Specially Denatured Alcohol (Appendix to Regulations No. 3).
Tariff Act of 1930 on Imports into the United States. Lists tariff rates and administrative regulations.
Treasury Decisions, etc. (*W*) lists changes in tariff rates.

Securities and Exchange Commission

Survey of American Listed Corporations, 1936–1942 and 1942–1943. Data on Profits and Operations, in five parts. Includes separate sections on chemical, drug, fertilizer, paint, paper, soap, rubber, and other industries. (Write for check-list of available sections or photocopies.)

U.S. Tariff Commission

Synthetic Organic Chemicals, U.S. Production and Sales (*A*). Includes directory of producers of 4,500 chemicals.
Facts for Industry Series 6-2. Synthetic Organic Chemicals (*M*).
Special surveys on many subjects: Cane Sugar (1934), Chemical Nitrogen (1937), Flat Glass (1938), Glue and Gelatin (1940), Rayon Industry (1944), *et al.*
Industries and Reciprocal Trade Agreements reports (1940) and (1941): Leather, Fats and Oils, Petroleum Products, *et al.*
The Commission has issued hundreds of other large and small reports which delineate competition between imported and domestic products.
Subject index of tariff commission publications.

Business Services

Special Libraries Association (345 Hudson St., New York)
"Directories for the Business Man," (1938).
"Guides to Business Facts and Figures," (1937).
"U.S. Government Periodic Publications—A Descriptive List" (1942).
"Handbook of Commercial, Financial, and Information Services" (1944).
"Index to American Petroleum Statistics" (1943).
"Source List of Selected Labor Statistics" (1944).
"Trade Names Index" (1944).

Boyd's City Dispatch, Inc. (114 E. 23d St., New York)
Mailing lists for thousands of business classifications (e.g. dry cleaners, wholesale druggists, cosmetics manufacturers, etc.).

Dun & Bradstreet, Inc. (290 Broadway, New York)
Dun's Review (*M*) and *Dun's Statistical Review* (*M*). Cover industrial and trade activity.
Credit Reports (by special subscription). Provide valuable business information on individual companies, including ownership, names of officers, history, method of operation, financial statements, and credit rating.
Reference Book (*A*). Lists 2,000,000 firms, showing trade classifications, financial, and credit ratings.

Moody's Investors Service (65 Broadway, New York)
Stock Survey and *Bond Survey* (*W*). Include statistics and discussions on general business conditions and positions of specific industries and companies; special analyses and reports on request.
Moody's Manual (*A*), supplemented twice weekly. Consists of the following five volumes: "Industrials"; "Public Utilities"; "Steam Railroads"; "Banks,

Insurance, Real Estate, and Investment Trusts"; "Government and Municipals." While these volumes are essentially reference books on corporate finance, operations, and securities, they contain, for each company, data on sales, plant facilities, location of properties, and products.

Monthly data are published, including an index of potential purchasing power in the United States; "prosperity" index; and an analysis of supply and demand in connection with major commodities, such as copper and automobiles.

Standard & Poor's Corporation (345 Hudson St., New York)

Standard Corporation Records (*A*). Information on operations and securities of 6,000 major corporations: (1) Loose-leaf Alphabetical Volumes, revised monthly. (2) Daily news section, and (3) Dividend section (daily or weekly).

Poor's Register of Directors and Executives (*A*). Lists over 90,000 individual officials.

Also 20 other services for investors, covering all types of securities. Special investigations, such as industrial surveys, management reports, valuations, and reorganization plans.

Trade Directories and Catalogue Services

Chemical Industries (522 Fifth Ave., New York 18, N. Y.)

Chemical Industries Buyers' Guidebook Number (*A*)

1. Chemical manufacturers' catalogue section.
2. Directories of (*a*) chemical companies, and (*b*) equipment and container companies arranged by states and cities, with street addresses and telephone numbers.
3. Directories of manufacturers, importers and dealers: (*a*) Raw materials, (*b*) Chemical products, and (*c*) Chemical specialties. Data on chemical formulas, principal physical constants, trade names, types of containers, uses, and tariff rates.
4. Directory of equipment and container manufacturers.
5. Brands, trade names, and synonyms.
6. Directory of trade and technical associations.
7. Five-year price records of principal chemicals.

Industrial Publications, Inc. (59 E. Van Buren St., Chicago, Ill.)

"Ceramics Data Book": Contains data, arranged in cyclopedic form relative to equipment, materials, and processes employed in the manufacture of ceramic wares (including glass, enamel, pottery, terra cotta, brick, and tile products).

Lockwood Trade Journal Co., Inc. (10 E. 39th St., New York)

"Lockwood's Directory of the Paper and Allied Trades" (published annually): Includes lists of paper, wood-pulp, and chemical-fiber mills; mill equipment, kind of power used, and products manufactured; grades of paper stock and rags consumed, together with the name of the purchasing agent. A section is devoted to the sources of supply for machinery and raw materials used in this industry.

Oil, Paint, & Drug Reporter (12 Gold St., New York)

"The Green Book Who's Who" (published annually): Lists buyers, and sellers in the chemical, dyestuff, drug, paint, oil, fertilizer, and related industries.

Howe Publishing Co., (440 Fourth Ave., New York)

Year Book of the American Association of Textile Chemists and Colorists (*A*): Includes comprehensive directory of manufacturers of dyes and textile chemical specialties, with data on trade names.

Plastics Catalogue Corp. (122 East 42d St., New York 17, N. Y.)
Modern Plastics Encyclopedia: Contains names and addresses of concerns manufacturing and selling chemicals, raw materials, machinery and equipment for the plastics industry. The suppliers of plastic materials, fabricators and molders, products manufactured wholly or in part from plastics and the manufacturers of these, also are included. Statistics, trade names, glossary and technical data.

Printers Ink Publishing Co. (205 E. 42d St., New York 17, N. Y.)
Brad-Vern's Reports (*A*). Index to advertising schedules of 30,000 companies, in 600 trade journals.

Reinhold Publishing Corp. (330 W. 42d St., New York)
"Chemical Engineering Catalog" (published annually in September): Contains catalogue data of manufacturers and producers of chemicals, chemical engineering equipment, general engineering equipment, and supplies.

Thomas Publishing Co. (461 Eighth Ave., New York)
"Thomas' Register of American Manufacturers" (published annually in December): An extensive register arranged alphabetically, by commodities, and geographically. Gives approximate financial rating (size, not credit rating). Brand and trade names.

Ware Bros. Co. (1330 Vine Street, Philadelphia, Pa.)
"The American Fertilizer Handbook" (Published annually under the direction of *The American Fertilizer*). Contains a directory of fertilizer manufacturers; a buyers' guide of the allied fertilizer trades, and lists of fertilizer machinery, factory construction, equipment, and supplies; fertilizer materials, feed-stuffs, brokers, exporters, importers, and commission merchants.

Trade Journals

Chemical Engineering (*M*). Annual statistical and economic reviews. Monthly sections on chemical economics, charts and comments on production and consumption trends, current prices and statistics.

Chemical Industries (*M*). Articles containing statistical and economic information. Monthly supplement on chemical economics and statistics; price quotations.

Industrial & Engineering Chemistry (*M*) and *Chemical & Engineering News* (*W*). Articles containing statistical and economic information. Current prices; market comments; financial notes.

Modern Plastics (*M*). Articles include statistical and economic reviews.

Oil, Paint & Drug Reporter (*magazine*). Current price quotations on thousands of chemicals and allied products.

There are numerous other tráde publications which supply market data in regular departments or special articles, such as *American Fertilizer, Iron Age, Oil & Gas Journal, Coal Age,* and *Soap & Sanitary Chemicals.*

Trade Associations

American Petroleum Institute (50 W. 50th St., New York)
Reports of production and consumption of petroleum and its products.

Bureau of Raw Materials for American Vegetable Oils and Fats Industries (National Press Club Building, Washington, D. C.)
Production and consumption statistics are collected; also, records are kept of world and domestic prices of fats and oils.

Manufacturing Chemists' Association (Woodward Building, Washington, D. C.
Monthly releases, with lists of new publications.
Statistical Report (*M*). Indexes of chemical manufacture and other major industries.
Chemical Facts and Figures. Handbook of chemical statistics (1947).

National Fertilizer Association (Investment Building, Washington, D. C.)
An index of wholesale prices of all commodities, based on 476 price quotations, and giving indexes for 14 groups of commodities, is compiled and issued each Monday for the preceding week.
Trade statistics are issued monthly on production, shipments, and stocks of superphosphate; sale of fertilizer tax tags in 16 states; movements of imports and exports of fertilizer and fertilizer materials; also letters discussing commodity price trends and general business conditions.
An annual review of conditions in the fertilizer industry, discussing sales trends and industry outlook, is published in the proceedings of the annual convention.
Articles on developments in the fertilizer industry, on agricultural purchasing power and related topics, are published in the bimonthly periodical, *The Fertilizer Review.*
Annual data on consumption of fertilizer in each state are published in *The Fertilizer Review.*

Rubber Manufacturers Association, Inc. (444 Madison Ave., New York)
Monthly statistics are compiled on shipments, stocks, and consumption of all crude rubbers and production, shipments, and inventories of automobile tires.

An example of the elaborate statistical services provided by some trade associations is the

U.S. Pulp Producers Association (122 East 42d St., New York)

1. Wood Pulp Statistics "Blue Book" (*A*) Standard reference book, covering all countries.
2. Monthly Statistical Summary. All current statistics.
3. Graphic Supplement (*M*) Charts of above.
4. Pulp and Paper Trends (*M*) Charts of the industry, compared with other industries.
5. U.S. and Canadian Wood Pulp Production (Q) Charts.
6. Pocket Folder Convenient reference, with two years' statistics.
7. Basic Facts. Special data of the War Production Board and Census Bureau.
8. Soda Pulp Reports (*M*).
9. Exchange Statistics (*M*). Data on market pulp operations.
10. Market Pulp Supply and Consumption (Q). Current summary.
11. Sweden's Wood Pulp Exports (Q).
12. Econometric Institute Reports (bi-*M*) Analysis of pulp industry, relationships to economic conditions.
13. Miscellaneous. Special services for members and association committees.

Items 1 and 6 only are available to nonmembers.
For data on other trade associations, see catalogues listed.

National Research Council (Washington, D.C.)
"Industrial Research Laboratories of the U.S." (1946). Facilities, size of staff, principal fields of work.

CHAPTER XII

MARKETING

PART 1. INTRODUCTION

BY CHAPLIN TYLER

Because the products of the chemical and allied industries are so diverse, suitably diverse types of distribution are necessary. Broadly classified, such products are of two types:

1. Industrial products.
2. Consumer products.

Industrial products may be staples, such as acids, alkalis, salts, compressed gases, and solvents; or specialties, such as synthetic resins, synthetic fibers, dyestuffs, wrapping films, and detergents. Consumer products are, of course, those which go to the public in finished form, such as automotive antifreeze, flysprays, ready-mixed paints, amateur roll film, and baking powders.

Staples represent a problem in that the leading brands are practically identical in quality, and price therefore must be identical for identical quality, quantity, and delivery. In such circumstances the source of supply is determined largely by the service rendered or by preferences, which may or may not be based on tangible factors, such as reciprocal and other relationships between buyer and seller. Since the marketing of staple chemicals is so highly competitive, the profit advantage of one producer over another must derive from lower cost of manufacture, better plant location with respect to freight, or lower selling and general administrative expense.

Specialty products, because of their particular properties and uses, require a great deal of sales effort. Such effort may involve technical work directed to proof of the utility of the product. For example, before cellophane was adopted as a wrap for tobacco products, it was necessary to demonstrate a great deal more than visual appeal; it was shown that the product reached the consumer in better condition. In other words, cellophane did not sell itself.

Staple chemicals are sold direct to various industrial users and also through distributors and jobbers. Specialties are sold largely direct to the industrial user for the reason that technical service is such a necessary part of the distributive function. While consumer products are sold to some extent through a manufacturer distributor system, as for example, petroleum products, the greater part moves through such channels as mail-order houses, chains, department stores and independent distributor-jobber-retailer systems.

Whatever the product, or distributive channel utilized, basically sound marketing policies and practices are necessary on the part of the manufacturer. First, it is important that sales be associated closely with manufacture. Thus to the extent that a company's manufacturing operations are split into divisions, it is usually wise to split sales according to the same lines. Just as production is a specialized job requiring concentration for mastery, so sales is a specialized job. The staple chemicals salesman should not be asked to extend his responsibility to plastics, dyestuffs, or paint. Whenever the jack-of-all trades philosophy has been applied to the individual salesman, it has failed.

The statistical aspect of a sales organization may be of some interest by way of orienting the financial and physical aspects of the subject. In a typical prewar year an organization that sold a diversified group of specialty chemicals to various industries comprised 70 salesmen who handled a volume of approximately $14,000,000 per year, or an average of $200,000 sales per man per year. Some 4,000 customers and prospective customers were covered, the larger ones at monthly intervals. The annual volume represented some 140,000 separate invoices. Selling expense amounted to approximately $1,000,000 or 7 per cent, of which $400,000 was technical service expense. Warehouse and delivery expense amounted to $300,000, which was additional to the $1,000,000 selling expense. In a business of this type, conducted on a national scale, adequate warehousing is essential. As a rule orders are not filled directly from factory stocks. Accordingly, a manufacturer may find it necessary to carry a finished-goods inventory amounting to as much as 4 months' output, half of which would be at the factory and half in branch warehouses and en route thereto.

Selling expense varies according to the product, market, and distributive channel. In one type of business, such as staples, it may be 5 per cent or even less. In selling specialties which require considerable technical service, selling expense rarely is as low as 5 per cent; usually it is nearer 10 per cent.

The channels of distribution vary, even with the same type of product. Thus a paint manufacturer may sell direct to large users, such as automobile manufacturers and the railroads, or he may sell to painting contractors and to individual consumers through dealers. Automotive antifreeze is sold largely through distributors and jobbers of automotive supplies, and thence to retailers such as filling stations. Large quantities also are marketed through oil companies and chain stores. Staple chemicals are sold largely direct to industrial users, although the distributor and jobber are important factors in the less-than-carload business. Their function is to assemble and to maintain a wide variety of chemicals, which can be delivered quickly by truck from local warehouse stocks. Even the larger chemical companies cannot profitably maintain complete stocks of their own lines in every industrial center, nor could they usually ship direct from the factory when delivery is required within 24 hours. Thus the distributor and jobber of chemicals perform an essential function.

The distributive channel chosen by the manufacturer depends upon the requirements of the consumer as well as upon the extent to which the manufacturer wishes to go into distribution. Obviously the distribution of antifreeze to five million automobile owners is a wholly different problem from the distribution of potash to five hundred manufacturers of fertilizer and chemicals, even through the dollar volume in both cases may be the same. Thus, because of the diversity of operations, chemical industry utilizes every type of distribution.

Chemical industry also does a great deal of "creative" selling as contrasted with "straight" selling. Cellophane, for example, was sold in large volume only after years of creative effort through which the product was adapted to the specific requirements of the user. The utility of the product had to be demonstrated. Protective properties had to be proved before the product was widely accepted. So well was this selling job done that when the war broke, cellophane was diverted from many civilian uses in order to secure adequate supplies for the armed forces.

PART 2. INDUSTRIAL MARKETING

BY ELMER F. SCHUMACHER[1]

Marketing is one of four basic elements in the business structure. Without attempting to indicate order of importance, because they are equally important, these elements are usually labeled:

Finance.

Production.

[1] Director of Sales, Ammonia Department, E. I. du Pont de Nemours & Company, Wilmington 98, Del.

Marketing.
Research.

All are supervised and coordinated by general management. Without all four elements there cannot be an enduring business.

Obviously, there must be money and money management to operate a business. Likewise, goods must be produced to have any business, and it is obvious that production would be futile without sales. And research is what keeps the business young, alert, and dynamic, abreast of developments.

The Marketing Function Analyzed.—The marketing function in business is an extremely complex thing. The mechanism of marketing is, in itself, complex because it involves, among other factors, responsibility for quality, package design, freight movements, warehousing, and price relationships; but basically, marketing is complex because it is essentially a human relationship.

The marketing function can be considered from three broad viewpoints:

1. The sale itself—the mechanism of the sale.
2. Organization of the marketing function.
3. Qualifications and type of personnel.

These three points of view are fundamental, and it is important to get down to fundamentals, because there are many in industry who for years did not experience the full force of selling. There was no true selling, in the marketing sense of the word, in the six years 1941–1946. It was a "sellers' market," that is, a market in which everything was favorable to the seller, who did little or no work to move goods produced. The only work involved was allocation, and that is not selling or marketing.

Mechanics of Selling.—Starting with the mechanics of the sale, every sale, every purchase goes through four steps:

Attention.
Interest.
Desire.
Action.

The time interval between attention and action may be anything from the seconds involved in the impulse purchase of some bauble to a period of years between the time a purchaser is first attracted, for example, to a fine Cadillac automobile and the time when he feels equal to swinging the purchase; but short or long, every selling or purchasing transaction progresses through those four steps.

Were this book concerned wholly with sales, an entire chapter could be profitably given to each of these steps in a sale. It would be important to study and to understand all the ways and means of gaining favorable attention, all ways and means of creating interest, all ways and means of arousing desire—what motives are involved and how they should be appealed to in order to get action. Each merits careful study and preparation.

Organization for Marketing.—The second viewpoint from which marketing or selling will be considered is that of organization, examining this aspect empirically to determine the "why" of each activity in the organization. There are, of course, a great many varieties and types of selling, ranging all the way from the highly skilled technique involved in selling an intangible but valuable service, through selling a specific commodity or group of commodities, selling at retail, selling at wholesale, and direct consumer selling, such as door-to-door. Fundamental principles, however, are the same, whether the business is automobiles, food products, or chemicals.

The salesman's place in the organization will first be considered. Because the market for the product is not in the office and actually is quite scattered geographically, the salesman has no time to keep his feet under a desk. He must be out working with customers and therefore needs adequate backing up in the office. Inquiries that may come to the office must be handled, suitable replies must be made and referred to the salesman. Orders that the salesman sends to the office, or that come in direct, must be handled and prepared for shipment, which involves selection of shipping routes and preparation of shipping papers. Shipped goods must be invoiced. Clearly then, there is need in the organization for trained sales correspondents, trained shipping personnel, and trained personnel for invoicing and typing. In a large organization, all these staff services become highly specialized and skilled activities. They must be well performed, as the salesman's best efforts will go for naught if the customer is made unhappy as the result of bungling any of these details.

As the salesman and his associates study the time needed to gain attention, to create interest, to arouse desire, and to get action and as they plan ways and means to get maximum efficiency, the need for preparatory work becomes manifest. For the salesman to tackle each prospect "cold turkey," as the saying goes, seems wasteful of time and effort. What is more natural than to condition the customer, that is, prepare in advance some of those steps in the sale. Thus, a carefully prepared letter from the sales office to a list of prospects might pave the way, calling their attention to what is offered for sale, trying to create some interest and even some desire. A more ambitious plan would be a special mailing piece making use of such attention-getting devices as color, typography, and arrangement of space.

Advertising and Sales Promotion.—Obviously, to prevent waste, it is wise to carefully select names of firms or individuals to whom such material is mailed. This takes time and study. It is also worth time and study to determine which features of the product should be emphasized to the prospective purchaser and even, perhaps, the order of presentation of those features. Very quickly, then, a real need is seen in the organization for some individual, or even a small group to specialize in this work of preparation, or what is commonly called "sales promotion." This conditioning of the sales prospect may take on such proportions that it becomes worth while to use space in trade publications or even in national magazines and metropolitan newspapers, or possibly even to use the radio and poster boards. Such effort requires an advertising man or group in the organization.

It should not be forgotten that the primary purpose of sales promotion and advertising is to condition prospective purchasers—to gain favorable attention, to create interest, and to arouse desire. As much of this as possible should be accomplished in advance so that the salesman's call can be made most effective and productive, most efficient in terms of time and effort—to get the order in the shortest time.

Generally speaking, at least in the chemical business, the final step in the sales sequence—action—requires personal contact. The salesman does not always need to be present when the order is placed, but his personal utilization and application of all the forces that have been set in motion are needed to consummate the sale and to put the customer in the frame of mind to place his order with the salesman's firm as his needs arise.

Market Research.—Yet another step taken by many firms to increase the effectiveness of the "field organization," as the salesmen are frequently called, is to study the market for the company's products in terms of such factors as geographical location, types of industries, specific types within industries, and consuming power of various purchasing groups. It is important to study all phases of costs, so that a suitable price structure or pricing system can be evolved for all products. It is often important also to study all phases of competitive situations. Obviously this is done in order to determine where best to apply sales effort and how much. Thus, a market or commercial research individual or group finds a place in the organization. Where such a group exists, it is frequently desirable to assign to it the responsibility for maintaining records of sales and calls, because proper analysis and utilization of all the material contained in such records will often reveal information and data of great value in enlarging volume of sales or increasing the effectiveness of the sales organization.

Technical Service.—There is also growing recognition in many sales organizations of the need for a technical service group. Just how this group functions varies with the sales organization and the type of business. In the chemical industry, the technical service group comprises trained technical men with adequate company and product background so they can act as product experts. They also act as a connecting link between sales and research. They can, and should, when working most effectively among customers and markets, set the direction of product research work.

It is the function of such a unit to evaluate and to bring to the point of commercial exploitation new uses for products already being marketed, as well as uses for new products produced by the company. This evaluation would consist primarily of determining how products can be used; with what processes or materials; the quantity of the product per unit of material or process; and comparisons with competitive materials with which the product will have to cope in the market. They would act as product experts because it seems reasonable that even a trained chemist or chemical engineer—once he devotes himself to selling—finds his time so taken up with the many commercial requirements of sales work that he will occasionally have need for and will welcome the assistance of technical service men.

Sales Management.—Obviously, this whole group of related activities needs direction, hence there must be a sales manager, in some organizations called a "sales director." The sales manager's job is not primarily personal selling; it is the primary function of the sales manager to coordinate all the activities previously outlined and keep them in proper balance. His job can be envisioned as utilizing all these activities to assist him in setting up policies, prices, sales programs, budgets, territories, sales objectives by territory or in total, all of which in turn will enable him to arrange for the recruiting and training of the proper number of salesmen and to set their compensation and to arrange for sales promotion, advertising, and the type of reports he wants.

It is important to consider in connection with any sales program just how the salesman will operate. Will each of the salesmen be assigned a territory and the task of selling all the company's products in that territory, or will each be assigned one product and attempt to sell that one product in a larger territory? Or yet again, shall a salesman specialize in selling all products or a group of products to one or perhaps two industries?

There are strong proponents of each program, but which is best must depend upon several things, as for example, the number of products produced by the company, the number of industries served, the potential volume of business in each industry, and geographical bounds of the business. It should be borne in mind that as a general rule the most effective salesman is one who not only know his products well but is also reasonably expert in the use and the application of those products. This, of course, is an argument in favor of handling sales by industrial groups.

Sales Personnel.—The salesman is the driving front of any business. He is the company's contact with its customers. Indeed, to the customer and to a very important degree to the public, the salesman *is* the company. It follows then that the salesman must be selected with great care and must be just as carefully prepared for his work. What manner of man should he be? Here again, one might elucidate at great length because there are many concepts, depending upon such factors as the type of business, products, and geographical distribution of markets.

The salesman should probably be an extrovert, though not necessarily a pronounced extrovert. However, his interests should be essentially outside himself; he should enjoy being with and dealing with other people.

He must assuredly be a man of high character and strong character. To an important degree he works alone, that is to say, he is not every day surrounded by fellow employees with the same interests, successes, and failures as his own.

He must be emotionally stable. Again, he, in the main, meets successes alone. Do they go to his head? He meets failures alone. Do they unduly depress him? He must not go to either extreme. He must be emotionally stable—well balanced.

It follows then, he must be a good manager of himself, not only emotionally, but in terms of time, effort, and money.

A successful salesman is at heart a pioneer. He is interested in developing new customers, new territories, promoting new products, and setting new sales achievements.

He enjoys competition. His daily work will put him up against all kinds of competition every day of the week. He can certainly be no defeatist, that is, one who thinks "no" means "no." When a customer says, "no," that is when the salesman starts to think and work.

A salesman is a big man—big and tolerant in his understanding of people and their many and varied interests. He knows the importance of little things. He knows perhaps better than anyone that success is made up of many little things done well and that failure too often results from only one thing done wrong.

He believes in action. Faced with a problem, he will do something. After all, he is on his own, and often he just has to do something—right or wrong. The problem is to have himself so thoroughly prepared that his mistakes will be minor and in a minority. And, of course, he must make a good impression and must so conduct himself that he "wears well," that he can call again and again.

Is all this a large order for a man? It is. But that is the challenge of selling, and to find a man who will fill those qualifications is well worth all the time and trouble it takes because, as has been said before, to the customer and to a large portion of the public, the salesman is the company.

Significance of Sales and Selling.—Webster defines sales as a noun: "The act of selling, the purpose, end, or fact of selling." Of selling, Webster says: "The act of making a sale." In the marketing profession, however, selling has literally a hundred or more definitions, depending upon the personalities involved, products sold, markets reached, etc. But, of all the definitions of selling, one of the most provocative is this one:

"Selling is the transfer, at a profit, of goods that won't come back to customers who will." This definition is packed with meaning. "Selling is the transfer, at a profit." That will always remind the salesman that business—any business—must have a profit. A good salesman knows that and consequently never thinks in terms of cutting prices. He reports competitive situations, of course, but he does not, himself, cut prices because that cuts profits.

"Of goods that won't come back." Here again the very essence of good business is emphasized—strict attention to quality. "Quality" goods do not come back. Of course, the salesman does not directly control quality, but he is the one who, in his contact with customers, will know or learn whether the quality of his products is all that it should be.

"To customers who will" (come back). Here is another essential of good selling: Careful attention to all the details of the service rendered customers and careful attention to all details of handling customers. They must be sold so they do come back; a salesman cannot find new customers forever. Reselling is expensive.

Thus, it is clear there is a great deal more than just words in the definition: *Selling is the transfer, at a profit, of goods that won't come back to customers who will.*

Pressure vs. Creative Selling.—Selling is associated in many people's minds with a kind of pressure. Real selling, artful selling, is creative in character, and persuasive—not "pressurized." Pressure is something that comes from without. It tends to extort, bully, intimidate, or otherwise force a sale. It invariably sets up strong opposition, so the effort involved is excessive and wasteful.

Attempts to sell by pressure techniques are, perhaps, exemplified by the remark of a defeated salesman who gave as an excuse for his failure to sell a stubborn prospect, "You can lead a horse to water, but you cannot make him drink." The sales manager's reply was, "Where did you ever get the idea that your job is to make him drink; your job is to make him thirsty!"

For those who are alert, there is limitless opportunity for creative and persuasive thinking, and in fact this is at the very root of the so-called "American way of life," the expanding American economy. It was creative and persuasive when someone transformed the prosaic railroad train into a thing of beauty, streamlined, clean, air-conditioned, all of which resulted in a stimulus to the railroad business—bigger and more profitable sales. Business history is replete with such incidents.

Supply and Demand.—One other thought should be mentioned in conclusion, and that has to do with the much used term, "supply and demand." Demand is not something that springs, unbidden, from the grass roots. Demand is something created out of the intelligent promotional selling of a supply. Demand did not bring the bathtub, the gas stove, the electric range, the automobile, Lucite plastic, or nylon. Nor was there a demand for the newest plastic material, polythene, or a host of other things with which those in research may be working. The creative thinking that went into these products and the persuasive presentation of them created the demand, and thus it must always be except for only occasional short periods in any economic cycle, such as usually follow a war, when the momentum of demands previously created moves those demands ahead of production facilities.

Marketing—selling—is a creative, dynamic, moving force. It can never be static.

Finally, everyone in business has, in the last analysis, only one boss—the customer. No customer, no business; it can be as simple as that. But while the salesman is out there looking after the boss, he needs a team behind him—and a good one.

PART 3. CONSUMER MARKETING

By O. F. Benz[1]

There are about 140,000,000 people in the continental United States, and they need to be clothed, housed, and fed. In addition, they want entertainment and to keep well. Whatever may be the product to be sold, these facts should always be in mind. The difference between "needs" and "wants" also should be recognized. Satisfaction of needs will maintain the population at a subsistence level, but this is not particularly interesting to a substantial percentage of those occupied commercially or professionally.

It is when "wants" are created in the minds of the public and when the public is willing to work to satisfy those wants that the wheels of commerce really turn. Good constructive, informative advertising and selling on products, which properly serve, satisfy in performance, and give pleasure or comfort, are always in order.

Under the subject "Consumer Marketing" two products will be covered, illustrating two common methods of selling chemical products to the consumer. It will be assumed that the manufacturer is launching a new product and has secured either through experience or market research, or both, the following data:

1. Logical users of the product and what quality will serve them.
2. Geographical concentration of users.
3. Channels of distribution.
4. Competition.
5. Price range.
6. Potential volume (which governs size and character of sales organization).

However approached, selling is a complicated process, and in an effort to facilitate discussion, the subject will be considered in two parts:

1. The sale of a chemical for direct consumer general use, such as hydrogen peroxide.
2. The sale of a chemical for a special or prescribed consumer use, such as a sulfa drug.

[1] Sales Consultant, E. I. du Pont de Nemours & Company, Wilmington 98, Del.

Determination of Marketing Policy.—Generally, but not necessarily, such products are sold by different types of business houses. Taking first a common product, which is illustrated by hydrogen peroxide, virtually any manufacturer, dealing with the drug wholesaler or retailer, can produce peroxide in concentrated form, dilute it, package it, using both a trade name and the company name on the label, and market it. The quality is standard and prices do not vary substantially.

The manufacturer can employ several methods of distribution. If the peroxide is the only product made for sale to the consumer through drug channels, the manufacturer may elect to sell his entire production to a single large distributor, and escape practically all selling costs; or the manufacturer might use one or more brokers who will sell the wholesale drug houses on a straight commission, which means a minimum of selling expense. In either case the manufacturer usually will lose control of the product on the first sale and will get no credit from the final consumer for quality or a low price, if either exists, as both these channels prefer that their own trade name or label be used.

Consider now the manufacturer who, through the manufacture and sale of good products at a fair price, has built up a worthwhile reputation. Such a manufacturer would be wasting a valuable equity—public acceptance—if the peroxide were not packaged and directly distributed, especially if other items are available for distribution through the same channels.

In order to determine the proper marketing policy, a manufacturer will consider such fundamental factors as the following:

1. Who uses the product?
2. Why do they use it?
3. Should the units of sale be small, large, or both?
4. Where does the consumer generally buy this sort of item?

Peroxide is a product used by most every one, even though perhaps restricted for use as an antiseptic; and generally speaking, it is not used frequently nor in any quantity in each application. The consumer buys peroxide through the drug store.

That answers the four questions. Of course, there are a multitude of other details, regarding shape and type of container, character and extent of label information, discounts to distributors, per capita consumption, and many others.

However, it has been decided that peroxide is logically sold through drug stores; it is needed only in moderate-sized bottles; it has a limited application of use; and that virtually every family has or should have a unit in the house.

Mechanism of Distribution.—The peroxide is now ready for the market. The manufacturer has a stock on hand. How will it be possible to secure sales to the final consumer as, when all is said and done, the manufacturer has not disposed of his product until it has reached the consumption stage? Selling it to the wholesaler or dealer means little. They merely put it on the shelf and naturally will buy no more until a part or all the shelf stock is sold.

Paradoxically then, the manufacturer has not actually sold his peroxide when it is shipped and billed to the wholesaler, even though it may start to flow through to consumption due to the profit incentive given the wholesaler and dealer, through the medium of trade discounts or mark-ups.

Should the manufacturer wish to develop a larger sale of peroxide than generally follows the conventional pattern of distribution, various types of advertising and promotion will be necessary in order that an acceptance for the product will be built up quickly straight through to consumption. Therefore, before the salesman takes his samples and price list to the trade, or simultaneously with that action, the manufacturer should have under way an advertising and promotion campaign.

There are many reasons for this procedure. In the first place, no matter what may be the reputation of the manufacturer, it must be recognized that the wholesaler and the dealer in the drug industry have all the way from 8,000 to 18,000 different items in stock at all times. The wholesaler and dealer naturally think twice before adding to this vast collection of goods. Generally, an item will not be added until and unless the manufacturer has demonstrated that it has salability, is profitable, and that the demand will be reasonably permanent.

This is a rather roundabout journey to get to the sale of a chemical product, but it is necessary. In fact, to successfully sell an item to the general public whom we know as "the consumer," requires a vast amount of preparatory work and planning and is what might be termed "perpetual motion."

The salesman for the manufacturer has finally started out, and among the items he has to sell is peroxide. He calls on the wholesaler and solicits business in the line of goods he is selling; when this is completed, he brings forth the new unit of peroxide. However, before he can expect an order, he must establish the following things in the mind of the wholesaler:

1. The manufacturer has an excellent reputation and is fully able to make this type of product.

2. The peroxide offered is a high-grade product based on painstaking research and production by the manufacturer.

3. There is a market for such peroxide in the territory served by the wholesaler.

4. The per capita consumption of peroxide in this territory is X units, and the dealers this wholesaler serves should be capable of selling Y units of peroxide per year.

5. Finally then, the manufacturer expects the wholesaler to corral all or a share of the demand for peroxide because of the

- *a.* Reputation of the manufacturer.
- *b.* Quality of the product.
- *c.* Acceptable price.
- *d.* Convenience of package.
- *e.* Consumer demand.
- *f.* Reputation of wholesaler—on which he can capitalize.
- *g.* The amount and character of advertising to be done by the manufacturer.
- *h.* The educational program for wholesaler's salesmen done by the manufacturer either orally or printed.
- *i.* The help the manufacturer's salesmen will give by calling on dealers direct in the wholesaler's name.
- *j.* The profitable venture it will prove to be, profit being the only recognized incentive for commercial activity.

There are other minor points that a capable salesman will utilize to convince the wholesaler that it is to the wholesaler's profit and general advantage to buy, stock, and resell this particular peroxide.

Assistance to the Wholesaler.—The effort of the manufacturer and his salesmen is not completed when the order is taken from the wholesaler—not if they expect to do a real volume of business on their peroxide. As indicated in items *g*, *h*, and *i*, just referred to, the manufacturer expects to give advertising and promotion support to the item. The manufacturer also will enlighten the wholesaler's salesmen regarding the qualities and the advantages of the peroxide to be marketed. Finally, the salesman for the manufacturer, or a special representative, called a "missionary salesman," calls on the better of the dealers served by the wholesaler and in the wholesaler's name endeavors to secure an order. Because of the expense of this activity to the manufacturer, it generally can be done only in the introduction of a new product. The wholesaler's salesman generally has to be depended upon to establish an item with the dealer.

The same general talking points are used with the dealer as were used with the wholesaler, except that even greater emphasis is placed on profit. That is what the dealer is in business for, and that is what he lives on. Increased profit therefore is the basis of the sales presentation, and the salesman endeavors to show why and how those increased sales and profits are possible. The points and the sequence of presentation in selling would be about as follows:

1. Profit per unit times per capita sales times customers served.
2. Investment × annual turnover × unit profit = annual profit.
3. Public acceptance or consumer demand.
4. Quality of product plus acceptable price plus convenience of package.
5. Advertising support—national, local, or store.
6. Reputation and public acceptance of manufacturer.

Assistance to the Retailer.—A further factor in this matter of building volume on new and old items is the activity in the retail store carried on by the dealer generally, but sometimes by the wholesaler or by the manufacturer's salesmen.

Consumers are influenced markedly to buy through their eyes, that is, they are much more likely to buy the things they see or are reminded of than those they have to remember. The location of the stock in the retail store is therefore important; and for the best final results the manufacturer's missionary salesman re-calls on those dealers who have ordered the peroxide to arrange for a proper display of both stock and advertising material. This is so important that the manufacturer goes to considerable expense to supply window displays, counter cards, and other reminder advertising material usable in the retail store. The missionary salesmen spend much of their time encouraging the dealer to continue the use of this display advertising and to keep the product close to the possible customer. As stated previously, both the wholesaler's salesmen and the manufacturer's salesmen when calling on dealers are supposed to initiate and to maintain this activity if there are no missionary men operating in the area.

Summing up then, and to illustrate the complete undertaking, the marketing or distribution process for a consumer chemical product, such as peroxide, comprises the following steps:

1. Proper packaging.
2. Storage and availability in the plant to fill orders.
3. Transportation and delivery to the warehouse, either manu-

facturer's or wholesaler's. If the former, it may again be delivered to the wholesaler.

4. Transportation and delivery to the dealer in original or broken units.

5. Selling, advertising, and promotion.

Functions of the Middleman.—Although the dictionary differentiates between a wholesaler and a jobber, in effect and in standard practice, they are both placed in the category of middleman. In this instance, the middleman receives from the manufacturer bulk quantities of peroxide and generally in a comparatively limited geographical area serves the drug store in either full, standard, or broken packages. Whereas the wholesaler receives two dozen quart bottles of peroxide in a carton, a dealer may want only three or six, so the wholesaler breaks the carton and delivers the smaller amount to the dealer. Naturally, a wholesaler, having a number of dealers who follow the same practice, gradually absorbs the carton of peroxide. In some instances a large wholesaler will receive a full carload of peroxide and will resell it in only full carton units to the dealer.

There is a great deal of controversy as to the usefulness of wholesalers, and many persons believe they are a hindrance in reducing the cost of distribution. Nevertheless they perform essential functions, and no satisfactory substitute has as yet been devised. When some manufacturer thinks that by selling direct to the dealer and thus saving the wholesaler discount he is going to reduce the cost of distribution, he is due for a sad awakening. The manufacturer finds he cannot economically serve any great number of dealers in the small quantities they can afford to buy by shipping direct from the plant. Branch warehouses soon will have to be established at strategic points, and the cost of maintaining such service warehouses many times exceeds the discount the manufacturer allows the wholesaler. The slogan "from the factory to you at a great saving" usually is advertising license, the "saving" being more apparent than real.

Distribution Costs.—It must be recognized that each step in the distribution process costs money, and should no profit be enjoyed by the dealer, wholesaler, or manufacturer, it would still be necessary to add considerably to the cost of manufacture in order to pay the charges accruing during the movement of the product from the manufacturer to the consumer. To illustrate with approximate figures:

Breakdown of Retail Price

Retailer's price of a unit of the product to consumer is......	$1.00
Net profit to retailer..................................	0.10
Retailer's expenses....................................	0.30

The retailer's expenses represent the following items:

Rent.
Labor.
Light, heat, and telephone.
Delivery.
Carrying charges on investment.
Taxes.

BREAKDOWN OF WHOLESALE PRICE

The wholesaler's price to the retailer of the same unit is	$0.60
Net profit to wholesaler	0.06
Wholesaler's expenses	0.12

The wholesaler's expenses are made up of at least the following items:

Rent of warehouse and office.
Labor in warehouse and office.
Light, heat, and telephone.
Selling expense.
Delivery.
Carrying charges on investment.
Taxes.

BREAKDOWN OF FACTORY PRICE

The manufacturer's price to the wholesaler of the same unit is	$0.42
Manufacturer's net profit	0.06
General administrative expense	0.02
Selling and advertising	0.04

This leaves a residual sum of 30 cts. to cover manufacturing cost, which must include the following items:

Materials, fuel, power, containers, and supplies.
Labor.
Depreciation on plant and machinery.
Taxes.
Research and development.

MARKETING OF SPECIAL OR PRESCRIPTION PRODUCTS

A sulfa drug will be used to illustrate another phase of "Consumer Marketing." Such items, generally known as "ethical drugs," are produced by the chemical manufacturer or by manufacturers who generally produce pharmaceuticals, homeopathics, proprietaries, or patent medicines. The chemical manufacturer does not process the chemical; that is done by the pharmaceutical manufacturer.

However, there is a wide difference between the method of selling the ethical drug and the patent medicine type of chemical or drug. Generally speaking, the market for the ethical drug is relatively small, as the incidence of any disease for which a chemical may be used as a cure per thousand inhabitants is seldom over 25 and may be only five or six per thousand. Moreover, the consumer seldom knows about any ethical drug and if he did, he would not know how to use such knowledge.

In former years, the chemical manufacturer would expect the pharmaceutical manufacturer and the ethical medicinal producer to explore the clinical possibilities of a new chemical. Today, however, the initial work in this field is usually assumed by the chemical manufacturer with the result that the pharmaceutical manufacturer who supplies the finished medicine in forms for administration may do only a relatively small part of the promotion and distribution job.

It will be desirable to trace from the beginning the history of a chemical destined to be an ethical drug. Some scientist, as for example, one connected with a chemical manufacturer, after considerable experimentation finds a new chemical, which shows promise of being a cure for a particular disease. Possibly the scientists have been looking for it for years, as for example, a replacement for quinine, or it may have been developed through fundamental research as was penicillin.

Sequence of Development and Marketing.—The sequence in developing and marketing such a chemical is essentially as follows:

1. Discovery of the drug.
   a. Start of research to discover its uses and limitations.
2. Development of a procedure to establish the value of the drug on a commercial basis.
   a. Continuation of research, including:
      (1) Tests on animals (toxicity, physiological effects, dosage, etc.).
      (2) Treatment of humans ("clinical investigations").
3. Submission of the drug to the Food and Drug Administration for approval.
4. Submission of the drug to the Council on Pharmacy and Chemistry of the American Medical Association for approval.
5. Sale of the new drug by the chemical manufacturer to the pharmaceutical manufacturer.
   a. Pharmaceutical manufacturer by direct mail and personal

calls on physicians ("detailing") assists in getting understanding of clinical researches, acceptance and use by physicians.

6. Sale by the pharmaceutical manufacturer to wholesaler.
7. Sale by wholesaler to retail druggist, hospital, etc.
8. Thence to the user.

Research and Development.—As step No. 1, the chemical formula and the physical properties of this new chemical are first charted. Investigation determines its therapeutic possibilities, toxicity, and dosage efficacy. If all reports up to this point are satisfactory, the medical department of the chemical manufacturer then institutes a thorough medical research program.

Step No. 2 is a most involved and important one, and the chemical manufacturer must consequently have highly trained physicians on his medical staff. Clinical study on humans under all sorts of conditions would require a long period of time if only a few physicians had the opportunity of carrying out the work. Under the circumstances, the medical staff therefore makes arrangements with many independent physicians in private practice, research institutes, hospitals, and clinics, so that the action of the chemical can be studied in thousands of cases and in a short period of time.

This second step in the procedure also includes the simultaneous activity of establishing production facilities which might ultimately require an investment of not less than $100,000 and possibly several million dollars. Assuming that laboratory batches of a chemical prove satisfactory, the next move is to operate a semiworks plant.

While this preliminary work is going on, step No. 3 is taken by the chemical manufacturer, who approaches the Food and Drug Administration, a government department responsible for acceptance of the new chemical. The F.D.A. is vitally interested in the toxicity, the label and package insert statements, and the advertising claims of the new chemical. Ideal standards of quality are established by the government against which final commercial production is to be gauged. Once approval has been obtained from the government, commercial production must measure up to the standards decided upon.

Step No. 4 is to submit the new chemical to the Council on Pharmacy and Chemistry of the American Medical Association for approval and listing in the official "Pharmacopoeia," a formidable reference volume used by the medical profession and in which a listing is a "must." There are two other channels open to the chemical manufacturer in publicizing the new chemical—through the printed page and through personal calls on physicians. Both are possible only after selected medical specialists have used the drug in actual cases and are willing to publish their clinical procedure and findings. These articles are then published in the accepted medical journals, which have a wide circulation among professional men. Leaders in the profession, seeking short cuts or improvements in curing ills, may show interest by writing for further information and samples to the author of the article or possibly to the manufacturer.

Products accepted by the Council of Pharmacy and Chemistry of the American Medical Association are advertised in the *Journal* of the A.M.A., which is read by virtually every physician in the country.

Mechanism of Distribution.—Then comes the fifth step: The chemical manufacturer, through publication of scientific papers and widespread professional trade journal advertising, has paved the way for acceptance of the final administration forms that will be offered by the pharmaceutical manufacturers. He sells them the basic chemical and secures their cooperation in publicizing it. The pharmaceutical manufacturers then also widely circularize all physicians and hospitals, and through their sales organizations—known as detail staffs—personally acquaint physicians with the properties of the medicinal.

In the past, general practitioners and even specialists in the medical profession have been somewhat reluctant to adopt new medication, and it has generally taken several years of promotion effort before full acceptance has been obtained. Today, however, because of the vast amount of research and development indulged in before a new medicinal product is made available to physicians and hospitals and because of the stringent safeguards set up by the government, physicians are more inclined to utilize new medicinal agents.

The chemical manufacturer does not rely wholly on the pharmaceutical manufacturer for getting acceptance of the chemical among the profession. The chemical manufacturer also has salesmen, although they do not actually take orders for the drug—they are more punctilious representatives, as it were. These men (and sometimes women) are well educated, well dressed, and quite polished, and have a professional air, if not a medical education. A group of city areas and the more important suburban areas are covered, and most all the top men in the medical profession are called upon. The procedure is to recite the successful case histories and those responsible for them drawing attention to published technical articles and the advertising done by the chemical manufacturer and by the pharmaceutical manufacturer processing the chemical. The doctor is asked to remember this particular chemical when he has a patient with the disease for which it is a cure. Subsequently, if the doctor is impressed, he will specify the manufacturer's drug when prescribing for the patient.

This seems a roundabout way to secure acceptance of a product, but every step is necessary.

The next question would be: "When does the manufacturer actually sell, ship, and bill the new drug?" This is generally done simultaneously with the missionary work previously mentioned.

This brings up step No. 6: The sale of the chemical in its usable form by the pharmaceutical manufacturer to the wholesale drug house. There is nothing unusual in this step, as the particular chemical used as the illustration for this phase of marketing has no legal distribution limitations as do certain narcotics, dangerous poisons, and habit-forming drugs. As pointed out previously, both the chemical manufacturer and the pharmaceutical manufacturer have done a tremendous amount of work in originating, producing, securing the necessary approvals from the government and medical authorities, and the acceptance of the profession, so that the wholesaler has not much more than a mechanical distribution function. The wholesaler's salesmen, regularly calling on all drug stores, hospitals, and institutions make available a wide variety of goods for the medical profession, in addition to the example under discussion.

Step No. 7 is also purely mechanical. The retailer, his pharmacist, or the pharmacist of the hospital or institution, merely waits for a prescription for the drug, which is then taken from the shelf and is put into a convenient package. The prescription department of a drug store carries hundreds of chemicals that must be compounded by the pharmacist before they are usable or useful to the consumer. They are dispensed only on prescription from the doctor. It is evident, therefore, that for any new chemical to proceed smoothly and profitably over this long and tortuous course requires much effort, imagination, originality, and initiative on the part of the manufacturer and the various distributing agencies.

How different then is the distribution and sale of the two chemicals? With respect to sulfa drug, there is no standard identifiable package, no consumer advertising, and no dealer helps, such as counter displays. Everything is done to apprise the professional medical men through publicity and promotion, on the basis that professional guidance is necessary in regard to suitable dosage for the individual length of time it can be safely taken—some medicines have a cumulative effect on some people whereas others do not—and other precautions, which neither the ultimate consumer nor the distribution factors could decide.

Distribution Costs.—Before mention is made of the profit margins enjoyed by the various agencies referred to in this instance, it is desirable to review certain activities of the druggist or his pharmacist:

1. Selecting the chemical from the shelf stock; the sum total of all chemicals carried representing a substantial investment which in too many instances has no appreciable turnover factor.

2. Compounding and making the chemical usable in powder, pill, capsule, or liquid form; package, label, and wrap for delivery. This occupies the time of a trained man, who makes an individual sale—there is no chance for mass production, self-service, or any other labor-saving device.

3. Possible emergency delivery to customer. Generally, 24-hr. service is required of the druggist, which means, under labor conditions today, having three registered pharmacists on the payroll.

It should be evident that no standard can prevail in figuring a selling price on such a commodity, based on raw material cost, turnover, or competition. In most drug stores the prescription department accounts for not more than 10 to 15 per cent of the gross business and even less than that in percentage of net profit to over-all investment. The best that can be said on profit margins for this type of product is from 100 to 300 per cent mark-up, based on cost, not on the wholesale price. Thus, for a prescription, which costs the druggist $1.00 or $1.50, the consumer pays $2.00 to $6.00. This variation in mark-up is due to such factors as size and frequency of sale; special storage facilities, such as refrigeration; rapid deterioration resulting in spoilage; waste; and of course the over-all cost of doing business for the individual druggist.

The over-all cost of operation of a drug store is about 30 per cent, which means a 40 per cent mark-up on the cost of goods. This is not far from the figure shown in most all independent retail store statistics. The answer is that the final sale in the retail store is an individual sale—one clerk, one customer, which is therefore expensive. The wholesaler in turn requires a 20 per cent mark-up over the price charged by the pharmaceutical manufacturer.

CHAPTER XIII

ORGANIZATION

BY CHAPLIN TYLER

When the late Elbert H. Gary was chairman of the United States Steel Corporation, he is said to have remarked that it is just as easy to run "Big Steel" as to run a peanut stand. The judge referred, of course, to the importance of organization as a factor in business administration. Management's job is to see that the right kind of organization is set up and then to maintain the organization in good working order.

Organization is fundamentally the same in all kinds of industry, whether the industry is concerned with steel or peanuts; whether the industry employs thousands of people or few people. Only in complexity and detail does organization vary. Following are outlined the elements of organization, with particular emphasis on chemical industry.

Stockholders.—In order to start a business, operate it, and expand it, someone must put up the money. The suppliers of corporate share capital are called "stockholders." Although a business may be started by a family or some other restricted group, age and growth usually bring about diversification of ownership. For example, on Dec. 31, 1945, the capital stock and surplus of E. I. du Pont de Nemours & Company was $775,520,713. There were 1,688,850 shares of preferred stock outstanding and 11,122,512 shares of common stock outstanding. There were 73,596 common stockholders and 18,543 preferred stockholders.

In this total there were a number of instances in which a stockholder held more than one class of stock. With these duplications eliminated the ownership comprised 87,936 different stockholders. Geographically, this ownership is coextensive with the national boundaries, since the stock is held by residents of every state in the Union and all its important territorial possessions.

Of the 73,596 owners of the company's common stock, more than 90 per cent hold lots of 100 shares or less. The average common stockholding is less than 200 shares. There are substantially a greater number of stockholders than of employees.

More than 37,000 of the company's stockholders, approximately 42 per cent of the total, are women. More than 13,000 stockholders are trustees. About 4,000 stockholders are employees of the company.

Among the larger stockholders are many insurance companies, whose beneficial ownership is divided among a great number of policyholders; a considerable number of investment trusts, educational institutions, hospitals, and charitable organizations, in the continuing revenues of which still broader groups of American citizens have an important interest, so that the above figures substantially understate the actual number of persons who have an interest in the earnings of the company.

Directors.—Responsible to the stockholders and representing them are the directors. The business and property of a corporation are managed and controlled by the board of directors, who in turn may appoint committees having special powers, as for example, an executive committee and a finance committee. Except for financial activities, the executive committee possesses all powers of the board of directors during times when the board of directors is not in meeting.

Officers.—Responsible to the board of directors or to committees thereof, are the executive officers, comprising the president, vice-presidents, treasurer, and secretary.

The activities of the officers vary according to the size, scope, and policies of the organization. In a small company, the president, more likely than not, is in effect the sole executive officer. He is versed in the detail of production, sales, research, finance, and accounting. He designs machinery, calls on customers, dabbles in the laboratory, negotiates loans, and makes cost estimates. He attends conventions, interviews the press, adjusts grievances, writes advertising copy, and executes reports required by state and federal agencies.

In a larger corporation, the president shares authority and responsibility with a small group of officers. Thus, there might be a vice-president in charge of production; one in charge of sales; one in charge of finance and accounting; and one in charge of research, development, and engineering. Except in very large corporations, such officers are active heads of departments.

Departmental Organization.—With increasing size and diversification, the number of officers increases, and the trend is further and further toward specialization. The specialization may be industrial, functional, or both. In the du Pont Company, for instance, there are 11 functional (auxiliary) departments, each of which serves the entire company:

Advertising (Advertising campaigns; preparation of copy; coordination with advertising agency; printing; coordination with sales divisions).

Chemical (Long-range research).

Development (Economic studies and management studies).

Engineering (Design; construction; estimating; engineering research; manufacture of special equipment).

Foreign Relations (Foreign service offices; information service; management of investments abroad).

Legal (Patents; general legal; taxation; trade-marks; real estate).

Public Relations (Press contacts; information service; advisory service).

Purchasing (Market studies; commodity studies; price studies; purchasing).

Service (Industrial relations; personnel; medical; safety and fire protection; real estate; communications; salvage).

Traffic (Procurement of transportation; rate studies; plant location studies; studies of containers and packages; handling claims).

Treasurer's (Accounting; finance; banking; credit and collection; auditing; financial reports).

In addition to these functional departments, there are 10 industrial departments:

Ammonia (Synthetic ammonia, synthetic alcohols, and derivatives thereof).

Electrochemicals (Chlorinated hydrocarbons; cyanides; sodium metal; peroxides; ceramic chemicals; formaldehyde).

Explosives (Commercial explosives and intermediates).

Fabrics & Finishes (Coated textiles; paints, varnishes, lacquers, enamels).

Grasselli Chemicals (Acids, heavy chemicals; wood-preserving chemicals; insecticides).

Organic Chemicals (Dyestuffs, intermediates, and other synthetic organic chemicals).

Pigments (White pigments and dry colors).

Plastics (Nitrocellulose, cellulose acetate, methacrylic, nylon, polythene, and other plastics).

Photo Products (Motion picture film; x-ray film; roll and cut film; sensitized paper; fluorescent screens).

Rayon (Viscose rayon; acetate rayon; Cellophane cellulose film; nylon textile yarns).

Each functional department is headed by a department director, and each industrial department is headed by a general manager.

As indicated by the administrative organization chart, Fig. 1, the general managers and department directors report to the president. Actually, a large portion of the administrative burden is delegated by the president to the vice-presidents. Thus, one vice-president is in charge of advertising, public relations, and sales; another is in charge of research and development; and so on through the list.

In some companies, the industrial operations are organized as subsidiary corporations, in which case the parent company becomes essentially a holding company. Although much can be said for the holding-company scheme of organization, existing tax laws are unfavorable to it.

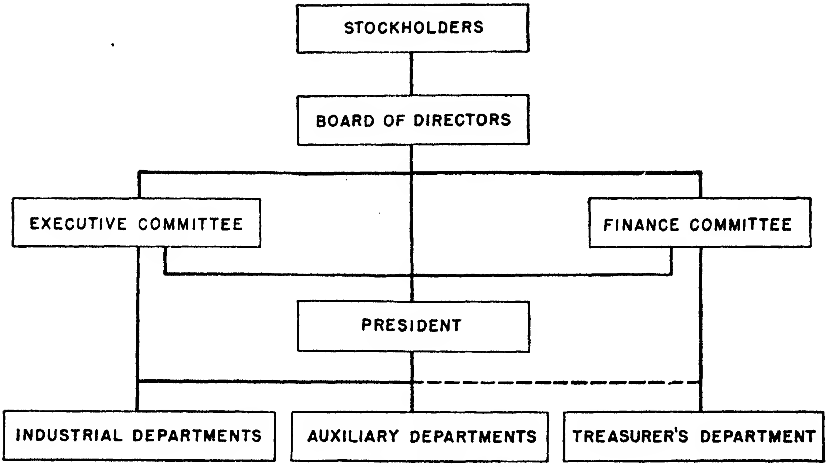

FIG. 1.—Administrative organization.

Functional Organization.—Each previously mentioned industrial department has its own production, sales, research and accounting divisions. Centralization of such functions is increasingly difficult as size and diversity increase. Long experience shows that a compromise between centralization and decentralization yields the best results. For example, in the du Pont Company there are 85 manufacturing plants in 27 states. The nature of the operations varies from the manufacture of box shooks in Maine, dyestuffs and synthetic rubber in New Jersey, acids and heavy chemicals in Ohio, dynamite in Colorado, to paint in California. Obviously, one production director could not properly supervise the operations of 85 plants in 27 states, making thousands of products. Similarly, the scope of sales and research is altogether too broad for one man to supervise. Consequently, a compromise is effected between a functional type of organization and a line type of organization. A typical industrial-department organization is shown in Fig. 2.

In this organization, each general manager has complete authority and responsibility for sales, research, accounting, and production *within his department.* However, the advertising, legal, engineering, and other auxiliary services are provided partly or wholly by the

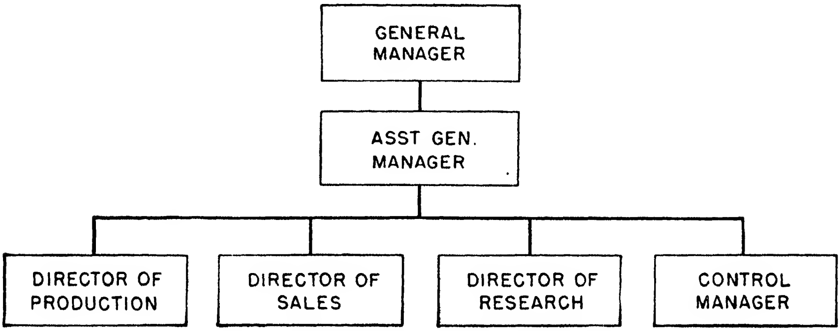

FIG. 2.—Industrial-department organization.

respective functional departments which serve the entire company. The division of work, however, is not carried to extremes. For instance, one plant has a chief engineer and a group of staff engineers engaged in design, experiment, maintenance, and construction. This departmental engineering staff coordinates with the functional engineering department and conforms with the practices specified for the entire company.

Typical organization charts for production, sales, and research are shown in Figs. 3, 4 and 5.

Production functions are complex, particularly in a large plant. This is indicated by the following outline of responsibilities assigned to the top three men—plant manager, process manager, and engineering manager—in an existing operating department. Responsibilities assigned to the sales director and research director likewise are outlined:

Plant Manager:

1. Operates all production equipment in accordance with standard procedure.
2. Maintains all production equipment.
3. Maintains all instruments.
4. Starts up all new production equipment.
5. Assumes responsibility for quantity and quality of product.
6. Compiles records for operating costs.

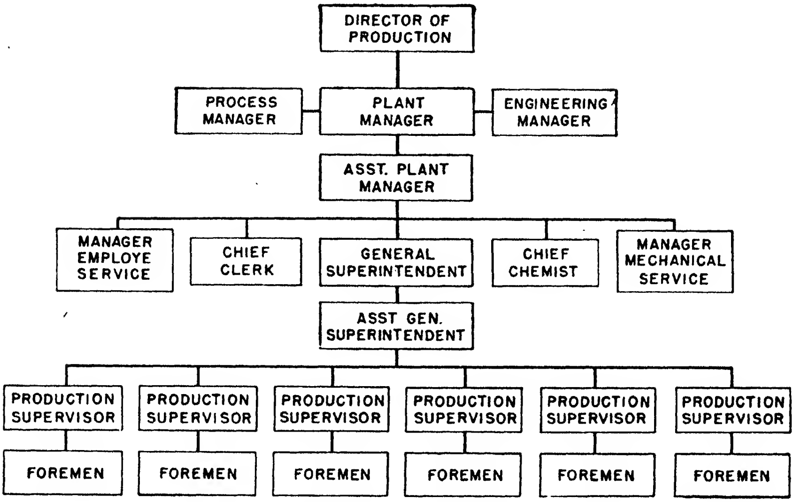

FIG. 3.—Production-division organization.

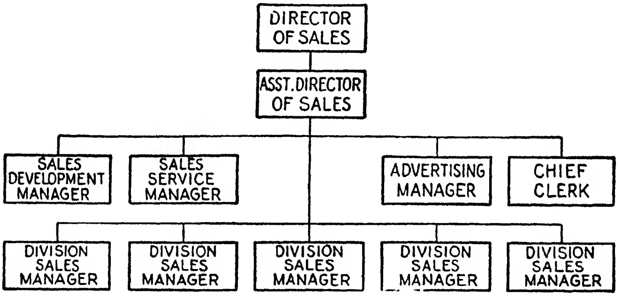

FIG. 4.—Sales division organization.

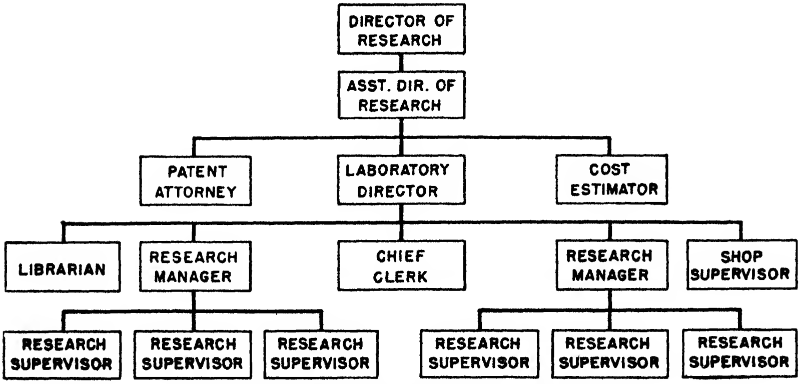

FIG. 5.—Research-division organization.

7. Prepares all operating reports.
8. Maintains storeroom.
9. Gives operating assistance to other departments when making tests.
10. Has joint responsibility for changes in operating equipment and processes.

Process Manager:

1. Compiles technical data on all processes.
2. Makes tests on plant operations.
3. Makes operating cost estimates on new processes.
4. Develops information to determine standard conditions for operating processes.
5. Prepares such technical reports as are necessary.
6. Assists in solving operating difficulties.
7. Assists in starting new equipment.
8. Has joint responsibility for changes in operating equipment and processes.
9. Edits operating manual.

Engineering Manager:

1. Makes improvements in design of equipment.
2. Makes mechanical tests.
3. Makes contact with the company's central engineering department.
4. Prepares construction projects.
5. Prepares construction orders.
6. Makes preliminary drawings and sketches.
7. Makes preliminary estimates on construction costs when necessary.
8. Assists in starting new equipment.
9. Follows details of new construction to insure correct installations.
10. Has joint responsibility for changes in operating equipment and processes.

Sales Director:

1. Makes all sales, whether through home office, branch offices, or distributors.
2. Collects, maintains, and analyzes sales data.
3. Renders technical service to customers.
4. Prepares sales forecasts for use by the director of production and general manager.
5. Prepares competitive sales reports.
6. Prepares sales manual.
7. Trains sales personnel.
8. Introduces new products.
9. Develops new uses for existing products.
10. Makes market research studies.
11. Maintains warehouse stocks at strategic locations.
12. Conducts all product advertising and sales promotion.

Director of Research:

1. Conducts long-range research.
2. Conducts research aimed at improved products and processes.
3. Conducts research aimed at new products and processes.
4. Conducts semiworks scale research.
5. Conducts pilot-plant scale research.
6. Prepares research budgets.
7. Prepares research reports.
8. Assists in prosecuting patent applications and in other patent matters such as licensing and litigation.

9. Assists production department in starting up new processes and in solving operating difficulties.
10. Assists sales department in developing new uses for products and in rendering technical service to customers.
11. Makes preliminary cost estimates for new products and processes.
12. Assists engineering department in plant design.
13. Trains research personnel.
14. Maintains contact with universities, research foundations, scientific societies, and scientific publications.

The foregoing are of course neither complete nor unvarying descriptions of the responsibilities of the three major departments with which this book is concerned—production, sales, and research. But they are typical descriptions, and they indicate particularly the extent to which technical work must be correlated. The production department, for example, must be advised by the sales department regarding the quantity needed of various products and standards of quality. The sales department in turn requires assistance from the research department as to technical service to customers and new uses for products. The research department also advises the production department in a variety of matters, such as the solution of operating difficulties, starting up new processes, and the conduct of plant-scale research.

The final test of organization is the degree of its effectiveness: good organization clearly defines lines of authority and areas of responsibility, expedites action, reduces paper work to a minimum, cuts costs, and lessens frictional disturbances. But the organizational chart itself is only a chart. As the late Arthur D. Little once said, "There is danger in an organization chart, lest it be mistaken for an organization."

CHAPTER XIV

MANAGEMENT

By Chaplin Tyler

Any sound management policy must be based on the fact that there are three parties to the private enterprise system—the consumer, the worker, and the investor—and that the three parties are equal in importance. Management's job is to organize this three-party system, keep it in balance, and achieve maximum productivity from it.

Management of Scientific Personnel.—In chemical industry, the foundation of which is science, the selection, training, and management of the scientific personnel are of paramount importance. Employment techniques are so highly specialized and well developed that there seems to be no advantage in discussing them in this book. However, a word should be said for the advantages of maintaining an orderly succession of recruits from the colleges. The practice of sharply curtailing or suspending employment of recruits in cyclical downswings is bad for both industry and the colleges. It is bad for industry because the chain of succession is broken and because opportunity to employ many deserving men is lost. The adverse effect on the colleges is obvious.

Also to be considered is management policy subsequent to employment. In these days, when team organization in research and development is so generally practiced, it is particularly desirable that each employee be recognized as an individual and that his part in an achievement, however modest, also be recognized. While equitable salary scales, opportunity for advancement, and good working environment are basic requirements for attracting and holding a high type of employee, management should not overlook the importance of recognition, which costs nothing and which may spell the difference between good morale and morale that is only "fair."

Another management opportunity resides in employee training. It would seem self-evident that a scientific employee, who represents an expense of $12,000 or more per year, should receive indoctrination training in company history, policy, and practices, followed by training in the specific function to which he is assigned, be it research, production, or sales. Such training cannot be accomplished wholly by assigned instructors. Management itself must participate.

Product and Process Obsolescence.—Management also is concerned continually with the changing character of chemical industry. Some writers have referred to the high product mortality in the industry. This point has been greatly overemphasized. Products do "die" in chemical industry, but the examples are neither impressive nor numerous. However, products become less profitable after a term of years, and processes and techniques become obsolete. Uses likewise change. More often than not, changes in the chemical economy are foreshadowed by events that provide ample warning against loss.

The nitrogen industry affords an example of the changing chemical scene. The arc process of fixation hardly had gotten under way when, several years later, the cyanamide process was developed. Then, in 1912 the Haber-Bosch synthetic ammonia process was announced. All three processes were developed within the short period of 10 years. Each represented tremendous advances in science, technology, and economy. Despite advantages inherent in the Haber-Bosch process, the arc process continued to operate commercially some 30 years. The cyanamide process, long since in a secondary position, nevertheless by no means is "dead." It is already 40 years old and undoubtedly has some time to go.

In the plastics industry the incidence of new products is particularly high, yet the old products have not been driven out. They merely have been obscured. Thus, there still is a substantial output of cellulose nitrate plastic, which was introduced in 1870; of hard rubber introduced in 1854; and of casein plastic, introduced in 1897. While each successive development among the newer plastics undoubtedly has in some degree lessened the profit and potential consumption of the older plastics, this trend has been evident since 1907 when Baekeland showed that plastic polymers could be produced economically from phenol and formaldehyde.

Importance of Diversification.—Facing the practical certainty that any given type of operation ultimately reaches a low-return area as illustrated by Fig. 1, two conditions, among other more general conditions are essential to the maintenance of satisfactory earnings:

1. Diversification.
2. Periodic addition of new products, or of improvements, within existing lines.

Diversification serves not only to insure against the probability of all lines becoming less profitable at the same time, but to insure against the effect of cyclical variations in consumption. The addition of new products or of improvements serves, of course, to maintain health in any given line of business.

The perils of nondiversification have been pointed out by W. B. Bell, board chairman of the American Cyanamid Company. In the early 1920's the company's operations were restricted largely to cal-

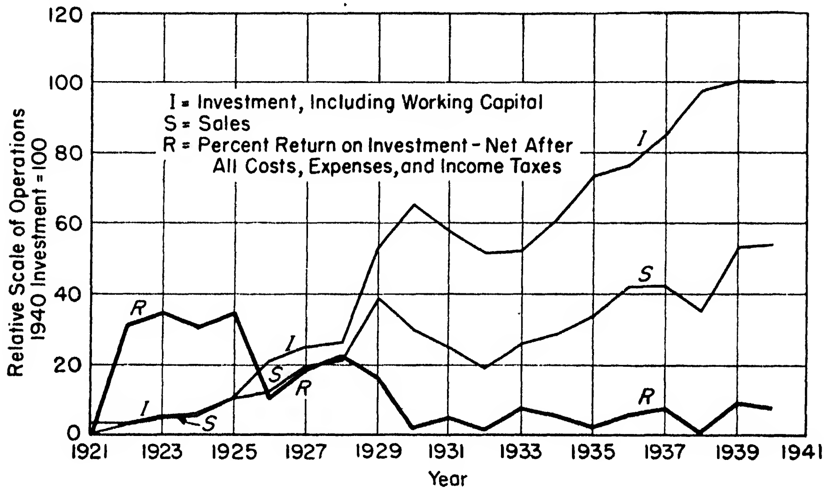

FIG. 1.—Financial history of a chemical venture.

cium cyanamide, which was the basic product, and Ammo-Phos ammonium phosphate both of which were used as fertilizer. At one time, because of depressed conditions generally—and more particularly in agriculture—the Ammo-Phos plant was shut down, and the cyanamide plant was operated at only 14 per cent of capacity. In this instance, the impact was twofold, since both products were used in the same industry. Fortunately the company's financial condition was strong enough to withstand the shock. Subsequently, as is well known, the company became one of the larger and better diversified companies in the industry, both as to products and outlets.

Similarly the du Pont Company was for many years a specialized business. Black powder in its variations was the sole product from the company's establishment in 1802 until 1880. There was some diversification of use—in gunpowders and in blasting powders—and consumption increased with the nation's rapidly expanding economy. Nevertheless black powder was soon to reach its peak. Accordingly, diversification was begun in 1890 when nitrocellulose-base powders were introduced. This program was continued in subsequent years until an established position was achieved in numerous lines. The present business is larger, more secure, and more profitable than would have been possible with single-line exploitation.

Experience shows that the period of high return in any branch of the industry usually is relatively short—sometimes as short as 5 years and certainly no more than 10 to 15 years. Moreover, profits do not as a rule commence with production, even though years of research, development, and semiworks operation may have preceded factory-scale production. Neither are continuing profits assured; there is always the possibility, if not probability, of a severe cyclical decline in general business acitivity. A safe rule is to assume operation at 85 per cent capacity as a probable working figure and to base costs on some such percentage of theoretical capacity. In practice, operations may fluctuate from 50 per cent or lower in severe cyclical downswings as in 1932 to 100 per cent or higher in periods of peak activity.

As a rule, one line of chemical activity leads to another, or to several other lines, so that the logical routes to expansion and growth are reasonably clear. Thus, the producer of a cellulose ester would logically consider modifications of that ester, and as a further step he would consider other esters and perhaps ethers of cellulose. Beyond that point, several steps might be taken: Integration backward to such ingredients as chemical cellulose and acids; forward into such compounded products as films, lacquers, and plastics; or it might be better to develop other types of plastic bases that would broaden the line and would give better diversification. Generally, the sounder policy is to proceed from a familiar field to an analogous field or related field rather than to attempt long jumps into wholly unfamiliar fields.

Acquisition vs. Internal Growth.—When a company undertakes to enter a new field (that is, new to that company) the entrance can be accomplished in one of three ways:

1. Acquisition of an established business.
2. Manufacture of an already established product or products.
3. Development of a new product or products.

Acquisition of an established business has the advantage that the industry's capacity is not increased—nor as a rule would trade lines be upset, as the purchaser normally could expect to retain existing customers. Valuable know-how is obtained, and there is no period of developmental deficits. However, there are disadvantages. Under conditions approaching normal, valuable industries are not for sale at bargain prices. The price asked for the tangible assets plus know-how, patents, and good will may be so high as to preclude a satisfactory rate of return.

The period between the two world wars was characterized by important acquisitions and consolidations, such as the formation of the Allied Chemical & Dye Corporation from the Barrett Company, General Chemical Company, Semet Solvay Company, National Aniline & Chemical Company, and Solvay Process Company. The du Pont Company acquired the assets and business of a number of companies including the Viscoloid Company, National Ammonia Company, Grasselli Chemical Company, Roessler & Hasslacher Chemical Company, and Krebs Pigment & Color Corporation. American Cyanamid Company acquired the Calco Chemical Company, Lederle Laboratories, Chemical Construction Company, and Kalbfleisch. Union Carbide & Carbon Company acquired the Bakelite Corporation. Monsanto Chemical Company acquired the Swann Corporation, Merrimac Chemical Company, and the Fiberloid Company. Libbey-Owens-Ford Glass Company acquired the Plaskon Company. Celanese Corporation acquired the Celluloid Corporation.

Such acquisitions and consolidations have provided greater diversification, increased economies, and strengthened managements. The results appear to have been advantageous alike to employees, stockholders, and the public as indicated by the increased number of jobs provided at extraordinarily good wages and the stability of employment; the equally extraordinary growth of the capital employed; and finally in the variety of new and improved chemical products offered at low prices.

Manufacture of a staple product should be considered only if the growth trend still is markedly upward, indicating satisfactory potential volume and profits; or if substantially lower costs can be achieved, thereby indicating the capture of a satisfactory volume of business.

On the other hand, participation in a relatively new industry that has large growth potential, is quite different from entering a long-established industry. The new field can be exploited by acquiring patents and processes and is equivalent to the purchase of research results ready-made. It was by this method that the du Pont Company entered the dyestuffs field in 1917, viscose rayon in 1920, and cellophane in 1923. However, the rights so acquired by no means guaranteed the success of these enterprises, a fact that should be understood by all who would enter a new field. In the cellophane case for example, large volume and satisfactory profits were dependent upon creating a product of vastly greater utility, that is, moisture-proof cellophane as contrasted with plain transparent cellophane.

Integration.—Integration is a means of expansion. It may be horizontal, in which case industries of generally similar type are grouped together, or it may be vertical, where the sequence of operations within an industry is extended either "backward" toward the ultimate raw materials or "forward" toward the ultimate consumer.

Both types of integration are seen in companies of appreciable size. Du Pont's plastics operations are an example: at one time pyroxylin plastic was the only type made; subsequently other types were added, such as cellulose acetate, methyl methacrylate, vinyl acetals, and nylon. This was horizontal integration. To an important extent the ingredients for these plastics also are produced within the du Pont Company. This is vertical integration.

No rules can be formulated as to the wisdom of integration. The course followed by a company depends upon the circumstances of the particular business. The usual incentive for vertical integration is lower cost (or greater over-all profit). While a large producer of plastics might profitably make its own ingredients, the requirements of a smaller producer might not be sufficient to support large-scale ingredients manufacture. Other factors may, however, play an important part, such as control of quality and greater security of supply. Then again, the manufacture of an ingredient might appear so attractive as to afford opportunity for outside sale as well as meeting internal requirements. Similar factors enter into consideration of forward integration—the expectation of expanded outlets, increased profit, and experience in fields that might afford outlets for new products.

Often as not, good reasons exist against integration. Thus a chemical manufacturer who consumes large quantities of coal might think twice before going into coal production, since, in general, earnings in the coal industry are less than in chemical industry so that his capital would be more profitably employed in the chemical business. Moreover, entrance into an entirely different type of business introduces new problems of management and, usually, new troubles. The same is true of forward integration. A manufacturer who has produced only for the industrial market and who then integrates forward into consumer products finds himself in a new sphere of distribution and sales.

Expansion through Research.—Research is firmly established as an essential function of industry. No longer is there a question whether research should be done, nor is there broadly a question how research should be done. The techniques are well established. The benefits have been demonstrated by thousands of examples. The critical question is one of choice—what lines of research and what specific projects should be undertaken? In dealing with this question, a management can explore the following possibilities:

1. *New Uses for Present Products.*—The value of this type of research resides not only in expansion of a business, by increase in sales, but in a greater degree of diversification. Thus, anhydrous ammonia, at one time used largely as a refrigerant, subsequently became more significant for such chemical uses as in nitric acid, salts of ammonia, and urea. These new applications give greater stability to an industry that otherwise would be much more vulnerable to change.

2. *New Products from Present Materials and Techniques.*—The presence of a material or technique undoubtedly provides tremendous incentive for research. This is illustrated by a company which had developed high-pressure catalytic techniques for synthetic ammonia. Subsequently the same techniques were applied to synthetic methanol.

3. *Demands for a Specific Product or Service.*—With the growth of the automobile industry, various wants were created. In the early 1920's painting was not only costly and time-consuming, but the resulting finish was not durable: Duco nitrocellulose lacquers satisfied the industry's requirements for a quick-drying, easily applied, and durable finish. Ordinary plate glass represented a serious hazard when used in windshields and windows: safety glass was developed. The old straight-run gasolines were fairly satisfactory in low-compression engines. However, when compression ratios were raised, it quickly became apparent that antiknock fuels were needed. This demand resulted in the development of additives for gasoline as well as gasolines that were inherently better.

4. *Unrecognized or Latent Needs.*—The public did not demand air conditioning until long after air conditioning was a proved achievement. But the demand was latent, even though unrecognized by the man in the street. Nylon represents a similar case. Prior to the development of nylon hosiery, silk was accepted as the ultimate fiber for the purpose. Few, if any, consumers even envisioned hosiery having the appearance of silk, yet being several times as durable.

5. *Development of Ideas from Outside Sources.*—A business cannot hope to originate more than a small fraction of the ideas it might exploit. Ideas are the product of creative minds and may originate with big business, little business, a competitor, or an individual having

no business interests. Nearly every sizeable company has at one time or another acquired an idea, invention, or smaller business, which offered promise. Whether an idea comes from inside or outside an organization makes little difference so long as it is sound. Analysis of sales in one chemical company showed that in 1939 half of the business was based on inventions originating within the company, the other half being based on acquired inventions and on free fields.

6. *Improvement of Processes and Products.*—A large part of the research expenditure of any established industry is concerned with improvement studies. The improvement may be minor, such as an increase of a few degrees in the softening point of a plastic, or it may be radical such as the substitution of neoprene for natural rubber in a coated fabric.

7. *Development of Radically New Techniques.*—The various contact processes for sulphuric acid greatly reduced the cost of making strong acid, which previously was made by concentrating chamber acid. Similarly the whole aspect of the alkali industry was changed by the electrolytic cell.

8. *Development of New Raw Materials.*—When nitric acid was made only from nitrate of soda and sulphuric acid, the cost depended not only on the cost of the two ingredients but on the credit from the by-product niter cake. The cost of nitric acid could not be forecast with any degree of assurance. Moreover the nitrate of soda was imported, thus adding another variable to the economic equation. However, the ammonia oxidation technique eliminated all these variables. Neither nitrate of soda, sulphuric acid, nor niter cake was involved in the new process. Only the cost of ammonia need be considered, and this has been a relatively low, gradually declining cost.

9. *Fundamental Research.*—Research undertaken with no immediate practical objective may be termed "fundamental research." Thus, a company engaged in manufacturing derivatives of cellulose might study the structure of cellulose. The objective of such a study would be purely theoretical. Years might elapse before the attainment of any significant results.

Should the research be undertaken in order to discover new derivatives of cellulose, with the hope that these might exhibit useful properties in relation to the company's existing business, then there would be a practical objective. Such research may be termed "pioneering applied research." Thus, the distinction between fundamental research and pioneering applied research is principally one of scope and the extent to which it is limited by recognized practical objectives.

Fundamental research invariably has practical significance. When, in 1869, Mendelejeff postulated a periodic classification of the elements, the mechanical household refrigerator did not exist. But more than half a century later, Midgley and his associates found Mendelejeff's table highly useful in developing the dichloro-difluoromethane type of refrigerants.

In 1928, Carothers began studies of certain linear polymers, and at the time commercial fibers were not an objective. Nevertheless the polyamides that he and his co-workers produced were to become the basis of a whole new industry—nylon textile fibers, nylon monofilaments, and nylon plastics.

The economics of fundamental research have been elucidated by Irving Langmuir,[1] research director of the General Electric Company:

> The road from the scientific principle to its successful industrial application, without which its benefits cannot be given to the masses of our people, is usually long and difficult. To reach the desired goal frequently requires work of high quality and originality and an expenditure of effort far greater than that involved in the establishment of the underlying scientific principle. It is a common experience of industrial laboratories that the cost of research on a problem, up to the point where a patentable invention is made, is only a small fraction of that required to make the invention commercially successful.
>
> One reason why it is not possible for a laboratory to devote a large fraction of its efforts to fundamental research is that any successful application of the fundamental research requires a long period of development before it is ready to be turned over, even to the engineering departments of the company capable of carrying it to the commercial stage. Another reason is the speculative nature of fundamental research. Results may be useful, but not to the laboratory doing them.

Evaluation of Research Proposals.—What happens to research ideas? William B. Bell[2] has answered this question by tracing the disposition of one hundred ideas as they might be handled in his company (American Cyanamid Company).

First, the ideas go before the New Projects Committee. However, 35 of the hundred ideas are so clearly impractical that they merit no further consideration. Thus, 65 of the hundred ideas are passed along to the second stage screening, which comprises two committees—the Research Advisory Committee and a committee of the Sales Division. These committees determine whether manufacture is practicable and if practicable, the probable commercial value.

The surviving ideas then go to a third stage screening, comprising

[1] *Chem. Eng. News*, **15**, p. 188 (1937).

[2] *Chem. Eng. News*, **18**, p. 185 (1940).

the Patent and Abstract Departments where patentability is examined. At the same time various aspects of manufacture and chemistry are searched by another group of readers.

The foregoing procedure comprises the preliminary survey, whereby an additional 50 ideas are rejected in the several committee screenings, making a total of 85 rejections.

The cost of handling an idea is, of course, widely variable. Some require no cash outlay, the cost amounting to several hundred dollars, measured in terms of salary and overhead expense of members of the New Projects Committee and investigators. Bell points out, however:

> . . . a preliminary survey of any real idea is more likely to represent, in salaries, laboratory work. and other expenses, something between $5,000 and $25,000 . . . Is it any wonder that we refuse to pay inventors more than nominal sums for options? Of recent years most inventors with confidence in their ideas regard the good faith and interest proved by our agreement to investigate as worth more than option money.

Some 15 ideas survive the preliminary survey. Each of these ideas is assigned to a seasoned investigator for further consideration. A fundamental study is made of the product and of routes by which it may be produced. Needed information is fed to the investigator by the Reading Division and the Patent and Abstracting Departments. Process possibilities outlined by the investigator are followed up by assistants assigned for the purpose. Such group effort may indicate laboratory-scale studies, followed by transfer of the preferred process to semiworks or even to pilot-plant scale.

The few remaining ideas then go through the "customer evaluation" stage. This evaluation is a two-way process. Potential customers are supplied with samples of the new product together with salient information concerning properties and possible uses. The potential customers on the other hand usually are able to point out deficiencies in the product and to discuss the relative importance of various requirements with the Sales Division representative. These deficiencies must be evaluated and vital ones remedied if feasible.

Regarding the final score of surviving ideas, Bell says:

> "In the Cyanamid Company we are more than delighted if two of the hundred ideas . . . eventually yield any substantial profit. If one in two hundred were to put us in a great basic industry with large profits over a long period of years, we would now be the greatest company on earth."

Research Management.—In this rapidly changing age, an industry that stands still—that is, does no research—actually moves backward relative to other industry. Thus, the value to be derived from research is twofold: first, the value of remaining in business, and second, the value of achieving progress. Research is necessary in order to avoid wasteful expenditures and excessive obsolescence, as well as to develop improvements and new products.

Merely to spend money for research is, however, no guarantee of success; the money must be *efficiently* spent. Of the many elements in the research "equation," choice of problem, caliber of staff, and the kind of judgment exercised in direction undoubtedly are the top ones. How these elements shape up determines whether research achieves the objectives sought, or whether it only contributes to expense.

Top management has much responsibility with respect to the success or failure of research. Particularly essential on management's part is an abiding faith in the essentiality of research in depression as well as in boom periods. The policy of overspending in good years and drastically "economizing" in poor years is as shortsighted as it is inefficient. It is characteristic of the private enterprise system that despite the ups and downs of the business cycle, the underlying trend is always up. A consistent policy of research management will ameliorate the effect of declining volume and price in times of depression while preparing a business for boom-time opportunities.

Under the American patent system, speed is important, in the development of new products and processes, because at best, a great deal of time is consumed in attaining an economical process and in constructing and starting up commercial plant. Years may elapse after the basic patent is issued before profits are realized. A patent is in force for 17 years, but it is doubtful whether a company realizes more than 10 years practical protection before competition is open to all comers.

As Karl Compton[1] has pointed out, the time interval between discovery and sustained profit is at least 10 years. In an address before the same audience, E. R. Weidlein confirmed this view when he said that about 10 years is required to develop a chemical process. These authorities referred, of course, to processes involving new chemistry and technology rather than improvements in existing processes. Examination of a large number of cases shows that about 3 years elapse between discovery and the issuance of a patent. Thus a patent may have been issued 7 years at the time sustained profits begin. This leaves a 10-year period of basic patent protection.

[1] Address before National Association of Manufacturers, New York City, Dec. 8, 1937.

Research is the only means by which this period of protection can be extended. While expanding production as rapidly as seems prudent, research is continued in order to develop improvement extensions and variants of the basic art. Exposure of the investment to obsolescence is, of course, commensurate with the investment. Hence on the one hand, expansion of plant should take into account the probability of early obsolescence; whereas on the other hand, such expansion may be necessary if low costs, and therefore low prices, are to be achieved.

From a management viewpoint, the objectives of research may be grouped as follows:

1. Improvements in process, in quality of product, or in utility of product. Improvement is taken in the broad sense and includes cost reduction; utilization of alternative raw materials; waste utilization; elimination of nuisances, such as dust, fume, odor, and stream pollution; and contributions to increased safety of operations.

2. Additions to a product or group of products, thereby extending and rounding out a field of exploitation.

3. Development of products in new fields.

4. Investigation of new fields of science, without respect to any immediate result of commercial value.

In drawing up research budgets and in reviewing research results, it is a good plan to classify the various projects into some such grouping as the foregoing, in order to maintain proper balance. It is also a good plan to apply an economic yardstick before and during the progress of an applied research project. This will assist management in determining how much emphasis is warranted on a project, when to discontinue work, and when to redouble effort.

This matter of choice is particularly important, since there are normally more ideas for research than can possibly be investigated by any one company. There are briefly two criteria by which the choice is made—first, technical and second, economic. These might be paraphrased by the questions: "Will it work?" and "Will it pay?"

All applied research has one objective—commercial exploitation. Therefore, at the outset, even before any experimental work has been done, some answer to these questions is necessary. Assuming technical feasibility has been established, reasonable initial assumptions are made regarding ingredients, yield, energy consumption, process steps, equipment, and so forth. This establishes a cost figure. However, the profit cannot be forecast until sales price and quantity of sales are estimated by the sales department. Here management may find itself in an economic "no man's land," but some decision must be reached between research and sales. Thereafter, research and production must decide how cost will be affected by volume. Usually this is not so difficult as dealing with prices and volume, since the factors are more tangible.

The importance of re-estimates as the development work progresses cannot be overemphasized. These will indicate when work should be stopped or accelerated, as well as what particular part of the project is economically weak, that is, high ingredient cost, low yields, excessive energy input, high labor cost, low turnover of investment. By-product credits must be conservatively estimated and must not be taken for granted any more than sales of the principal product. For convenient reference, charts should be prepared showing the effect of variations in selling price and plant capacity on rate of return on investment.

Research in Small Business.—The meaning of the term "small business" obviously is relative. In some industries an investment of $1,000,000 would be considered large; in the chemical and allied industries it would be small. An investment of $5,000,000 would be substantial though not large; it could be considered the upper limit of "small business."

How much research can the small business afford? A small business can afford at least as much research, proportionately, as the largest business. Assuming that a research budget of 3 per cent of sales is reasonable for an established business and assuming a unit cost of $12,000 per research man-year, budgets for various scales of operation would be as follows:

Annual sales	Research budget	Equivalent number of research man-years
$ 100,000	$ 3,000	0.25
500,000	15,000	1.25
1,000,000	30,000	2.50
5,000,000	150,000	12.50
10,000,000	300,000	25.00

The tabulation shows that $100,000 of sales will support one research man 3 months per year, or one-quarter of his time on a continuous basis. This is not an efficient way to do research, though it could be done. Sales of $1,200,000 would support three research men on a continuous basis, and such a staff could be fairly well balanced, as for example, one organic chemist, one chemical engineer, and one mechanical engineer. Sales of $5,00,000 would support a substantial research program and a well-balanced staff.

From these figures, one might generalize that up to $1,000,000 sales a company would be better off by having all research done by an outside research consultant organization. Between $1,000,000 and $5,000,000 sales, a company undoubtedly should do part of its research with a permanent staff, the proportion increasing with increasing sales.

Another question frequently raised is this: Is it possible to derive worthwhile results with research budgets as small as $3,000 to $30,000? The answer is yes, provided good judgment is exercised in formulating and in executing the program. The research consultant can contribute a great deal in such circumstances, by advising as to the project or projects most likely to yield good returns. The management of a small business, unless it be experienced in research, may be inclined to select projects which though sound, are beyond its capacity. Or, the small business, with an understandable desire to exercise rigid control of costs may be tempted to employ a novice or even worse, a second-rate man. Nothing could be more ill-advised "economy."

As a business increases in size, say beyond $1,000,000 in sales, it should do part of its research within the organization. Collaboration between consultant and client is facilitated by employees who are qualified to interpret the business to the consultant and vice versa. Moreover, research should be a permanent and organic part of an industry, so that if it were necessary or expedient to change consultants, or discontinue consultant services, there would be no serious loss of function. Finally, an inside research man is needed as potential managerial talent, otherwise the future management might be lacking in technical balance.

A great deal has been said, particularly by self-styled protectors, concerning the welfare of small business. Actually the soundly conceived and well-managed small business needs neither sympathy nor subsidy. It can and does succeed because it is an essential part of competitive enterprise. As Clyde E. Williams, director of Battelle Memorial Institute has said:

> The major difference between small business and big business is one of history. The one has grown either because it is older or has had more business acumen or was more progressive. Small business is really young, potential, big business.

Returns from Research.—How profitable is research? A quantitative answer to this question is difficult, if not indeterminate, since research is only one of various factors contributing to profit.

While research cannot be evaluated with high degree of precision, it is possible to cite research expenditures in relation to profits. Thus, a careful examination was made of eight products which were developed through scientific research. At the time of study, these eight products had been operating commercially a total of 115 product-years, or an average of 14 years. In that time, the cumulative operating profits amounted to eight times the cumulative research expense. It should be emphasized that this ratio is an operating ratio and does not take into account the effect of general administrative expense and federal income taxes.

During these 115 product-years of experience, costs were progressively reduced. Part of this reduction, which amounted to an average of 66.5 per cent, was attributable to economies inherent in increased volume, large units, and production experience. Part, however, was made possible by research. Thus, in any field, improved quality brings about a wider acceptance of the product. Likewise, inherently better technology is bound to be reflected in lower costs.

Obviously a large proportion of research carried out in industrial laboratories shows no profit whatever. It may barely break even, or it may show a substantial loss. Only a superhuman research director could choose projects invariably destined to be profitable. The ordinary mortal must necessarily rely on "percentage," that is, so manage a research program that the promising projects are pushed and the dubious ones dropped before inordinate loss has been incurred. This phase of research closely resembles certain forms of gambling.

Because of the often misleading nature of averages, certain data are presented in Table I concerning the eight chemical developments to which reference was made. The second column from the left in Table I shows the number of years of operation required to attain "normal" conditions, which means sustained production at substantially the projected cost and quantity. The third column shows the number of years of normal operation taken into account in calculating the research expense and operating profit shown in the remaining two columns.

The number of years required to attain normal operation relates to full-scale plant operation. It does not include the time required to develop the product on a laboratory and pilot-plant scale. Products A, E, and G were based on acquired patents, processes, and know-how, which is pointed out merely to show that purchased know-how does not necessarily eliminate all the rough going connected with industrial development.

The considerable range of research expense and operating profit ratios is characteristic of chemical ventures. At any given time, in a broadly diversified business some lines are likely to show extremely good returns, while others are only moderately profitable or may even show losses. As has been pointed out elsewhere, a research expenditure of 2.7 per cent of sales is not unusual (this being a weighted average figure) in chemical industry. Neither is an average operating profit of 22.1 per cent of sales unusual. It is equivalent, after deduction of general administrative expense and federal taxes on income to approximately 13 per cent net on sales and 9 to 10 per cent net return on invested capital, assuming a turnover of 70 to 80 per cent on the total investment including working capital.

TABLE I.—OPERATING PROFIT HISTORY OF EIGHT PRODUCTS

Product	Years required to attain normal operation	Years of normal operation	Cumulative research expense as per cent of cumulative sales	Cumulative operating profit as per cent of cumulative sales
A	5	11	3.7	16.3
B	1	4	1.0	40.0
C	4	11	2.7	39.0
D	4	16	2.2	24.5
E	2	21	3.2	13.9
F	6	6	14.6	0.1
G	2	14	1.8	34.1
H	1	7	2.5	13.5
Average	3½	11¼	2.7	22.1

Research Expenditures.—How much should be spent for research? None can answer that question except in general terms. The simplest yardstick is percentage of sales. Examination of a number of well-established chemical industries for the year 1939 showed a range of 1.4 to 5.3 per cent of sales, the average for ten industries being 3.6 per cent. The corresponding figures for the year 1929 were 0.8 per cent and 5.6 per cent and an average of 1.6 per cent. These figures indicate a substantial increase in the decade 1929–1939 in the "average" research expenditure.

"Value added by manufacture" is a more rational basis for expressing research expenditures, since distortions introduced by widely varying ingredient costs are thereby avoided. However, published reports do not as a rule include the data necessary for such calculations.

It is well established that manufacturing industry as a whole still is far behind the chemical and allied industries in average research expenditure, probably being more than 0.5 per cent of the total value of product. Thus, on a value of product basis the chemical and allied industries appear to spend at least five times as much for research as manufacturing industry as a whole.

Development Activities.—In addition to the evaluation of processes and products which originate in the research department or which originate outside a company, a development department may be called upon to exercise a wide variety of work. It may for example make a continuing study of major raw materials needed by the company. Continuity of supply, long-term price trends, possible alternate materials, and estimates of production cost are a few of the factors entering into such studies.

A development department should also consider broadly a company's growth over the years ahead. In this regard, it is first necessary to define the fields of activity of the company in terms of branches of chemistry or technology, types of raw material, product groups, the extent to which integration is desired, and so on. It is also necessary to set certain financial goals, that is, what rate of return is desired on the invested capital, what proportion of earnings are to be retained in the business, and whether outside capital is to be sought if and when an unusual opportunity for investment occurs.

As a business grows, certain complexities arise, which are not present in the small "one-man" organization. Usually it becomes necessary to create product divisions, each possessing more or less autonomy with respect to research, manufacture, and sales. Invariably, when this type of organization is adopted, need for correlation arises. Some duplication is likely to occur, particularly with respect to sales effort. There may be a tendency also for two or more divisions to engage in the same fields of research. This may happen, for example, when a new field of considerable promise is opened up. The effect is analogous to the oldtime gold rushes in that everyone wishes to stake a claim in the new field. In such circumstances correlation is needed to determine which division of the company is best situated to exploit the field.

Another useful type of continuing effort is the industry study. A chemical company, for example, might study an industry such as the electrical industry in order to ascertain what chemically made materials are consumed, what improvements are needed, and what trends in consumption are indicated.

With the attainment of substantial size and financial stability, a company usually has offered to it various established businesses, which their owners wish to sell. The problem thereby created is much the same as a process or product evaluation, in that such factors as raw material supply, processes of manufacture, costs, markets, and patents must be investigated. There are, however, additional features of the acquisition study that make it somewhat broader than a process or product study. The personnel of an acquired concern should, if possible, be fitted into the acquiring company. This entails examination of scales of compensation, employment contracts, employee welfare plans such as pensions, and contracts with labor unions. Financial condition must be examined, as well as the earnings record over a period of years. Physical properties are evaluated and the state of repair noted. Important customers and suppliers are interviewed as to their attitude in event of a consolidation. However, the value of the business depends in general upon the earnings record, as will be noted in the following section.

Evaluation of a Business.—The theoretical value of a business is its net worth, or book value. Thus, a business should be worth at least its property value. However, in practice a business is evaluated largely with regard to its earning capacity, either as established earnings over a period of years, or as potential earnings. Thus an established business might be evaluated at anywhere between five times and fifteen times net earnings (earnings after federal taxes on income) depending upon the stability and trend of such earnings. The greater the upward trend in earnings, the less the weight given book value, and vice versa. The factors affecting the trend are, of course, extremely important. In general such factors as the patent position, quality, and price of product in relation to competition and capability of the management are significant in determining the direction and velocity of business progress. Special considerations are of course important. For example, the evaluation may easily be affected significantly by mineral resources of particular interest to the acquiring company.

Capital Requirements.—The amount of capital required for a new enterprise will depend on the state of the art and the complexity of the field as well as on the scale of operation. The capacity in turn must be at least that required for economic operation. Undeveloped inventions may require anywhere from a year to a decade to attain large-scale operation—even then profitable operation is not necessarily assured. Capital must therefore be adequate to cover permanent investment in plant and facilities and working capital.

Working capital must be sufficient to withstand depletion resulting from operating deficits, the magnitude of which varies considerably, depending upon the speed with which product of good quality can be manufactured and a satisfactory volume attained. Some idea of these variations can be gained from the following experience with three major projects in widely differing fields of chemical technology:

1. In industry *A* an operating loss of $17,702,000 was incurred over a period of 6 years before profits were consistently earned. The investment at the end of the sixth year was $22,267,000.

2. In another industry *B* of comparable magnitude an operating loss of $2,906,000 was incurred over a period of 7 years. The investment at the end of the seventh year was $26,568,000.

3. In industry *C* an operating loss of $35,000 was incurred in the first year, after which operations were consistently profitable. The investment at the end of the first year was $2,420,000.

Methods of Financing.—The income of the typical chemical business is derived largely from product sales—a simple fact which at times is forgotten by those who are engaged in staff (money-spending) activities. Supplemental income may be derived from dividends from subsidiary companies and other investments, rental of facilities, royalties on patents, fees from contract manufacture, and bank interest. Usually however, the aggregate of supplemental income is small compared with income from product sales.

Out of current income comes all current expense such as cost of manufacture, research and development expense, selling expense, general administrative expense, rents, royalties, and interest on indebtedness. As pointed out in the chapter on cost accounting, cost of manufacture includes among other items, depreciation and obsolescence on buildings, machinery, and equipment. In a diversified, well-established business depreciation will average 5 to 10 per cent per year of the various depreciable assets. This charge also appears on the books as a reserve. Theoretically, an asset that is obsolete or physically worn out may be replaced from the reserve created against it. Practically, excess working capital is reinvested in the business as the time becomes opportune, irrespective of the accounting position of any specific asset.

Chemical companies, while dealing with ventures to which more than average risk attaches, are notably conservative in their financial management. Relatively few of the medium-sized and larger companies in the industry have bonded indebtedness of any consequence.

Because of its policy of plowing back earnings, the typical chemical company retains 20 to 50 per cent of its net earnings for growth needs. However, it may happen that the demand for a company's products and the fruition of its research developments may outstrip its ability to provide new facilities from earnings. In that case, which is characteristic particularly of the early years of growth, capital must be obtained from outside sources.

The usual type of public financing in chemical industry is through the sale of stock, either "preferred" stock, or "common" stock, or both. Preferred stock, as the name indicates, has preference as to assets in event of liquidation, preference as to dividends, and in certain circumstances may have preference as to voting rights as in the event of nonpayment of dividends on the preferred stock. The variations in the details of preferred stock are many, as for example, the price at which the stock may be "called" or liquidated; provision for conversion to common stock at a designated price and date; provision for cumulative payment of dividends not paid currently, and participation in profits beyond the designated face dividend. Further, a company may issue two or more series of preferred stock, each with separately designated provisions.

Preferred stocks meet the requirements of the investor who desires a somewhat higher yield than bond yield but who on the other hand may not desire to assume the greater risks inherent in common stock of the same company. While bond income is more secure than preferred stock income, and preferred stock income is in turn more secure than common stock income, such security is only relative. It may not be valid between securities of two companies: thus investment in the common stock of a well-managed company might well involve less risk than the bonds of a company whose management was not first-class.

From management's viewpoint the form of financing depends a great deal upon circumstances at the time the funds are needed, such as the price of stocks in general, the yield on bonds, and the financial standing of the company. Although preferred stock is senior to common stock, the common stockholder in the well-managed company may actually benefit from a reasonably proportioned issue of preferred stock, since all the profit in excess of preferred stock dividend requirements usually accrues to the common stock. Normally additional stock is sold in order to provide needed working capital or to provide funds for acquisition or internal development; and if the purpose is sound, substantial benefit should accrue to all concerned, stockholders as well as management and employees.

As pointed out by Eberstadt,[1] chemical industry is in a favored

[1] Eberstadt, F., *Chem. Met. Eng.*, **45**, p. 68 (1938).

position with respect to public financing because of the strong growth trend and future prospects. He also points out that common stock is the ideal medium by which to finance long-term projects, although fixed-interest securities may be preferable when the issue is small relative to tangible assets and when interest charges will be small relative to net earnings.

Basic Conditions for Success.—Literally scores of factors may be enumerated as bearing importantly on the success of a chemical enterprise. However, three factors are basic:

1. Sound underlying technology.
2. Adequate capital.
3. Competent management.

Unless the underlying technology is sound, not even superlative effort in other directions can achieve success. The product and process must be "right." If the product is an old one (sulphuric acid, for example), the most advanced technology must be embodied in the plant design and operation. If the product is new, the underlying technology must be inherently sound. Plant design and operating technique may be relatively crude at the start, but refinements will result from experience. Patents must be adequate in order to protect the infant industry in its most vulnerable period of development.

Capital must be adequate. In business, as in personal finance, inadequate capital is a continual source of difficulty. As pointed out elsewhere in this book, approximately $1.50 of capital is required per $1.00 of sales when operating at practical capacity. However, this rule applies to an established, smoothly functioning business. In starting a new undertaking ample allowance must be made for operating expense incurred prior to commercial production and to operating deficits incurred in the period required to attain satisfactory volume and costs. For this reason, the initial production of a new chemical venture preferably should be in a field for which there is an established demand. When this initial production has been put on a profitable basis part of the accumulating surplus can be used to finance new products for which demand must be developed. In this way, profits from the established line can be "sunk" indefinitely in new products without danger of dissipating the capital to the point of failure. Actually, only relatively few new products are independently financed from the test-tube stage to profitable commercial operation; they are developed largely as branches of an established business. In this way, the risk inevitably associated with new products is borne by companies best able to do so.

By competent management is meant management that is experienced in the major functions of research, development, engineering, production, purchasing, sales, and finance and that has demonstrated its ability to conduct an enterprise profitably even under adverse conditions. Competent management also has vision and makes plans for tomorrow while at the same time doing the best it can today. Such plans envision not only new products and improved products, but raw materials supply, adequate finances, and the training of a succession to itself.

CHAPTER XV

PATENTS

By A. R. Plumley[1]

The purposes of the patent laws of the United States are explicitly set forth in Article I, Section 8, of the United States Constitution, which states that "the Congress shall have the power . . . . to promote the progress of science, and the useful arts, by securing for limited times to authors and inventors, the exclusive right to their respective writings and discoveries." It will be seen that the object of the framers of the Constitution was that there should be a stimulus to our people in the expenditure of their time, effort, and money in trying to discover and invent new and useful things by assuring them that should such expended time, effort, and money result in new inventions or discoveries, they would have the right of exclusive control thereover for a limited time, but for a sufficient length of time in which they might realize a reward or benefit for their efforts.

The history of this country since 1790, when the first patent law was enacted during President Washington's administration, shows such a period of intense development of new and useful inventions as to bear out the wisdom of the writers of the Constitution in providing the basis for our present American patent laws.

Definition of Patent.—Under the American patent system, a patent is in the nature of a written contract, between one or more individual inventors and the U.S. Government. Two or more inventors may join in applying for and receiving a patent when the invention is the result of their joint efforts. By this contract the inventor is granted certain rights or privileges in exchange or consideration for such a full and detailed disclosure of how to practice the invention, or how the invention operates, as would enable anyone skilled in the art, or subject matter of the invention, to practice it.

In exchange for this full disclosure of the invention, the inventor is given the exclusive right to prevent others from using or practicing his invention for a period of 17 years from the date the patent is granted.

[1] Manager, Patents Section, Ammonia Department, E. I. du Pont de Nemours & Company, Wilmington 98, Del.

During this period, as in the case of other contracts or property rights, the patentee, that is, the inventor to whom the patent is granted, may dispose of his rights to the patent as he wishes, such as by outright sale or by licensing others to use the invention claimed in the patent.

In actual, physical form, a patent consists of a document made up of a two-page folder of stiff paper within which is contained one or more pages of a description of the invention together with one or more claims. The claims are in the form of relatively short descriptions of exactly that process, composition, apparatus, or the like which comprises the patented invention. This folder, together with the pages of description and claims are bound together with a blue ribbon, the ends of which are sealed with the official seal of the U.S. Patent Office and on the first, outside page of the folder are to be found the patent number, a designation of the type of invention, and the actual grant of the patent with its date, signed by the Commissioner of Patents. There is only one copy of this official Letters Patent, and it is sent by the U.S. Patent Office to the patentee shortly after the actual grant of the patent.

What May Be Patented.—Following the adoption of our Constitution, with its provision for the promotion of the progress of science and the useful arts, a number of statutes were enacted by the Congress, which provided for the establishment of a system for the examination of inventions and discoveries and the granting of Letters Patent. From time to time during the years since 1836, when the United States patent system was established in its present essentials, there have been various changes and amendments in the requirements, the rules of procedure, and the steps that an inventor must follow in order to obtain a patent. Except for one major change in the subject matter that may be patented, there has, however, been no change from the inception of our patent system in those classes of things which are susceptible of being patented. On May 23, 1930, an addition was made to those subjects that may be patented, which provided that anyone "who has invented or discovered and asexually reproduced any distinct and new variety of plant other than a tuber-propagated plant" may, upon payment of the required Patent Office fees, be granted a patent.

Upon payment of the required fees, anyone, if he is the first inventor, whether a citizen of this country or of any other country, man or woman, child or adult, may now obtain a patent if he can convince the U.S. Patent Office that he has created, devised, or discovered something new and useful if it is an "art, machine, manufacture, or composition of matter, or any new useful improvement thereof," or a new and distinct asexually reproduced variety of plant.

There are but few qualifications to this general statement, and they relate primarily to the question of being the first inventor. Thus, it is a condition of the grant of a patent that (1) the invention must not be "known or used by others in this country before" the invention or discovery by the one applying for a patent; (2) the invention must not have been "patented or described in any printed publication in this or any foreign country before" the invention or discovery by the one applying for a patent nor "for more than a year prior to" application for a patent; (3) the invention must not have been "patented in a country foreign to the United States on an application filed by" the inventor "or his legal representatives or assignees more than twelve months before his application;" and (4) the invention must not have been "in public use or on sale in the United States for more than one year prior to his application, unless the same is proved to have been abandoned."

If an inventor should die before applying for a patent, his executor or administrator can make application for a patent and, if granted, it will issue to his executor or administrator. If he should die after applying for a patent, the executor or administrator can intervene, and the patent will issue to such executor or administrator. Similarly, should an inventor become insane, an application can be made by and a patent issued to the legally appointed guardian, conservator, or representative. Finally, the inventor may assign all or part of his invention to another in which case the patent may issue to the assignee if the whole invention is assigned or the patent may issue to the inventor and the assignee jointly if only a part interest is assigned.

Definition of Invention.—Invention must be present before a thing is patentable, and as a consequence the subject of invention is one of the most important in patent law. Because the presence or absence of invention determines whether or not a thing is patentable, if it is also new and useful, more has probably been said and written about what is and what is not invention than about any other subject in the field of patents. However, the fact remains that the question of invention in any given case must be decided primarily in the light of the specific case itself.

As with many controversial definitions, it may be more enlightening to recite first some of those instances wherein invention has been held not to exist, before endeavoring to outline what invention is. Thus, for example, the courts have held that it does not involve invention:

1. To produce a device or thing within the skill of a mechanic or chemist.

2. To produce a change in form or proportion of a device.

3. To substitute inferior for superior materials in making one or more parts of a thing.

4. To duplicate one or more parts of a device.

5. To omit one or more parts of a device.

6. To make a device portable.

7. To substitute an equivalent element in an existing device or thing.

8. To change the relative location of parts of a device.

9. To make an element adjustable.

10. To make two parts integral that had previously been separate and vice versa.

11. To apply an old device or process to an analogous subject, that is, to use a device or process old in one art in a closely related art.

12. To bring together operations or devices and unite them, unless the component parts coact with each other in such a manner as to produce a unitary result, which is not merely the aggregative effects of the individual elements.

With the foregoing examples of what invention is not, it may be easier to appreciate that in order for a device or process to rise to the dignity of invention it must, first of all, be the result of the exercise of the creative faculty and not of mere mechanical or chemical skill. It must be an addition to the general knowledge of something that did not exist before. It must be something beyond that which would be expected of a skilled artisan in his normal, day to day work. Thus, a change in an existing device or thing is patentable if the change produces an unexpected, unobvious or new result, or an old result in an improved or unobvious manner, and is therefore not the result of mere mechanical skill. A new combination, or arrangement of known elements, which produces a new and beneficial result, never obtained before, is invention. If a mixture of elements produces some new and useful result, the conception of the mixture is inventive. A new way of producing an old composition is inventive, if the method is evolved by the use of more than mere mechanical skill. In summary, if a composition, process, or device is new and useful, it is, in general, patentable if the act of conceiving goes beyond the expected, normal mental acts of a person skilled in the particular art to which the composition or process or device pertains.

Patent Office Organization.—The U.S. Patent Office is a separate and distinct branch of our government, within the U.S. Department of

Commerce, which has jurisdiction over the examination of applications for, and the granting of, Letters Patent. The Office is directed by a Commissioner of Patents, in whose name all transactions of the Office are carried on. The U.S. Patent Office is divided into 69 separate Divisions, each of which is headed by a Primary Examiner who is responsible to the Commissioner, and each of which Divisions is responsible for a specific class of the art.

Each Division comprises a number of Examiners, under the Primary Examiner, who have special qualifications of technical education and experience for their work. Often times they are also legally trained. It is the duty of these Examiners to study the applications that pertain to the art of their Division and to decide whether or not patentable invention is present in each individual application.

The numbers and subjects of the Divisions dealing largely with chemical industry and chemical engineering follow:

6. Carbon chemistry.
15. Natural resins, rubber; proteins, carbohydrates and derivatives; heterocyclic compounds; plastics.
19. Liquid and gaseous fuel burners; stoves and furnaces.
30. Automatic temperature and humidity regulation; illumination; thermostats and humidostats; heating systems; ammunition and explosive devices.
31. Hydrocarbons; mineral oils.
32. Gas and liquid contact apparatus; heat exchange; gas separation; agitating; wells; earth boring.
38. Coating processes; coating or plastic compositions; rubber; ornamentation.
43. Medicines; poisons and cosmetics; bleaching and dyeing; explosive compositions; sugar and starch; fluid treatment of textiles; hides, skins and leathers.
46. Concentrating evaporators; fluid sprinkling, spraying, and diffusing; fire extinguishers; liquid heaters and vaporizers; kitchen and table articles.
49. Drying and gas or vapor contact with solids; ventilation; liquid separation or purification.
50. Synthetic resins.
51. Radiant energy; modulators.
56. Electrical and wave energy chemistry; paper making; acetylene; gas mixing.
59. Chemistry; fertilizers; gas, heating and illuminating; heterocyclic compounds.
63. Fermentation; foods and beverages; heterocyclic compounds; oils and fats.
64. Compositions: coating or plastic; fuel and miscellaneous.

As of the year ending in June, 1944, there were pending 49,034 applications, 29,305 patents were granted in that year, and there was then a total of 2,352,550 issued patents. During the Second World War, as in the case of the First, the number of patent applications filed, as well as the number of patents issued, dropped considerably, so these figures for applications filed and patents issued during 1944 do not represent normal peacetime activity in the Patent Office. For comparison, in the last peacetime year ending in June 30, 1941, there were filed 56,578 applications and 41,335 patents were granted.

Patent Office Procedure.—Only a short outline of procedure can be given in a limited time and space, and with only the more important points mentioned in the following discussion, reference should be made to "Rules of Practice in the U.S. Patent Office" for a detailed exposition of procedure. This publication of over one hundred pages is distributed without charge by the U.S. Patent Office, and in addition to lengthy treatment of procedure, it contains also the list of U.S. Patent Office fees for filing patent applications and for other actions occurring during the prosecution of an application.

From time to time inventors have acted as their own attorneys, but this course is not advisable. It is significant that experienced inventors do not attempt it, no matter how well informed they are regarding fundamentals of the patent law. Although they work closely with their attorneys, they work as technical advisers and not as attorneys. Because of the complexity of procedural steps in patent prosecution, it would seem wise to engage qualified legal counsel for, if an invention is worth protecting, it is worth protecting well.

The Patent Application.—The application for U.S. Letters Patent is made to the Commissioner of Patents and is made up of the following parts:

1. The Petition, in which the inventor asks that Letters Patent may be granted to him.
2. The Specification, which contains the following parts:
   - *a.* Preamble, in which the invention and the inventor are identified.
   - *b.* General statement of the nature, purpose and scope of the invention.
   - *c.* Drawings, models or samples, if necessary to understanding of the description.
   - *d.* Detailed description of the invention, including, preferably, examples showing how the invention may be practiced.
   - *e.* Claims, in which are stated the scope of the invention.
   - *f.* Signature of the inventor.

3. The Oath, in which the applicant swears (under oath) that he believes himself to be the original inventor; that to the best of his knowledge and belief the invention has not been in public use, or offered for sale in the United States for more than one year prior to his

application, nor published or patented in any foreign country for more than one year prior to his application.

After the application is prepared it is sent, together with a filing fee of $30, to the U.S. Patent Office where it is given a serial number and filing date, and is assigned to the appropriate Division for examination. The applicant, or his attorney, is notified of this serial number, filing date, and the Division to which the application has been assigned. The Examiner in charge of the particular art of the application then studies the alleged invention and compares it with the disclosures of all previous patents, periodicals, and publications in which pertinent art is believed to exist. At the conclusion of his study of the application and the prior art, the Examiner sends to the applicant, or his attorney, a paper called an "action" or "rejection" in which are set forth: (1) the references that are believed to anticipate the invention; (2) the claims that are rejected; and (3) all the reasons why the Examiner believes the claims are not patentable. Following this rejection or action, as provided by the Rules of the U.S. Patent Office, the applicant must reply before the expiration of 6 months from the date of the action. If no such reply is forthcoming, the application automatically becomes abandoned. In the reply, either the claims (which set forth what the applicant believes his invention to be) must be amended so as to avoid covering the art cited by the Examiner, or an argument must be presented, which shows the places wherein the Examiner's statement of lack of invention or patentability is erroneous. Normally, both an amendment of the wording of the claims and an argument are included in the applicant's reply. This procedure of an action by the Examiner, followed by a reply by the applicant within the statutory period, continues until it is apparent that the Examiner and the applicant can or cannot agree as to a wording of the claims, which does not describe something previously disclosed in the art.

If agreement is reached, the Examiner allows the application, and the applicant is so notified. The applicant then has 6 months in which to decide whether or not he wishes to pay a further fee of $30, called a "final" fee. It sometimes happens that the claims have been so restricted during prosecution that the breadth of coverage, or description of the invention, in the claims does not represent anything of real value to the applicant. In such a case he may decide to abandon the application and may not pay the final fee for a patent. However, upon payment of this final fee by the applicant, the U.S. Patent Office then acknowledges its receipt on a form showing the date when the patent will issue and what its number will be. Normally, this date occurs about one month after receipt of the final fee. It will be noted that the U.S. Patent Office filing and final fees amount to a total of $60, which is the absolute minimum expenditure, without taking into account any services of an attorney and their cost, in obtaining a patent.

On the other hand, if agreement cannot be reached, the Examiner has the right to reject the claims, finally, (this he may do after the second rejection, if he desires). The applicant must then, before the expiration of 6 months from the date of the last U.S. Patent Office action, abandon his application for a patent or appeal to the Board of Appeals of the U.S. Patent Office and, failing to win this appeal, to the Court of Customs and Patent Appeals.

Interferences.—Although it has been stated above that an application, after it has been found allowable, will normally be issued as a patent upon payment of the final fee, there is one situation which alters that procedure, namely, the existence of more than one application pending in the U.S. Patent Office at the same time and covering substantially the same invention. In such a case, a proceeding called an "interference" is instituted in the U.S. Patent Office to determine which of the two or more applicants is the first inventor. This has the effect of holding up the grant of a patent until after the question of inventorship is settled, and it is determined whether or not the applicants are entitled to a patent or patents covering part or all of the invention described and claimed in their respective applications.

Interferences are handled by a separate division of the U.S. Patent Office, called the "Interference Division," which is distinct from the examining divisions which have previously been described. Once an interference has been declared, the Examiner of Interferences requests written statements from the inventors setting forth data regarding their invention, such as when it was first thought of or conceived, when first reduced to practice, and when first disclosed to others, and then the parties give testimony in a manner similar to court proceedings in support of their written statements. Based upon this evidence, the Examiner of Interferences decides which applicant has priority, that is, who first conceived the idea of the invention and exercised reasonable diligence in reducing it to practice, and to this applicant the patent is granted.

Usually interferences are found to exist between allowable, pending applications, but this is not always so, for cases sometimes arise in which a patent covering a given invention has already issued, before an application on the same subject is filed or during the time such an application is pending. In such a case, an interference may be set up between the pending application and the issued patent. If it is found that the applicant has priority of invention over the patentee, a patent is issued to the applicant, and the first patentee must file a disclaimer in which he disclaims from his patent the invention or that part of it to which the later applicant has been found entitled.

Appeal from the action of the Examiner of Interferences may be taken to the same tribunals as in other cases.

Infringement.—Anyone who practices an art or who makes, uses, or sells a composition of matter or a machine for which a patent has been issued and who has knowledge of the existence of the patent, may be held responsible for infringement.

In remedy for the infringement of a patent, the courts may grant (1) an injunction, which prohibits the infringer from continuing the infringement, (2) recovery of damages, profits, or a reasonable royalty. Injunctions may be preliminary (pending a final decision of the courts) or permanent. Damages may be awarded when the plaintiff can show that the infringement has caused a definite loss of business profits which otherwise would not have been suffered. Profits may be awarded when the plaintiff did not suffer a loss in his own business, but when he can prove that the defendant, by virtue of the practice of the patent has made certain profits or savings. When the plaintiff cannot prove the exact amount of profits or savings made by the defendant, but can, however, prove that the profits or savings are substantial, the award may be a "reasonable royalty," that is, such an amount as the defendant could reasonably have been expected to pay the plaintiff for the use of the patent under a royalty agreement.

In the event that the defendant has infringed deliberately and without any substantial defense, the plaintiff may be awarded in damages as much as three times the actual loss proved.

As in the case of court proceedings in general, a suit for infringement and its defense are often lengthy and consequently expensive. It follows, therefore, that before bringing suit against an infringer, the patentee should be very sure of his ground with respect not only to the infringement itself but also with respect to the strength and validity of his patent. The assumption always is, of course, that a patent is valid, but it is always possible that the prior art search in the Patent Office failed to disclose actual, existing anticipations that would invalidate the patent. It must be remembered that one of the requisites of patentability is that the invention has not been known before and if anticipation actually does exist, even though not found by the

U.S. Patent Office, the patent may be invalid. The consequence is that in case of an infringement suit, it is best to have made a careful validity study by competent counsel before proceeding with the suit. Similarly, the defendant will, if he is wise, have made an exhaustive validity study so as to question the strength of the patent, if he can, by using as his defense a claim of invalidity of the patent due to the existence of art that clearly shows that the invention was known or used before the application was filed, which resulted in the patent.

Notebook Records.—In our consideration of inventions and the patent system that exists for the purpose of encouraging and protecting them, it has been apparent that establishment of the dates of invention is of great importance. Dates of conception and reduction to practice of an invention are important, not only in case of an interference with adverse parties while an application is pending but also in enforcement of patent rights after a patent has issued, in the case of infringement. It follows, therefore, that care should be taken in making and preserving suitable records, which show how the invention was made, from its conception through its successful reduction to practice.

Too frequently, technical men regard the keeping of records, such as laboratory notebooks, as a necessary evil arising merely from the ultimate necessity of writing a formal report. However, such records are very important for one can never be sure beforehand whether an idea or an experiment will subsequently be the subject of a patent application and, in such case, whether or not the application may be involved in an interference or, as a patent, be involved in litigation. In either case, the proof of conception and reduction to practice is a matter of prime importance in which the character of the original records is critical. The only safe practice, therefore, is to keep all technical records in accordance with standards which patent considerations make necessary.

The following rules for keeping research notes have been found to be satisfactory:

1. Write all research notes in ink and in bound notebooks.
2. Enter all notes in chronological order.
3. Sign and date the notes at the end of each day's work.
4. Keep the notes in a secure place at all times.
5. Review the notes and related work once a week with a responsible person familiar with, but not personally interested in, the particular research under question, and have the person sign and date the notes after each weekly conference.

The purpose of rule 1 is to make for permanency and to minimize the chances of loss of the notes. Ink lends to the evidentiary value of notes, because ink is not easily erased, and erasures are always regarded with suspicion. Loose-leaf notes are unsatisfactory, because of the possibility of loss and the ease with which pages may be substituted.

The purpose of rules 2 and 3 is to enable the attorney to establish that the work was always done in the order noted, and on the dates alleged, and by the person alleged to have done the work.

Rule 4 is not only a common-sense custom, but valuable because an attorney is always faced with proving the custody of any documentary evidence offered in court.

Rule 5 enables the attorney to establish corroboration of the invention. A corroborating witness must be disinterested (one of several joint inventors is of no value for this purpose) and intelligent (that is, capable of understanding the invention and remembering at some later date that it was explained to him in considerable detail).

An inventor in an interference must prove his conception of the invention by his own testimony and the testimony of at least one corroborating witness. Conception is mental visualization of every element of the invention with sufficient clarity to enable the inventor to explain the invention to someone else. The inventor is also required to prove that he has reduced the invention to practice. Reduction to practice is successful operation (of a process or machine) or identification or use (of a composition of matter). The inventor's evidence of reduction to practice must be supported by the testimony of at least one corroborating witness. Because of the necessity of proving both conception and reduction to practice, a technical man should report in his notes and have witnessed, not only actual work performed, but also any inspiration or conception that may occur to him.

Licenses and Royalties.—Earlier, mention has been made of the fact that once a patent has been granted, the patentee may treat his patent more or less as any other property or property rights, selling it completely or in part if he so desires. As a matter of fact, however, the most common procedures are for a patentee either to assign his patent completely, such as in cases where an employee-inventor has so previously contracted with his employer, or to license others to use his invention. An assignee of the whole invention, such as an employer, may also license others to use the invention. In such cases, the license may be the grant of the exclusive or a nonexclusive right to practice the invention. In the first case the licensee is the only one who can thereafter practice the invention, whereas in the second case the patentee has, in effect, reserved the right to give licenses to others if he so desires. The main difference between an exclusive license and an outright assignment resides in the usual reservation to the licensor of some contingency upon the occurrence of which the licensor may terminate the license.

In both exclusive and nonexclusive licenses, it is usually provided that, in consideration for the right to practice the invention, the licensee will pay a sum of money to the licensor. Because an exclusive license, as its name implies, gives so much more of the patent rights, the consideration required for this type of license is greater than in the case of nonexclusive agreements. This consideration is called a "royalty" and it may be a lump sum or, more frequently, a rate of payment, based upon the quantity or the number of pounds of material produced under the claims of the patent. Frequently the consideration in a license may be a combination of a money payment by a licensee, together with the right (or cross-license) given by the licensee to the licensor to employ an invention of a patent, which the licensee owns. Thus, as an illustration, one inventor may have a patent covering a plastic as a new product and then a second patent may issue, to a second inventor, which covers an improved method of making this plastic. In this case the first inventor might not be able to make the plastic so cheaply as the second inventor because he could not use the second inventor's improved process. On the other hand the second inventor could not make the new plastic because the first inventor has it covered by a product or composition of matter claim. If both parties wish to make the plastic in the improved manner, it is necessary for them to cross-license one another under their respective patents.

The rates of royalty must depend upon the facts of each case, but it might be well to keep in mind that 5 to 6 per cent of the net sales price of an article is generally accepted as not being an unreasonable royalty.

Employer-employee Relationship.—A patent is valid only when issued to the actual inventor and, therefore, an employer can have no title in a patent of his employees except by assignment. Thus, the fact that an employer hires an employee to work in a certain field and to invent a specific thing does not make the employer an inventor.

The employer does, however, have certain rights in the inventions of his employee. For example, when an employer has conceived an idea and then hires a technical expert to reduce the idea to practice, the employer is the sole inventor. Or, where the expert is hired to aid the employer in working out or in discovering how a certain thing may be done, the employer and the employee may be joint inventors.

Again, when the employee is hired for the express purpose of making an invention, he is bound to assign any patent on such invention to the employer.

Usually, the relations of research personnel to the employer are defined by written agreement, in so far as patent rights are concerned. When, however, an employee has no agreement with his employer respecting patent rights and the employee independently makes an invention while using the facilities and time of his employer, then the employer is entitled to a free, nonexclusive license to use the invention. Such a right is called a "shop right." Except for this shop right, however, ownership of the patent resides in the employee.

Government employees have, in general, the same rights as those employed by a private corporation or firm, although they have an added privilege in that they may obtain a patent without the necessity of paying the usual required fees, if a statement is filed with the patent application relating that the U.S. Government may use the invention royalty-free.

Negotiation of Inventions.—An inventor, working independently, need have no fear as to his rights and as to his proper course of action, provided he has competent counsel. He will be advised how to apply for a patent, how to protect his rights as a patentee, and how to negotiate assignments and license agreements.

It is customary, in the case of the larger corporations, to have employment agreements executed between the salaried employees and the corporation providing for the assignment of patent rights to the corporation in the case of inventions made by the employees. These rights are usually described as comprising all patent rights, thus including the foreign as well as United States patent rights.

Contrary to popular belief, the large corporation, perhaps more often than the independent inventor, needs to be watchful when negotiating inventions. A large corporation operating in a technical field, such as chemical manufacture, is likely to have many inventions offered to it by independent inventors. The matter would be very simple if such offers were made only to the corporation's attorneys. Usually, however, the individual starts to negotiate or discloses his invention to some employee outside the corporation's legal department. If he does so before securing his patent or before filing the application, the corporation may find itself in an embarrassing situation. Not infrequently ideas are conceived simultaneously, or nearly so, particularly if the field of the invention is active. Thus, the corporation may have offered to it or disclosed to it, an invention identical with, or similar to, one already conceived but not yet embodied in a patent application. In that case, the individual might readily conclude that the corporation had appropriated his invention.

In the interest of the individual and of the corporation, inventions should not be negotiated until they are protected properly. The employee of the corporation, when approached by an individual who desires to negotiate an invention should refuse to listen to a disclosure of the invention until he is satisfied that the one disclosing the invention is protected by a patent application or by an issued patent.

Foreign Patents.—Frequently, inventions are of such importance that the owner of a patent covering them may find it desirable to obtain protection in countries outside the United States. The importance of such inventions is a relative one, however, and studies of the economic value of the given invention should be made before deciding upon foreign patent protection. Normally, this is a matter requiring the services of foreign trade experts.

Most of the countries of the world have joined together in signing an agreement popularly called the "International Convention," which reciprocally gives to the citizens of those countries who have signed this agreement the benefit of the filing dates of applications in the country where the application is first filed, provided filing in the foreign country is made before the expiration of one year after the inventor files in his own country. This Convention makes it possible for an inventor to obtain protection in foreign countries even though his patent issues in another country first. If it were not for the Convention, a year after a patent issued in one country, it would act, generally speaking, as a bar to the grant of a patent in other countries.

The preparation and filing of foreign applications is generally handled by experts in foreign patent prosecution, and several large legal firms devote practically all of their time to study and practice of International patent law.

Official Gazette.—After the final fee has been paid and a patent application has been allowed, it is scheduled for issuance on the fourth Tuesday after the Thursday following the day on which the fee is received, and it is then published in the next *Official Gazette* of the U.S. Patent Office. This publication, which is available from the Superintendent of Documents, Washington, D. C., is printed on each Tuesday and may be obtained at 35 cts. per copy or for $16 per year, including an annual index. In the Gazette will be found a description of all the patents, indicated by number, which issue on the date of the Gazette, in the form of a representative claim together with a reproduction of the patent drawing, if any. Also included are notices from the Commissioner of Patents; lists of adjudicated patents and recent, important court decisions in patent and trade-mark cases; lists of patents which have become involved in litigation; and a register of patents available for licensing or sale.

This publication is a necessity for those who need to keep up to the minute with respect to new inventions, and it is the usual practice for patent attorneys and interested inventors to go through the Gazette each week for the purpose of noting those patents bearing upon their particular fields of interest. Copies of the patents listed may be obtained from the Commissioner of Patents at 25 cts. per copy.

Foreign countries have weekly publications corresponding to our *Official Gazette*, in which may be found listings of the foreign patents as they issue.

Anti-trust Laws.—Much has been said and written, particularly during the past 10 or 12 years, which is critical of our patent system. The gist of the criticisms have been to the effect that (1) the patent system and the antimonopoly laws are in conflict; (2) there are grave misuses of our patent system in creating monopolies; and (3) because of the foregoing, the patent system should be abolished. Actually, the flood of discoveries and inventions promoted by our patent laws has raised our country to the top among nations; and the criticism of these laws is based, in large part, upon (1) an unclear or erroneous understanding of the nature of patent rights; and (2) a desire by certain individuals to tear down anything in connection with which the word "monopoly" has ever been used.

Before examining the question of conflict between the patent and antimonopoly laws, it would be well to outline briefly what these antimonopoly laws are. The Sherman Act, which prohibits any act in restraint of trade, and the Clayton Act, which prohibits any act that tends to lessen competition or to create a monopoly, are the two laws of the land, which are loosely referred to as the antimonopoly laws.

It is unfortunate, but true, that the rights granted by a patent have been characterized by writers and the courts as being "monopolies" or "patent monopoly." This is so because the patentee has the power, for a limited time, to restrain others from practicing his invention. However, the patentee actually has no more a monopoly than the man who owns an automobile and can prevent others from using it, and the term "monopoly" should no more be employed in the description of patent rights than in the case of other property, such as the automobile.

Furthermore, the ownership of the patent is much more limited (a maximum of 17 years) than in the case of other property and, importantly, nothing has been taken away from the public by a patent grant, which the public previously had. As a matter of fact, the reverse is true for, by the grant of a patent to an inventor, the public is *given* the discovery or invention, after 17 years from issuance of the patent, which the public would not have had were it not for the patent grant. It can thus be seen that there is no *conflict* between the antimonopoly and patent laws. However, when property is employed in a manner such as to restrain trade or to create a monopoly which by itself will restrain free trade, then the antimonopoly laws are broken and there should be prosecution and punishment of the infringer.

With respect to patents, then, the antimonopoly laws come into play only when the patent owner uses his patent in such a way as to restrain trade *outside and beyond the restraint to which he is entitled by reason of his patent.* Thus, for example, if a patent owner enters into a contract which restricts the activity of other individuals and the restriction or right to restrict is not inherent in the patent grant, then the antimonopoly laws have been infringed, and he is liable to prosecution thereunder. For an able and comprehensive discussion of the antitrust laws with respect to patents, see "Patent Property and the Anti-monopoly Laws" by Otto Raymond Barnett.[1]

Significance of the Patent System.—The American patent system offers rewards to the inventor and to those who back him. The public benefits from the many new and useful products thus developed, and from the lowered cost and improved character of old products. New industries are created, and immense numbers of workers receive profitable employment. Finally, upon the expiration of the patent, any member of the public can use the entire invention free from the rights of the inventor and his assignee and can enjoy its benefits indefinitely.

The present system has encouraged invention and has made it possible for the individual inventor safely to disclose his idea to those who are in a position to help him develop it. Were it not for this protection, the stimulus to invent, which now exists, would be lessened considerably. The great difficulties that would face the inventor—limited resources, inadequate facilities, the problem of maintaining the secrecy of the invention and trying to keep others from profiting at his expense during the development of his idea—would tend to dis-

[1] "Patent Property and the Anti-monopoly Laws," The Bobbs-Merrill Company, 1943.

courage invention and thus would deprive the public of countless necessities and luxuries, which it now enjoys because of the incentives created by the patent system.

The following is a list of leading authorities for those who wish to study further the subject of patents:

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