PRINCIPLES OF
Food Freezing

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ALL AT SCHOOL OF NUTRITION, CORNELL UNIVERSITY

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To

H. E. Babcock

A pioneer in freezing who saw in this process a way of "upgrading the human diet." Many have caught the fire of his enthusiasm to make frozen foods available for all.

A Foreword
by
Leonard A. Maynard

IT HAS become increasingly clear as survey data have accumulated that malnutrition in this country results, for the most part, from diets of low nutritional quality rather than from a failure to obtain sufficient food. This is especially true seasonally when certain highly nutritious fresh foods cannot be had or are available only in forms which have lost much of their original nutritive value. The recognition of this fact has given a large impetus to studies of the losses of nutrients which occur all across the board, from the farm, through processing, storage, marketing, and cooking, to the consumer's table. At the same time, increased consideration has been given as to how these operations may be improved to conserve for the consumer the nutritive value and palatability of the original products. Here, freezing and zero storage, the most recent development in food preservation, has received particular attention, not only as a commercial operation, but especially as a home and community enterprise. The results have been promising indeed. Thus, with the removal of wartime restrictions, the commercial production and marketing of frozen foods have increased, many new freezer locker plants have been built, and, particularly, many types of home freezing and storage equipment have come into use.

Many thousands are now eating frozen foods for the first time, especially those who have been fortunate enough to obtain the home equipment for processing and storing their own supply. In a sense, the experimental testing of the value and consumer acceptance of these foods, and of home equipment and processing has been transferred from the laboratory to the home. The food industry, equipment manufacturers, power companies and others, as well as the consumer himself, are all vitally interested in the outcome.

Laboratory studies have demonstrated that many foods can be processed in a more palatable and more nutritious form by freezing and zero storage than by any other method. In fact, when properly processed, certain frozen fruits and vegetables are superior to the fresh products as commonly marketed. The laboratory studies have also shown, however, that knowledge and skill are required all along the line to obtain superior frozen products. Far more is involved than merely turning on the mechanical equipment. For a given food, some varieties or kinds are more suitable for freezing than others. The treatment of the foods prior to freezing, the care and operation of the freezing equipment, the temperature of storage, and the thawing and cooking procedures used in the kitchen are all important factors in determining the nutritive value of the product as it reaches the table. Different foods require different treatments. The proper procedures are not difficult but the extent to which they are understood and carried out will largely determine the success of the Nation-wide consumer experiments now being made with frozen foods.

From this standpoint, the present book seems particularly timely. It deals with all the aspects involved from the raw materials to the finished product as it goes to the consumer's table. Although a consideration of commercial operations is included, major attention is given to home, farm, and community equipment; their suitability for various situations; and the problems involved in their use. The book is no mere set of directions for the selection and use of equipment and for carrying out the various procedures involved. The authors recognize that it is the basic principles which are all-important, rather than rule-of-thumb directions that are subject to change, frequently becoming a matter of personal choice, and that are invariably influenced by many interrelated factors. Thus, the book emphasizes the principles which underlie the handling of the various foods. In the intelligent application of these principles rather than the blind use of freezing recipes lies the future of the development of food freezing.

The book is a technical one in the sense that it explains the biochemical and nutritional aspects concerned in the freezing, storage, and cooking processes and deals with the engineering principles involved in the construction and operation of the equipment. The technical information given is thoroughly documented with numerous references. Opposing viewpoints are cited where the point under discussion is considered to be unsettled. Thus, the volume should prove a valuable handbook for food packers, locker operators, and others particularly needing an understanding of all the technical aspects involved in freezing and storage operations. The book should prove of equal value, however, to the homemaker who may not be interested in the chemical and engineering bases but who wants to know how to select equipment suitable to her needs and carry out all the operations in a way that will insure the best possible products. This practical information is presented in a language that is easily understood.

The book is an authoritative one on all the aspects discussed, because the authors are experts in the fields concerned. One is a biochemist and food scientist, another is an engineer, and the third is a home economist, and all have had experience both in the laboratory and in practice. During the past four years they have served as a team in a broad research project dealing with community and home frozen-food services, equipment, and operations. Thus, the book has grown out of activities which have enabled them to present new findings from their own research, as well as to interpret more effectively the findings of others.

The book should not only prove useful to all individuals concerned but should also help in the promotion and evaluation of this comparatively new method of food preservation which may well prove to be a large contribution to better nutrition and health.

Preface

THE AUTHORS have collected in this volume some of the basic principles governing the various steps of selecting and processing foods for freezing, and of storing them in the frozen state.

We have no intent to cover the *art* of food freezing. Several excellent publications are available to the reader who wants a handbook on the details of processing. The technical operations involved in food freezing vary greatly, depending on the specific product, the marketing channels, the scope of the packing operations, and other requirements imposed by the product, the equipment and the consumer. The detailed operations, however, are regulated by certain fundamentals equally applicable to the commercial processor or the homemaker freezing small amounts of food in her own kitchen. The present volume is concerned with these basic principles, drawing on the engineering, economics, biology, and chemistry of foods.

Classes in food processing may find in this book a useful text. A background in agriculture, biochemistry, economics, or engineering, although helpful, is not required. References are not extensive but have been included to substantiate the principles in question and to provide the student with a start in his search of the literature for more detailed information. Commercial processors of food, and manufacturers of food processing and refrigeration equipment and packaging materials should find herein information to bear on their special problems. It is the authors' hope that individuals interested in food freezing also will gain a better understanding and appreciation of the process. Because home freezing is new and has been taken on first by the more venturesome, the common cookbook variety of information does not always satisfy the owner of home freezing equipment. The answers to many of the questions raised by homemakers, such as "Is scalding really necessary?", are here.

The material is divided into three general sections so that the reader may turn to the section of his special interest.

The authors are greatly indebted to Dean S. C. Hollister and to Dr. L. A. Maynard, without whose encouragement and helpful suggestions this book would not have been possible. To Miss Elizabeth Freestone go our thanks for assistance in proofreading the manuscript. Numerous individuals and concerns have been most generous in supplying illustrative and tabular material and in granting permission to quote from their publications. This assistance has been acknowledged at appropriate points throughout the book.

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Ithaca, New York
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THE PRODUCT: FROZEN FOOD

Chapter 1

AN INTRODUCTION TO FOOD FREEZING

During most of man's existence on earth, the preservation of food has been an art. Indians living in their "Stone Age" preserved their surplus buffalo meat by salting and hanging strips of the flesh in the sun to dry. Eskimos living in their "Ice Age" preserve their surplus bear meat by the simple expedient of leaving it to freeze in the frigid climate. Asiatics and Europeans since the start of recorded history have preserved their surplus milk products by the preparation of cheeses through fermentation processes. Food was indeed preserved by such devices, and over the centuries man has learned how to prepare and keep many delicious forms of food. But not until very recent times has man's knowledge of biological materials developed to the point where *science* has been able to supplement *art* considerably in food preparation and preservation.

Rector [1] has defined food preservation as "the man-directed interruption of the natural cycles of evolution and decomposition of food substances," and goes on to say, "in attempting to preserve foods, however, we are flying in the face of some of nature's most zealously enforced laws." Through a gradual understanding of these laws of nature it has been possible to improve greatly old and accepted means of preserving foods. And, equally significant, it has been possible to devise entirely new means of preserving foods. To a nation that annually preserves over 2,000,000 tons of perishable foods by canning, it may seem strange to refer to this means of food preservation as new. Yet canning was "born" as late as 1810, when Appert won a prize offered by Napoleon for a new means of preserving perishable food. This was actually one of man's earliest successful ventures into applying scientific knowledge and fundamental principles to the logical and successful interruption of the deteriorative changes in food.

[1] T. M. Rector, *Scientific Preservation of Food,* New York, John Wiley & Sons, Inc., 1925.

Food canning is relatively modern, but the establishment of the freezing of food on a scientific basis is even more recent. True, for centuries man has used freezing weather as an aid in preserving meat over the winter, and for many years man has successfully frozen a few special items such as fish. However, only within the last two decades has the freezing preservation of a great variety of fruits, vegetables, and animal products developed significantly, successfully, satisfactorily, and scientifically.

Production figures show the steady growth of the frozen-food industry following the early years of experimentation.

TABLE 1. UNITED STATES FROZEN-FOOD PACKS

In millions of pounds

Year	Fruit	Vegetables	Fish	Fowl	Eggs
1911–20	1	...	*	*	*
1921–30	37	...	102	*	*
1931–40	99	35	150	10 †	171 †
1941	210	107	247	28	237
1942	226	163	247	41	258
1943	266	237	246	79	413
1944	337	233	267	84	512
1945	437	302	282	70 ‡	375 ‡

Source: *Western Canner & Packer*, **38**, 6 (1946).
* Data not available.
† Short term average.
‡ Preliminary.

Commercial beginnings. As early as 1842 a patent was granted in England to H. Benjamin[2] for freezing foods by immersion in an ice and salt brine. Other patents were granted during the following years both in Great Britain and the United States covering methods for freezing fish and meats. These early methods all made use of ice and salt mixtures in one form or another. Direct-contact freezing was accomplished by immersion. Indirect contact was obtained when the ice and salt mixture was placed in a pan over the product to be frozen, and air circulation was de-

[2] D. K. Tressler and C. F. Evers, *The Freezing Preservation of Foods*, New York, Avi Publishing Co., 1943.

pended on to transfer the heat. In some instances the product to be frozen was placed in a tightly closed metal container and set in the ice and salt mixture, as in the making of ice cream.

First use of mechanical refrigeration. The use of ice and salt mixtures in preservation of frozen foods was cumbersome at best. It was not until mechanical refrigeration was developed that it became possible to use cold storage extensively for the preservation of foods, especially during transportation. The first refrigerated ships bringing meats from distant points to Europe, notably from Australia to England, were intended to use temperatures comparable to those obtained with ice, that is, around 35°F. It was by accident that low temperatures came to be used. A ship from Australia was loaded, and, because of inadequate controls or carelessness in the manual control of temperatures, the whole cargo of meat was frozen. The results were so satisfactory that freezing became standard practice.[2]

First institutional packs. The first packs of frozen foods were developed and standardized in the Northwest and consisted of frozen fruits for processors in the preserve, the ice cream, and the pie industries. A total of 1,200,000 pounds was packed in the first year of commercial venture (1918) in large containers from 30-pound cans to 450-pound barrels. Improvements in freezing methods enabled packers to include in their list of products "quick"-frozen vegetables for the institutional trade. In 1935 the Northwest fruit packers were distributing frozen fruits and vegetables in smaller containers to hotels and other institutional buyers. Processors and institutions alike were well satisfied with the frozen product, and sales rapidly expanded.

Pioneer retailing of consumer packs. The retailing of frozen foods in small consumer packages presented many difficulties. There were no distribution channels for frozen food. Facilities for transportation and warehousing were lacking. Retail merchants were not equipped with proper storage and display cabinets. Cabinets were expensive, and profit margins were not attractive enough to interest merchants in the new venture. Consumers were wholly uneducated in the use of frozen foods. In 1930 orderly distribution of frozen food to family-size groups was still in the experimental stage. Credit is due the General Foods Corporation for its pioneering in research and marketing of frozen foods and its development and maintenance of high standards of quality. The first real test of consumer acceptance was made in 1930 by General Foods and its subsidiary, Frosted Foods, Inc., controllers of the Birds Eye Quick Freezing Process.[3]

The majority of homemakers had had no experience with commercially frozen food at this time. Frozen food meant to them food to be thrown away; food ruined in gardens by sudden frost or spoiled in poorly protected root cellars or basement storage. Cold-storage foods had an unsavory reputation. Information as to the care of frozen food and its preparation for the table was completely lacking. Assertions that frozen food was equal to or superior to the fresh product were viewed with great skepticism.[4] The problem undertaken by the Birds Eye company in ten retail outlets in an eastern city (Springfield, Mass.) was that of winning consumer approval.

This introductory sales campaign was carefully planned and conducted. Birds Eye brand food was placed on sale in six stores of a local chain grocery which did not handle meats, in three high-grade neighborhood meat and grocery stores, and in a large downtown cash-and-carry store. Twenty-one cuts of meat, including roasts, steaks, chops; fish, including oysters, fillet of sole, and haddock; peas, spinach; raspberries, loganberries, and pitted cherries were displayed in refrigerated show cases in competition with and at prices comparable to those of the best quality of fresh foods.

Sales resistance was much less than anticipated. Novelty buying for the first few days was followed by repeat buying amounting to three-fourths the daily sales. Requests for products other than the ones being offered for sale were frequent. Store managers attributed an increase in the sales of strictly grocery items directly to the Birds Eye cabinet. Important grocery stores in nearby towns became interested and asked for cabinets and stocks. At the close of the experiment C. M. Chester, Jr., the president of General Foods, said,[3] "The ready acceptance of the public of frozen-food perishables indicates benefits to several large industries." He saw the Nation's grocery stores as potential users of frozen foods, the automobile industry called on for refrigerated trucks, and railroads and ships used for long-distance transportation. "Farmers will be able to sell perishables now wasted.

[3] Anonymous, Introductory sales campaign for quick frozen products, *Ice and Refrig.* **78**, 553 (1930).

[4] J. D. Mueller, Frozen food meets increasing favor from Dallas public, *Ice and Refrig.* **96**, no. 3, 248 (1939).

Housewives will have the equivalent of fresh perishables the year round."

The success of this and other similar experiments at home and the experimental shipments of frozen food abroad, led the Birds Eye company to develop new sales and promotion policies.[5] Retail efforts were concentrated in the Northeast, and less expensive mechanically refrigerated cases were installed in stores on a rental basis. The first promotional advertising was directed at the homemaker.

Advertising of frozen food was slow to develop. Very little attention was given to it by women's magazines. In 1939 distributors of frozen food still had no advertising programs. There was no national advertising. It was pointed out by Eric P. Johnson in 1939[6] that "to dispel the illusion that quick-frozen was just a fancy name for cold-storage merchandise, advertising was necessary to build public acceptance and demand." The gains in acceptance have been chiefly among the young housewives. The main appeals of frozen food are the same today as they were in the beginning—the convenience of ready-to-cook food, available the year round, and no inedible waste.

Consumer acceptance in Northwest. Frozen foods that had been grown and frozen in the Northwest were used by eastern homemakers some two years before western women were exposed to frozen food.[7] The total output of the Northwest had been shipped to eastern cities. Stiff competition for the western product came with the growth of processing in the eastern states. Western packers were forced to develop markets at home. Retail marketing in the West was seriously attempted for the first time in the fall of 1937.[7] Western women were enthusiastic over the new foods.

The demand for frozen foods grew as the popular knowledge about them increased. At first frozen foods were used regularly in the homes of the well-to-do and not at all in the homes of the low-income groups. More and more homemakers came to use and demand frozen foods as they began to appreciate the timesaving in meal preparation, the convenience of ready-to-cook foods, the

[5] Anonymous, Frosted food company expands, *Ice and Refrig.* **78**, 558 (1930).

[6] E. P. Johnson, A survey of fresh frozen foods, *Quick Frozen Foods* **1**, no. 7, 22 (1939).

[7] Anonymous, Northwest quick freezing firms start developing western retail marketing, *Ice and Refrig.* **96**, 335 (1939).

elimination of waste, and the fact that the foods were not so expensive as they first appeared to be, and that prices were steady and quality uniform. A survey in New York and suburban areas in 1945 indicated the highest sales of frozen foods and the greatest optimism as to their future were in stores located in districts of above-average income or of young white-collar workers.[8]

The *Milwaukee Journal* in its continuing study of food purchasing in its area of Wisconsin reports significant changes in the percentage of families now buying frozen foods. In 1941 only 18.3 per cent of the families sampled bought any frozen foods. In 1943 the figure had risen to 21.5 per cent and in 1945 to 28.3 per cent.

New consumer groups: locker patrons. The development of the community freezer locker plant created an enormous new group of users of frozen food. The locker plant brought freezing facilities to rural families. It became possible for farm families to freeze and store home-grown products and, in many communities, to have the choice of a wide variety of frozen foods offered for sale by the locker plant. Farmers found the locker plant invaluable for storing meat. Slaughtering was made possible at any season of the year. Farm wives welcomed the freedom from meat canning. For the farm families near community plants there was an end to the monotony of canned meat, an end to eating fresh meat to keep it from spoiling. As frozen-food locker plants developed, services were added, increasing the usefulness of the plants to the communities. Many community plants were well established before the beginning of World War II. By 1945 there were 5600 locker plants, serving an estimated 2,000,000 families.

Home-freezer users. Freezing in home units was off to a good start before the war. Owners of early freezing equipment were enthusiastic about home-grown and home-frozen foods. Home processors, like the patrons of locker plants, were delighted with freezing. The drudgery of canning was largely eliminated. Men were especially enthusiastic about the new process. The quality and variety of the products from home freezers were a continual source of pride and a sure-fire topic of conversation. It was often the man of the family who did the major part of the processing.[9]

[8] G. Johnson, Retail survey page, *Quick Frozen Foods* **8**, no. 4, 57 (1945).
[9] Nancy K. Masterman, Using the home freezer, *Cornell Univ. Ext. Bull.* **658** (1944).

Effect of war economy. The statement of Clarence Birdseye that wartime conditions advanced public acceptance of frozen foods by five years[10] is no doubt a conservative one. Rationing made shopping around necessary; housewives were forced to try out many new products. Frozen fruit and vegetables were on the ration-free list, and the general public had more money with which to buy them. Homemakers who had taken on war jobs found in frozen-food convenience part of the answer to combining homework with outside employment. Satisfying meals could be prepared with less time spent in preparation and cleanup.

TABLE 2. APPARENT CIVILIAN CONSUMPTION OF FROZEN FRUITS AND VEGETABLES ON A PER CAPITA BASIS WITH PERCENTAGE COMPARISONS 1935–46

Commodity	Pounds of Frozen Food Consumed per Capita						1946 as a Percentage of	
	Average 1935–39	1942	1943	1944	1945	Prel. 1946	1935–39, per cent	1945, per cent
Fruits	0.7 *	1.6	1.3	2.0	2.4	2.8	400	117
Vegetables	0.4	1.0	0.7	1.6	1.8	2.0	500	111

Source: 1946 Outlook, The National Food Situation, *U. S. Dept. Agr., Bur. Agr. Econ.*, **NFS-29** (1946).
* Average 1937–39. Data prior to 1937 are not available.

Wider use of frozen foods was encouraged by the fact that more information became available on the value of frozen foods and how to use them. Bulletins were prepared by colleges of agriculture and home economics, giving simple and explicit directions on how to freeze foods at home. The food-conservation programs of the extension service of the U. S. Department of Agriculture and the state colleges of agriculture and home economics included demonstrations of preserving foods by freezing and frozen-food cookery. Manufacturers of low-temperature equipment and distributers of packaging materials for frozen food

[10] C. Birdseye, Rationing helps frozen food sales, *Ice and Refrig.* **106,** 156 (1944).

took an active part in the education of the public in freezing. The National Frozen Food Locker Association undertook a wide program in frozen-food education. The press and radio joined the frozen-food band wagon. While home freezing greatly increased, the purchases of commercially frozen food were 400 per cent higher during rationing. The demand for the retail package of frozen food far exceeded the supply.

As the war food situation became more critical, the demand for lockers and home-freezing equipment increased. With home freezers no longer being manufactured, consumers discovered the ice-cream cabinet. No cabinet was too old to bring a price. Milk coolers were converted into home freezers. A black market in low-temperature equipment boomed. Locker plants expanded to the limit of the law, and new plants were built as fast as government regulations would allow.

Because of meat rationing and the shortages that developed in all varieties of meat, locker patrons and home-freezer users turned to fruits and vegetables to fill the space, and many discovered for the first time the advantages of preserving garden produce by freezing.[11]

Surveys of home freezers and locker plants and patrons in New York State (1942–43) revealed the products frozen in order of their popularity. Peas were the most popular vegetable frozen from home gardens, closely followed in popularity by green beans, then in order by corn, asparagus, lima beans, cauliflower, broccoli, corn on the cob, beet greens, squash, carrots, yellow beans, beets, parsnips, pumpkin, chard, Brussels sprouts, eggplant, turnips, kohlrabi, and tomato juice.

Strawberries led all fruits in popularity with farm, suburban, and city families (Fig. 1). Peaches and raspberries were the first choices of villagers doing their own freezing. Fruits in order of their popularity after strawberries were peaches, red raspberries, cherries, huckleberries, rhubarb, black raspberries, Columbian raspberries, apples, cider, orange juice, plums, melons, cranberries, gooseberries, boysenberries, and currants.

Home processors also stored butter, lard, eggs, cream, cheese, baked goods (bread, rolls, muffins, biscuit, cookies, doughnuts,

[11] Nancy K. Masterman, The patron and the locker plant, *Quick Frozen Foods* 7, I–VIII (1944).

pies), puddings, soups, gravies, spaghetti sauce, baked beans, scrapple, chili con carne, roast turkey and chickens, meat stews.

Commercially frozen foods were purchased for storage to fill the lack of products not produced at home or grown locally. Those requiring much preparation prior to freezing, such as spinach, lima beans, and peas, were often bought commercially frozen. Small fruits not grown locally such as cherries were bought either frozen or pitted and ready to freeze.

Courtesy Agricultural Advertising & Research

Figure 1. Strawberries, the most popular frozen fruit.

A rapidly increasing consumer demand has effected a continuing increase in production. The growth of the industry through the years may be seen in the records of the composition of the frozen-food pack. Fruits and berries increased from 62,491,000 pounds in 1926 to 437,636,000 pounds in 1945. The vegetable pack of 2,500,000 pounds in 1933 reached 301,500,000 pounds in 1945. The strength of the consumer demand for certain fruits and vegetables is indicated by their continued high percentage of the pack in spite of the introduction of many new items through the years.

Peas have continued to be the major item of the vegetable pack and represented more than one third of the total pack in 1945.[12]

[12] *Western Canner & Packer Statistical Rev. and Yearbook* **38**, no. 6, 263 (1946).

The increase in the spinach pack is noteworthy. One of the few packs showing a gradual decline over a period of years is that of corn on the cob. In only one year, 1940, did the pack exceed the first year's (1937) production figures. War directives brought

TABLE 3. U. S. FROZEN PACKS OF LEADING FRUITS—THE 1945 PACK COMPARED WITH THE FIRST YEAR OF PACK FOR WHICH FIGURES WERE COMPILED

Product	Pounds of Pack	
	1926–30	*1945*
Strawberries	29,238,000	37,358,000
Red pitted cherries	18,360,000	16,144,000
Red raspberries	9,271,000	13,255,000
Blackberries	2,406,000	21,503,000
Loganberries	1,191,000	2,542,000
Black raspberries	536,000	3,477,000
Gooseberries	58,000	1,558,000
Youngberries	2,000	2,551,000
Currants	188,000	2,668,000
Cherries		
Light and dark sweet	8,000	10,298,000
Plums and prunes	134,000	19,962,000
Rhubarb	27,000	6,852,000
	1931–35	
Peaches	10,000	103,633,000
Apricots	21,000	65,158,000
Blueberries, huckleberries	88,000	7,829,000
	1936–40	
Applesauce ana apples	2,377,000	92,984,000
Grapes, pulp and juice	7,366,000	10,185,000
Other fruits	6,084,000	10,586,000
	1942	
Boysenberries	2,061,000	7,084,000
	1943	
Nectarines	878,000	1,137,000
Pears	564,000	272,000

Source: *Western Canner & Packer Statistical Rev. and Yearbook* **38,** no. 6, 283 (1946).

about a reduction from 2,299,000 pounds in 1942 to 487,000 pounds packed in 1945. It is doubtful that consumer demand will ever bring the production figure for corn on the cob to a point where it approaches the pack of cut sweet corn, which has increased through the years. Frozen tomatoes appear in the record for the first time in 1943.

Of the early U. S. packs of fruits (1926–30), strawberries, red cherries, and red raspberries led all fruits. The pack of frozen fruits reached an all-time high in 1945. The pack increased one third over 1944. Berries were still a major portion of the pack, but other fruits, especially apples in the form of sauce, peaches, and apricots, reached a high point.

Tables 3 and 4 give the U. S. frozen fruit and vegetable pack of 1945 as compared with the first year of pack for which figures are compiled. Only the leading fruits and vegetables are included.

TABLE 4. U. S. FROZEN PACKS OF LEADING VEGETABLES—THE 1945 PACK COMPARED WITH THE FIRST YEAR OF PACK FOR WHICH FIGURES WERE COMPILED

Product	Pounds of Pack	
	1933	*1945*
Total vegetable pack	2,500,000	301,500,000
	1934	
Snap beans	250,000	31,461,000
Cut corn	500,000	25,551,000
Peas	1,750,000	103,834,000
	1937	
Asparagus	6,259,000	20,637,000
Lima beans	17,994,000	28,503,000
Broccoli	2,094,000	11,863,000
Brussels sprouts	239,000	6,606,000
Carrots	332,000	6,051,000
Cauliflower	282,000	7,473,000
Corn on the cob	2,783,000	487,000
Peas and carrots	163,000	5,322,000
Spinach	4,333,000	36,721,000
Squash and pumpkin	407,000	7,369,000

Source: *Western Canner & Packer Statistical Rev. and Yearbook* **38**, no. 6, 293 (1946).

Recent trends. One of the most important trends during the war years has been the development of the freezing of precooked foods. California is credited with the first packs about 1940. Considerable research in the freezing of precooked foods had been carried on before the war, but it remained for the shortage of metal for cans and shortages of food, particularly meat, to bring to the fore the freezing of food formerly canned. Frozen entrees, ready to reheat and serve, received wide acceptance and included such items as baked beans (pork and beans and applesauce were the two major items packed during the war), stews, corn beef hash, chicken à la king, chili con carne. The list has been added to steadily and now includes items such as frozen seafood cocktails, turkey à la king, assorted hors d'oeuvres, roasted stuffed fowls, shrimp à la Creole, and many others. At the meeting of the North California Section, Institute of Food Technologists, December 6, 1945, it was predicted that, thanks to frozen precooked food, the time is not far distant when a one-man kitchen will be able to serve a complete meal to a thousand people.

Complete, partially precooked, frozen meals such as served aboard Naval Air Transport Service planes during the latter part of World War II, are possibilities of the future for home and institution trade. Problems of processing and storage remain to be solved. Special machinery required for mass production must be manufactured.

In 1900 freezing methods were adapted to pies by a forewoman of a large Chicago pie bakery.[13] Test pies were made at this time of berries, cherries, and rhubarb. The idea remained just that until 1945 when frozen fruit pies appeared for sale in several widely separated areas. Time was ripe for their acceptance by housewives who depended on desserts from the bakery to supply the lack of the homemade product, a lack brought about by the departure of the family cook to other pursuits, the dwindling sugar supply, and the part-time homemaking now engaged in by many women. Though research has attested to the potential quality of frozen breads, doughs, rolls, cookies, and cakes, industry is just beginning to take on the processing of some of these products. Frozen milk was first reported in 1945.[14]

[13] Anonymous, Development of frozen food industry, *Ice and Refrig.* **78**, 546 (1930).

[14] *Western Canner & Packer* **38**, no. 6, 279 (1946).

New products and experimental packs. Several new products reached the commercial stage in 1944—elderberries, pineapple, beets, greens, and mixed vegetables. Experimental packs continued in 1945 and included fruit punch, lemon and lime juice, grated coconut, cantaloupe purée, baked apples, mangoes, litchi and papaya, sauerkraut, bean sprouts, artichoke hearts, soybeans, rabbits, and pet foods.

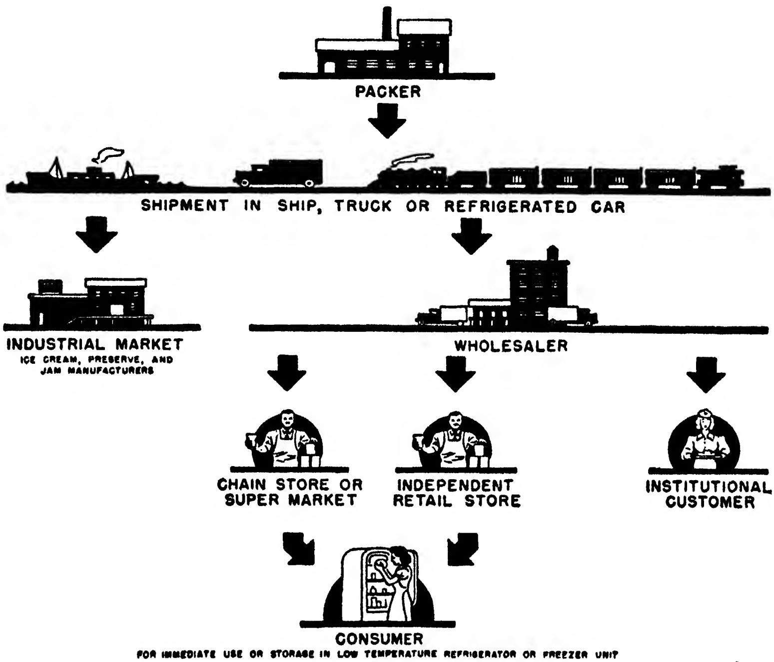
With experience and increased knowledge in home freezing and the use of frozen foods, there comes an ever-increasing demand from consumers for higher-quality products. Unfortunately, the quality of frozen foods fell during the war period. Help was scarce and often careless. The unprecedented demand brought opportunists into the business who failed to realize the importance of quality production. Less attention was given to packaging to preserve quality. Handling of food in transportation was not all that it should be. Some retail stores sold frozen food from stacks held at room temperature rather than from refrigerated cases. Users formerly enthusiastic about frozen foods expressed dissatisfaction. New users were often disappointed and blamed the process. If frozen foods are to meet competition with fresh and canned foods, they must meet them with both quality and price.

The homemaker must get from frozen foods satisfaction beyond the convenience of foods easily and quickly prepared. The family must like them and thrive on them. The attractive color and flavor of fresh foods and the high nutritive value must be held over months of storage. Shopping for frozen food must be made easy with all the self-service convenience of other foods. There must be equipment for taking care of it in the home.

Consumer acceptance of high-quality frozen food is assured. The consumption of frozen food has doubled since 1940, with the demand exceeding the supply. That there is room for great expansion of the industry is evident in that the consumption of frozen fruits and vegetables is barely $\frac{1}{12}$ that of canned and less than $\frac{1}{100}$ that of fresh fruits and vegetables.[15] Its progress is dependent on the development and distribution of equipment to take care of the food from its processing to its destination, the plate of the consumer (Fig. 2).

[15] Anonymous, Frozen foods: a new horizon, *Business Week*, Feb. 2, 1946, p. 30.

To further the aim of insuring high quality in frozen foods, the U. S. Department of Agriculture has established tentative standards for grades of 19 fruits and vegetables, including apples, apricots, asparagus, snap beans, berries (blackberries, boysenberries, dewberries, loganberries, youngberries, "nectarberries,"



Courtesy Farm Credit Administration, USDA

Figure 2. Distribution flow plan for frozen food. Recommended for expanded zero storage.

etc.), blueberries or huckleberries, broccoli, Brussels sprouts, cauliflower, sour pitted cherries, sweet cherries, whole grain corn, lima beans, peaches, peas, raspberries, rhubarb, spinach, strawberries. These standards are used in the Federal Inspection and Grading Service and are scored on the basis of such qualities as normal odor and flavor, color, uniformity of size, absence of defects, and physical character or texture of fruit.

Fresh frozen foods. Canning, dehydrating, salting, pickling, smoking—all are effective means of preserving certain foods, and all find an important place in satisfying the dietary peculiarities of man. Only the first two processes, however, leave the food without the addition of materials with distinctive flavors. And neither of these two means of food preservation truly retains the fresh appearance and flavor of the original food product. Freezing is the only process whereby an essentially unchanged, "garden-fresh" product can be obtained after many months in the preserved state. Herein lies its major virtue—a flavor, color, odor, and texture rivaling the original food.

There are other features of frozen foods of which the consumer is aware and on which he or she will insist. Convenience has already been discussed and is ever assuming more importance. Economy must receive consideration along with quality. And nutritive value, ever important, is now a point of concern to the educated shopper.

There are many gaps in our knowledge of how best to handle foods for freezing. But both the art and the science of freezing technology have advanced to the point where one can obtain a great variety of high quality, nutritious, and economical frozen pack foods. In the succeeding chapters, the conditions that ensure these qualities in frozen foods are discussed.

Chapter 2
THE RAW MATERIAL

The behavior of frozen foods in storage is greatly affected by the history of these products during growing and handling. The variety of the seed or the breed of animal, the climate before and during the harvest or the temperature while slaughtering operations are carried on, the time and temperature of holding prior to processing for freezing—all these prestorage variables influence the ability of the foodstuff to withstand prolonged frozen storage.

PLANT PRODUCTS FOR FREEZING

Most fruits and vegetables are adapted to freezing preservation. There are still a few exceptions, such as lettuce, cucumbers, celery, and similar products which wilt or become flabby upon thawing after being frozen by present methods. Tomatoes collapse completely. There are also some products which can be satisfactorily preserved by simple storage, so that freezing is resorted to only rarely. Included in this group are many root vegetables and tubers. But for a majority of the edible produce from the garden, freezing has proved to be a successful means of long-time food preservation.

It should be noted, however, that the freezing preservation of plant products is a relatively modern development in food preservation. As recently as 1921 fruits were considered [1] as typifying that class of foods which must be held at above freezing temperatures, owing to the "serious deterioration" which occurs on freezing. Tubers and root vegetables were also included in this class of food materials which, at that time, had not been successfully preserved by freezing. In the face of the present state of freezing

[1] W. Stiles, The scientific principles of cold storage, *J. Soc. Chem. Ind.* **40**, 112T (1921).

technology, wherein many of these same fruit and vegetable products are enjoying immense popularity as frozen-pack items, one hesitates to state even that the products cited in the previous paragraph are "not adaptable" to freezing. It may well be merely that the processing and freezing techniques thus far attempted are not adapted to the product, rather than the product not being adapted to this means of preservation. Perhaps through the study of the colloid chemistry of food constituents, the sliced tomato salad of the future may come from the freezer.

In the preparation of a high-quality frozen food, it is not sufficient that the harvested product receives the best of care in processing. Food *processing* and food *preparation* must go back further, forming a harmonious working team with food *production.* The selection of the seed, the environmental conditions of climate at the tops of the plant and of soil at the roots, and the stage and even the methods of harvesting—these are all of ultimate concern in the success of food freezing. It is not within the scope of this book to take up, even in general terms, the principles that enter into the successful production of top-quality food crops. A few illustrations may, however, be of value in pointing out both the magnitude and the importance of the role of the farm and the farmer in the food-freezing industry.

Variety. Genetic factors affect the yield, the adaptability of the plant to its surroundings, the date of ripening, the resistance to plant diseases and insect attack, uniformity, and many other qualities that go into the selection of a particular variety from many in a given species. And just as readily affected by the ancestry of the plant is the adaptability of the food to freezing processing and storage. Texture, flavor, color, nutritive value, and hardiness under the different conditions encountered in the processing, freezing, storage, and final preparation of frozen food are all variables influenced by the variety of the fruit or vegetable. Garber [2] points out that considerable improvement in flavor, sugar content, and other desirable characters of food quality has been made by means of selection and breeding of plants; furthermore, a beginning has been made in increasing the vitamin content of these foods through varietal selection.

[2] R. J. Garber, Plant breeding in relation to human nutrition, *Science* **101,** 288 (1945).

A study[3] of the adaptability to freezing of 56 varieties of peaches illustrates the great differences that may be observed for a given product. Of the 56, nine varieties were selected as being particularly satisfactory from the standpoints of texture, natural color, characteristic flavor, and odor. Eight varieties were acceptable but somewhat less satisfactory in texture or else were more susceptible to a browning when the tissues were exposed to air. An additional nine varieties that had satisfactory flavor and texture were very prone to rapid discoloration from oxidation; these varieties posed special problems in processing, owing to the extensive precautions necessary to prevent color change. The remaining 30 varieties of peaches, constituting more than half the varieties tested in that study, were not recommended for freezing preservation because they lacked all of the essential qualities of an acceptable frozen peach.

The same U. S. Department of Agriculture investigators have reported on the suitability for freezing of a number of varieties of several of the more popular frozen-pack vegetables. Seven of 14 varieties of snap beans,[4] 2 of 8 varieties of lima beans,[5] 6 of 18 varieties of peas,[6] and 12 of 35 strains and varieties of corn[7] that were tested were rejected as being unsuited to freezing when grown in the eastern section of the United States.

The choice of the correct variety, however, is merely the first of many hurdles in the production of a successful harvest. Considerable alterations in the suitability of the frozen product from the same variety are evident from the effects of insects, disease, and environmental conditions during the period of growth.

Climate. The wide differences between crops of the same fruit, vegetable, or berry grown in the same location but in different

[3] J. S. Caldwell, J. M. Lutz, H. H. Moon, and A. T. Myers, Varietal adaptability of peaches to freezing in small consumer packages, *Fruit Products J.* **12,** 366 (1933).

[4] H. Moon, J. Caldwell, J. Lutz, and C. Culpepper, Comparative suitability for freezing purposes in 14 varieties of garden or snap beans under eastern conditions, *Canning Age* **17,** 271 (1936).

[5] J. Caldwell, J. Lutz, and H. Moon, Suitability of lima beans for freezing, *Canning Age* **17,** 374 (1936).

[6] H. Moon, J. Caldwell, and J. Lutz, Peas for freezing. A study of suitability for freezing purposes in 18 varieties of peas grown under eastern conditions, *Canner* **83,** no. 4, 7; no. 5, 13 (1936).

[7] J. Caldwell, J. Lutz, C. Culpepper, and J. Moon, Corn for freezing. A study of comparative suitability for freezing preservation in 35 varieties and strains of sweet corn grown under eastern conditions, *Canner* **83,** no. 6, 11; no. 7, 11; no. 8, 15; no. 9, 13 (1936).

seasons or years serve to indicate the importance of climate in production of quality food. Yield, appearance, flavor, and nutritive value are affected to varying degrees by the rain, the heat, the quality and quantity of sunlight, the air movements, and other climatic conditions.

The effect of climate on yield is so evident and so close to the personal experience of the reader that no elaboration is necessary. Yield may be the deciding factor in the acceptance or rejection of a given variety of produce. For example, Kentucky Wonder pole beans give an excellent frozen product. In many sections of the country, they are a reliable crop from year to year, but in New York State the yield in many years is poor. Climate here introduces an uncertainty in the choice of an otherwise excellent vegetable for the frozen pack.

The appearance of the food product may be affected by one or more of the climatic factors. Thus, too much rain at the time when cherries are ripening may cause the fruit to crack.[8] Sunlight encourages green pigmentation—hence this element of the climate often must be excluded where a white product is desired. This is effected by mounding the soil where white asparagus is desired, and by tying the outer leaves over the head to produce a white head of cauliflower.

Anyone who has tasted strawberries grown during a cold wet season needs no further convincing that the climate may profoundly affect the flavor of the foodstuff. Berries produced under these adverse environmental conditions will be watery and will lack the sweetness and delicate flavor of the strawberry that has matured in more favorable weather.

Considerable evidence has accumulated in recent years to indicate that the nutritive value of food plants may be very significantly affected by the environmental conditions at the top of the plant. Perhaps the most important single climatic factor in this respect is the amount of sunlight which falls on the plant shortly prior to harvest. Thus, we have the observation[9] that winter-grown tomatoes have only one half the ascorbic acid (vitamin C) content of comparable products grown during the summer months. The supply of this vitamin in the diet is generally lower during

[8] S. Frazer, *American Fruits*, New York, Orange Judd Publishing Co., 1924.
[9] K. C. Hamner, C. B. Lyon, and C. L. Hamner, Effect of mineral nutrition on the ascorbic-acid content of the tomato, *Botan. Gaz.* **103**, 586 (1942).

winter months, owing to a less plentiful supply of fresh fruits and vegetables. Accordingly, any condition which leads to a lower vitamin content assumes considerable importance. Hamner and Parks [10] found that the ascorbic acid content of turnip greens may be varied experimentally *800 per cent,* depending on the light intensity on the tops of the plants for the week prior to harvesting.

Soil. Just as man will become anemic if his diet is too low in iron, so will plants develop deficiencies in those essential minerals which are lacking in the soil. These deficiencies may manifest themselves in a variety of ways—in yield, external appearance, internal structure. A balance in many soil factors is necessary for the production of quality crops. For example, an excess of nitrogen in relation to phosphorus and potassium may lead to the production of fruit greener in color, of potatoes that have luxurious growth of the tops and little growth of the tubers, of parsnips that have a coarser texture. On the other hand, if the plants are somewhat starved in terms of nitrogen, the growth of the stalk and leaves is slow, and the color of these structures is yellow or yellow–green rather than the usual bright deep green.

Such vegetables as asparagus and spinach will not grow satisfactorily on soils that are somewhat acidic. They show marked responses to liming of such soils, since the addition of sufficient lime will change the surface soil to a slightly alkaline medium. Many other examples could be cited to demonstrate that both quality and quantity factors in the soil environment are important to food production for freezing preservation.

Maturity. Many vegetables adapted to freezing preservation, such as peas, beans, corn, and lima beans, will lose their peak quality if they are not harvested once they reach maturity. Texture, flavor, and nutritive value are all affected very considerably by the stage of ripening of the product. Often a delay of only a day or two in harvesting may significantly lower the grade of the processed food.

As peas approach the peak of their maturity, the content of the sugar, sucrose, reaches a maximum.[11] This is important because sucrose appears to play a dominant role in determining the sweet-

[10] K. C. Hamner and R. Q. Parks, Effect of light intensity on ascorbic acid content of turnip greens, *J. Am. Soc. Agron.* 36, 269 (1944).

[11] C. S. Bisson and H. A. Jones, Changes accompanying fruit development in the garden pea, *Plant Physiol.* 7, 91 (1932).

ness and hence the flavor of the peas. The best evidence seems to indicate that the peak in the flavor when the peas are ready for harvest is also the time when the nutritional value is near a maximum.

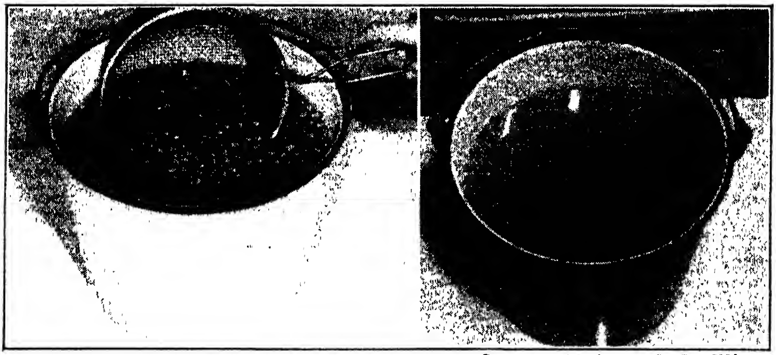
As the period of development progresses, tenderness progressively decreases. Indeed, differences in maturity of a vegetable

Courtesy Food Machinery Corp.

Figure 3. Testing the texture of peas for freezing by use of the Tenderometer. The machine is near the end of its cycle, with the counterweight swung off center and the indicator registering the shearing force in pounds per square inch.

such as peas or corn at the time of picking will lead to much greater variations in texture than will differences in the variety of the product. The period for harvesting peas, corn, and certain other vegetables for freezing must be from two to four days earlier than the stage of maturity deemed best for canning. In canning the cooking action of the long heat processing can favorably alter both the texture and palatability of the fully mature vegetable. The same results are not obtained when overmature vegetables are frozen, and only the more tender, juicy or succulent, flavorful "early-mature" products should be selected for the frozen pack.

An instrument known as the Tenderometer (Fig. 3) was described in 1937 [12] as a device for measuring the texture of fresh peas for the food processor. Since then it has gained wide use in evaluating the quality of peas for canning and freezing and has given some indication of value in determining tenderness or maturity of fresh asparagus.[13]



Courtesy Professor J. D. Winter

Figure 4. The principle involved in the use of specific gravity in grading peas. The peas which sink in the brine will be rejected as overmature and hence not suited for freezing.

A number of chemical and physical measurements have been applied with varying success to the determination of the general quality of processed foods as it is influenced by maturity. Among the more simple and successful of these tests has been the determination of the specific gravity of the product by comparing its weight in air to its weight in some known solution such as a standard brine (Fig. 4). As the maturity of many vegetables progresses, there is a gradual decrease in the moisture content accompanied by an increase in the solids, including starch. This fact has been used as the basis for grading frozen peas [14] and frozen

[12] W. McK. Martin, The tenderometer. An apparatus for evaluating tenderness in peas, *Canning Trade* **59**, 7 (1937).

[13] R. R. Jenkins and F. A. Lee, Tenderometer readings as an index of quality of fresh asparagus. A preliminary paper, *Food Research* **5**, 161 (1940).

[14] F. A. Lee, Determination of the maturity of frozen peas, *Ind. Eng. Chem. Anal. Ed.* **14**, 241 (1942).

corn[15] with respect to maturity by determining the specific gravity, using a solution of specific gravity 1.000.

Harvesting procedures. During the war years, when Victory gardens sprang up in urban and suburban areas, many people rediscovered the fact that produce freshly picked from the garden has a quality all its own. The tree-ripened fruit has an extra richness in flavor and sweetness. Even the day-or-two-old "market-fresh" vegetable does not have the flavor appeal of the freshly harvested foodstuff. Deteriorative chemical changes take place continually, and these may be hastened by many conditions associated with the stage of getting produce from the farm to the processing plant.

Temperature immediately assumes a major role in determining the rate of decline in the food quality. This fact is emphasized by the absence of any appreciable commercial production of sweet corn south of the Mason–Dixon line. As Thompson[16] notes, "At high temperatures the corn matures very rapidly, and it is difficult to harvest the ears at just the right time; if this is not done a loss results. After the ears are pulled from the stalk there is a rapid deterioration in quality due to the loss of sugar, the higher the temperature the more rapid the change. These factors give the cooler regions a decided advantage over the South in sweet-corn production." The northern sweet corn does not have a higher sugar content at the point of harvesting, but, because of the temperatures prevailing during the corn season, it does retain its sweetness better than sweet corn in warmer climates.

The advantages of prompt refrigeration are evident from data on changes under varying temperature conditions after harvest. For example, peas may lose one third of their sucrose in a 24-hour period;[17] yet this sugar will remain unchanged if the temperature is promptly lowered to the near-freezing range.

Peas in their pods do not deteriorate so rapidly as do the shelled peas ready for processing. The loss of sugar from shelled peas may be twice as rapid[17] as from the unshelled product held at room temperature. Peas in pods may lose only inappreciable

[15] F. A. Lee, D. De Felice, and R. R. Jenkins, Determining the maturity of frozen vegetables, *Ind. Eng. Chem. Anal. Ed.*, **14**, 240 (1942).

[16] H. C. Thompson, *Vegetable Crops*, 3d ed., New York, McGraw-Hill Book Co., 1939.

[17] H. A. Jones and C. S. Bisson, Changes in the composition of the garden pea after harvest, *Plant Physiol.* **7**, 273 (1932).

amounts of ascorbic acid in 24 hours, and yet have more than 20 per cent of this vitamin destroyed[18] when the peas are hand-shelled prior to the holding period.

Even more important, however, is the means whereby the shelling is accomplished. Bruising of the tissues releases enzyme catalysts (substances which accelerate specific changes in the foodstuff) from their confinement within the cells, allowing them to react with the various constituents which make up the tissues. The result of such bruising will be particularly evident with a prolonged holding prior to processing. Again, peas offer a ready example.

For home processing, the peas will be picked from the vine and will then be shelled by hand shortly before processing for freezing. Commercial practice, however, usually calls for the vines to be mowed and transported to a "viner," which mechanically separates the peas from the pods and vines by means of beaters. The resulting unavoidable bruising of the tissues of the vegetable makes it very important that subsequent processing be carried out with a minimum of delay. In as little as three hours at 80°F., 14 per cent of the ascorbic acid may be lost[19] from the vined peas. Flavor is likely to disappear even more rapidly. Furthermore, the skin of the vined peas will tend to be tougher than the hand-shelled peas, particularly if there is any delay in the processing for freezing. These changes will be minimized, however, if the temperature is lowered to the near-freezing range.

As with vegetables, fruit must be harvested and handled with reasonable care. Any bruising or piercing of the skin serves as a focal point for growth of microorganisms and action of enzymes. Either the quality or the yield of the frozen-pack item will suffer if these agents of deteriorative change are thus encouraged.

ANIMAL PRODUCTS FOR FREEZING

Feeding practice. For animal products, the feeding practice may have very significant effects in terms of quality of the final

[18] E. N. Todhunter and Ruth C. Robbins, Ascorbic acid (vitamin C) content of garden-type peas preserved by the frozen-pack method, *Wash. Agr. Expt. Sta. Bull.* 408 (1941).

[19] R. R. Jenkins, D. K. Tressler, and G. A. Fitzgerald, Vitamin C content of vegetables. VIII. Frozen peas, *Food Research* 3, 133 (1938).

foodstuff. The effects may be reflected in appearance, in odor, in taste, in nutritive value, and in keeping quality during subsequent frozen storage.

In many sections of the country it is occasionally the practice to raise hogs on a feed containing an appreciable percentage of peanuts, soybeans, soybean oil meal, linseed press cake, and other such products. These feeds contain oils that are highly unsaturated—and the unsaturated fatty acids are liquid at room temperature, in sharp contrast to the long-carbon-chain saturated fatty acids which make up the bulk of such hard fats as beef tallow. The feed has been shown to exert a very profound influence on the character of the animal fat, a high carbohydrate diet such as corn tending to produce a hard fat and a highly unsaturated fat in the feed tending to produce a soft oily body fat. If the pig is fattened on a "hardening" diet such as corn and tankage, the pork will have the usual desirable firm fat. If the softening feeds are present in too great amounts, the pork may be undesirable in appearance and texture, owing to the highly unsaturated fat from the feedstuffs.

Flavor and odor may be drastically changed by dietary influences. For example, ducks that have been raised on a diet of fish may acquire sufficient fishy odor and flavor to make the poultry flesh unmarketable. And in beef animals, the appearance, flavor, and tenderness may all be greatly affected by the degree of fattening during the few months prior to slaughter. A grain-fed steer should yield tender juicy steaks with bright red lean and well-marbled with firm light-colored fine-flavored fat. A steer fed on grass alone will produce less tender steaks, with dark lean and poor marbling, less fat, and fat that is yellow in color. Such carcasses seldom will grade better than "commercial" and often will be classed as "utility" beef.

The nutritive value of animal products is often affected by the nutritive value of the feed on which the animal was raised. Cream will vary greatly in its vitamin A value. Butter produced under winter feeding conditions contains on the average 11,000 units of vitamin A per pound [20] with individual samples containing as low as 5,000 units. On the other hand, the cow on summer pasture, higher in the provitamin (vitamin precursor) carotene, will pro-

[20] Bureau of Dairy Industry, Vitamin A in butter, *U. S. Dept. Agr. Misc. Pub.* 571 (1945).

duce butter averaging 18,000 units per pound, with some samples reaching a potency of over 21,000 units of vitamin A. Water-soluble vitamins may also be affected by feeding practice. Pork, which is notable for its high content of thiamine (vitamin B_1), may have this vitamin in limited amounts when the diet of the pig is low in thiamine. On the other hand, when the feed is high in thiamine, very high tissue contents are likely to result.[21] The thiamine content of eggs may be doubled or trebled by placing the fowl on diets high in that vitamin.[22]

Even the keeping quality of the food may be traceable to the diet of the animal before slaughter. It has been demonstrated[23] that the tendency of body fat to turn rancid may be lessened if the animal has been raised on a diet high in certain antioxidants, which are substances that can greatly delay the oxidation of fats. Apparently, the diet is the sole source of these antioxidants in body fats, including hog fat.[24] The keeping quality of the pork fat may well be affected by a variable content of highly unsaturated fatty acids and of the antioxidant, vitamin E (tocopherol), both of which may be appreciably altered by a change in the diet. The significance of such a finding for the freezing preservation of meat such as pork is evident. Indeed, the dietary history of the animal may offer some explanation for variable results that appear in the literature regarding the tendency of pork to develop rancidity during storage in the frozen state.

Breed. But feeding practice, despite its importance in determining the quality of the processed foodstuffs, is only one among many determining factors affecting the animal products. Breeding is as important here as it is with the plant products selected for freezing. The dairy cow was never intended for the production of blue-ribbon beef. The White Leghorn hen cannot approach the Rhode Island Red for quality or quantity in poultry flesh.

[21] J. W. Pence, R. C. Miller, R. A. Dutcher, and P. T. Ziegler, The rapidity of the storage of thiamine and its retention in pork muscle, *J. Animal Sci.* **4**, 141 (1945).

[22] N. R. Ellis, D. Miller, H. Titus, and T. Byerly, Effect of diet on egg composition. III. The relation of diet to the vitamin B and vitamin G content of eggs, together with observations on the vitamin A content, *J. Nutrition* **6**, 243 (1933).

[23] R. Barnes, W. Lundberg, H. Hanson, and G. Burr, The effect of certain dietary ingredients on the keeping quality of body fat, *J. Biol. Chem.* **149**, 313 (1943).

[24] J. Chipault, W. Lundberg, and G. Burr, The chemical deterioration of tocopherols in animal fats; the stability of hog fats in relation to fatty acid composition and tocopherol contents, *Arch. Biochem.* **8**, 321 (1945).

The dogfish can outscrap the yellow perch on the end of a fish line—but the perch is the choice when it comes to the frying pan.

Maturity. Maturity can also contribute to the desirability or the undesirability of animal products. The dairy heifer is acceptable veal, but with increasing maturity steaks give way to hamburger. The spike buck may not provide so much meat nor so much taletelling, but he will provide a palatable product that his sire could not approach. Maturity is a factor that now can be controlled more practicably. Freezing as a means of preserving foods has taken away much of the uncertainty or inconvenience of slaughtering the meat supply for the farm. Livestock can now be processed at the maturity desired for the highest economy and palatability. In the refrigerated cooler of the community frozen-food locker plant the meat can be hung for proper conditioning; in the freezer, this meat, at the peak of its appeal, becomes a year-round staple in the farm family's diet.

Slaughtering procedures. Just as harvesting techniques are of concern for the plant crops, so are the techniques employed in slaughtering the meat supply important in securing the best quality of frozen food. Here the emphasis is placed on proper bleeding of the carcass.

Helser [25] points out that blood will decompose very rapidly and that, accordingly, complete drainage of the blood from the tissues is necessary. Tissues in which some blood remains, such as bruised areas, tend to spoil more readily than properly slaughtered carcasses. As with plant products, bruising is thus to be avoided. And the animal, whether it be a hog, beef, sheep, or chicken, should not be fed for some hours prior to slaughter. Animals full-fed immediately before killing do not bleed so thoroughly as is desired for best results.

THE ALLOTMENT OF FREEZER STORAGE SPACE

Quality begins with the raw material. Freshness can be frozen in foods. But the freezer can only yield up such food as originally was placed in it. Freezing can neither replace freshness nor substitute for wisdom. Care in growing foods of the proper variety under the best conditions, care in selective harvesting at the optimum maturity, and care in the handling, processing, stor-

[25] M. D. Helser, *Farm Meats*, New York, Macmillan Co., 1923.

age, and preparation for the table—these are the criteria for a freezerful of quality food.

Choice of foods to freeze. Freezer space is usually limited. Selection of foods from the many suitable for freezing is no small part of freezer ownership and operation. A home-freezing and storage plan is necessary with an allotment of freezer space to the various foods selected in order that the variety of products needed in a family food plan may be provided for. Food goes into the freezer in large amounts at one time during the growing season and is removed in small amounts from day to day. Food must not be stored longer than its optimum storage life. Regular turnover is necessary if the highest returns from the investment in equipment are to be realized.

The pattern for storage will be determined by the composition of the family, its living habits, its likes and dislikes, and the food available. The foods best preserved by freezing and those most enjoyed should have the first claim on the space. If it seems desirable to educate the family tastes for certain of the less popular foods, certainly some space should be allotted to them. There should be some room for experimentation, for experiments often prove highly successful and worthy of being made a permanent feature of the over-all plan.

Amounts of foods to freeze. After a choice has been reached of what foods to freeze, some decision as to the amount of each must be made. In addition to personal preference, consideration should be given to the kinds and quantity of food needed to furnish good nutrition. The size of freezer to build or to buy depends on the amount of food that must be stored at one time. If fruits and vegetables are home-grown for storage, by the end of the growing season a peak load of practically an eight months' supply should be in the freezer. The requirements for furnishing good nutrition to a moderately active man at moderate cost include approximately 7½ pounds of fruits and vegetables per week. If one half of this amount is eaten fresh or stored in other ways and the remaining half frozen, the amount to be frozen and stored for one person would be 120 pounds a year.[26] On the basis of 3 pounds of meat per person per week, 156 pounds per year would be needed. Farm freezers are most valued for the storage of the

[26] Anonymous, Family food plans for good nutrition, *U. S. Dept. Agr. Circ.* AWI-78 (1945).

home-grown meat supply. Frozen meat is eaten throughout the year. Approximately 117 pounds of frozen meat would be needed by each person if 75 per cent of the estimated meat requirement is frozen. It is likely that at least one half the year's supply would be in the freezer at one time. Fruits, vegetables, and meats to the amount of 178 pounds would be one person's share of the stored food. With a storage allowance of 30 pounds per cubic foot, the space requirement for this food would be 5.9 cubic feet or about 6 cubic feet per person. Where the facilities of a locker plant are available, the size of the home space might be reduced by the number of cubic feet rented at the community plant.

The advantages of adequate freezer space with wise choice of raw materials is summed up in the statement of one homemaker who writes, "We consider our cabinet one of the best investments we ever made. We are agreed, since using ours, that this method of preserving food will surely become universal and that home owners will consider a freezing unit as essential as they now consider a refrigerator." [27]

[27] Nancy K. Masterman, Using the home freezer, *Cornell Univ. Ext. Bull.* **658** (1944).

Chapter 3

PROCESSING FOR FREEZING: FRUITS AND VEGETABLES

Plant products adapted to freezing are invariably highly perishable foods. They are subject to many deteriorative influences after they are harvested and during the handling and processing incidental to freezing preservation.

Enzyme-induced changes. A pea in a pod detached from the vine continues to show many of the changes associated with ripening. The pea removed from the pod is even more subject to these changes. Meat continually changes in flavor and in tenderness, even though the animal is no longer living. The green banana picked in Panama becomes ripe only many days later and some thousands of miles away. The flesh of a bruised apple turns brown and softens. These changes are all the result of the action of a group of special proteins called enzymes.

Enzymes have the property of catalyzing or hastening chemical reactions. The undesirable changes in the bruised apple or the pea after harvest and the desirable changes in beef during aging or the banana during its trip to market are enzyme-catalyzed chemical reactions not unlike the process of digestion. If allowed to continue too long the changes will lead to true spoilage of the food.

Changes induced by microorganisms. External agents of chemical changes, microorganisms, are also capable of changing the color, flavor, texture, aroma, or other food qualities. Yeasts, molds, and bacteria may produce desirable effects, such as in the fermentation of cabbage to sauerkraut or in the ripening of cheese. Where one desires merely to preserve rather than to create distinctly new food products, these microbial agents are generally catalysts of food spoilage. Bacteria and mold on vegetables and fruit break down the supporting pectic material, with the result that the tissues become soft and mushy through loss of structure. Certain bacteria also convert the carbohydrates in vegetables to lactic acid, which is the material in curdled milk having a sour smell and taste. Products subjected to the action of such microorganisms become unpalatable in the earlier stages of decomposition.

Control of deteriorative changes. The aim of food preservation thus centers on the control of the activity of two powerful agents of chemical change in foodstuffs, microorganisms and enzymes. Common measures of control are often possible. Both microbial growth and enzyme activity are greatly slowed by lowering the temperature. This temperature effect is true for chemical reactions in general, and on this principle is based the freezing preservation of foods. Microorganisms and enzymes are both sensitive to heat and can be destroyed by exposure to the temperature of boiling water. The successful application of this principle is observed in the scalding of certain fruits and vegetables prior to freezing.

THE PROCESSING OF VEGETABLES—BLANCHING OR SCALDING[1]

The functions of scalding. Scalding is not a practice peculiar to processing for freezing. The canner has used this technique for many years; in dehydration scalding is now an accepted process for the majority of the products to be dried.

The intent is not always the same where scalding is applied to different products or different food-preservation methods. For dehydration, scalding not only serves to inactivate enzymes, but also partially precooks the tissues, which facilitates drying by rendering the cell membranes more freely permeable to moisture. In canning, the inhibition of enzyme activity is a secondary objective of the scald. The process may serve as a hot-water wash to remove adherent matter, may effect a desirable softening of the tissues to facilitate packing sufficient quantities of the product in the can, and helps form a vacuum when the sealed canned product is cooled.

[1] The preliminary heat treatment of plant products prior to dehydration, canning, or freezing is most frequently referred to as "blanching." This use of the term by food technologists has yet to be accepted and properly recorded in standard dictionaries. Because of its somewhat unfortunate and misleading connotation, and because the term "scalding" more adequately describes the process to the nontechnical reader, the term "blanching" will be dropped in favor of "scalding" in the discussions to follow.

Scalding for freezing. For preservation by freezing, the preliminary heat treatment performs many functions. The prime objective here, of course, is the arresting of the action of the oxidizing and respiratory enzymes which are largely responsible for the development of toughness, change in color, musty odors, loss of flavor, and deterioration in nutritive value of unscalded vegetables during extended periods in frozen storage and during subsequent thawing.

A second advantage gained by scalding is a striking reduction in the microbial population. A one-minute scald on peas may reduce the bacterial count from a million bacteria per gram to approximately one per cent of this value.[2] Steaming spinach for 3 minutes reduces the bacterial content 99 per cent.[3]

Additional gains achieved by scalding for freezing include the enhancement of the desirable green color of products such as peas; the wilting of a product such as spinach, a bushel of which can be packed in nine pint containers after scalding;[4] the softening of vegetables such as snap beans and asparagus, thus facilitating the packaging of these products in a minimum of space; the removal of some undesirable odors and flavors from certain raw vegetables such as a bitterness in asparagus; and the displacement of air from the cells of the vegetable tissue, thus increasing the storage life of the product by reducing the chances for oxidizing reactions to take place.

The necessity for scalding vegetables. During the early days of food freezing, scalding was not generally carried out on vegetables. As a result, enzyme activity was able to continue although at a reduced rate. In these frozen products, the natural processes of decomposition were merely slowed by the lowering of the environmental temperature. Unless these reactions were interrupted by a scalding treatment, undesirable changes inevitably occurred during zero storage, and frozen vegetables remained somewhat in disrepute.

Even where the deterioration during frozen storage is minimized, either by extremely low temperatures or short storage

[2] H. C. Diehl, H. Campbell, and J. A. Berry, Freezing of Alderman peas, *Food Research* **1**, 61 (1936).

[3] Helen F. Smart and B. C. Brunstetter, Spinach and kale in frozen pack. I. Scalding tests. II. Microbiological studies, *Food Research* **2**, 151 (1937).

[4] H. H. Plagge and Belle Lowe, Preservation of fruits and vegetables by freezing in refrigerated locker plants, *Iowa State Coll. Agr. Expt. Sta. Bull.* **P46** (1942).

times, the detrimental effects from the presence of enzymes in the vegetable may be encountered. For example, the ascorbic acid content of a frozen unscalded vegetable may not decrease appreciably until the product is thawed. Since many of the retaining cell membranes are ruptured in the process of freezing the tissues, there is a considerable mixing of the contents of the cells and the intercellular fluids following thawing. At that time, therefore, the vitamin will be rapidly and extensively oxidized, owing to the enzymes in the vegetable tissue coming in contact with the readily oxidizable vitamin. Today, nearly all vegetables for freezing are first exposed to steam or hot water to inactivate the enzyme systems responsible for the lowering of quality of the unprocessed frozen vegetable.

Undesirable enzyme systems. Our knowledge of the specific enzyme catalysts capable of affecting the fresh appearance and flavor of vegetables is still very spotty and incomplete. However, the agents that appear to be primarily responsible for these changes include both oxidizing and hydrolyzing enzymes. Where the reactions are enzyme-catalyzed, many of the color changes, some of the altered flavors, and the destruction of certain of the vitamins appear to be the work of the oxidases. Thus the rapid darkening of mushrooms appears to be catalyzed by the enzyme *laccase,* and the oxidation of ascorbic acid is promoted by *ascorbic acid oxidase* as well as other enzymes, such as *peroxidase.*

On the other hand, some of the texture changes appear to be the work of hydrolytic enzymes which split the chemical molecules making up the tissue framework. Thus *protopectinase* cleaves the pectic materials in the cell walls. The protopectin is "dissolved" away with the formation of a soluble pectin. The cells of the product thus become less firmly united, leading to a softening or collapsing of the vegetable tissue.

The effects of scalding. In scalding a vegetable, one general aim is to destroy the principal enzymes while avoiding the pitfalls of overscalding the product, which may include the leaching of flavors and nutritive elements and a deterioration in both texture and color. The resulting treatment is a compromise, and some residual enzyme activity is generally present in the processed food. Indeed, there is considerable evidence that enzyme activity, lost through the heat splitting of the catalyst into two components, may partially regenerate itself under favorable conditions after the product is again cooled.

Enzyme inactivation. Most of these destructive catalysts are inactivated fairly readily at temperatures above 160°F., a few minutes often sufficing to destroy the activity. Peroxidase appears to be one of the more heat-resistant ones. Tests for this enzyme thus serve as an approximate index of the adequacy of scalding. Simple and rapid qualitative and quantitative tests for the presence of peroxidase are available, one of the more common procedures being the guaiacol test.[5] A tissue extract having even very weak peroxidase activity will, in the presence of hydrogen peroxide and guaiacol, produce a readily visible and measurable orange–brown end product. Many food-freezing plants depend on such chemical tests for a control check on their processing.

Destruction of microorganisms. Concerning the effect of the scalding treatment on the bacterial count, it should be stressed that the short period of heating is not effecting a sterilization of the food. Like the heat-labile proteins that make up the enzymes, microorganisms are very effectively killed by exposure to boiling water. However, some bacteria change in character during part of their life cycle, existing as hard capsulated, dormant *spores.* These spores are extremely resistant to heat. For the canning of corn, temperatures as high as 245°F. for as long as 80 minutes are necessary[6] to effect satisfactory sterilization, primarily because of the presence of these bacterial spores. Since the normal heat treatment for corn for *freezing* is only 6 to 10 minutes at 212° when on the cob and considerably less when cut from the cob, it is not surprising to find that many of the active forms of microorganisms and the majority of the spores will survive scalding. If allowed the benefits of favorable temperature conditions, these spores will revert to the active forms of spoilage bacteria.

Color changes in scalding. A striking effect of the few minutes' exposure of green vegetables to temperatures of boiling water or steam is the "fixing" of the green color. Indeed, the color is intensified over that found in the freshly harvested vegetable. Fresh asparagus has considerable red or purple pigmentation along both

[5] M. P. Masure and H. Campbell, Rapid estimation of peroxidase in vegetable extracts—an index of blanching adequacy for frozen vegetables, *Fruit Products J.* 23, 369 (1944).

[6] Anonymous, Processes for non-acid canned foods in metal containers, *National Canners Assoc. Bull.* 26-L, 5th ed. (May 1942).

the tips and butts. This coloration is due to a naturally occurring group of plant pigments known to the chemist as *anthocyanins.* Under the influence of heat, the red disappears with the formation of a colorless "pseudo base" modification, and the green pigmentation thus becomes more pronounced. Fresh green beans have considerable yellowish green pigmentation. This coloration is in part due to another group of plant pigments known as *flavonols.* Here the heat treatment intensifies the green color by changing the yellow–green to a blue–green shade. Similar striking fixation of a brilliant green coloration is evident in frozen peas, spinach, broccoli, and many other vegetables.

Precooking effects of scalding. A steam or hot-water scald ranging for vegetables from 1 to 10 minutes obviously effects a partial cooking. This is evidenced in a wilting and softening of the tissues, which frequently is an aid to the economical packing and packaging of the vegetable. During the freezing and thawing process, the physical effect of the ice crystals between and within the cells is to further soften the tissues. The net result is that scalded and frozen vegetables require much less time for cooking, perhaps one third to one half of the cooking period for the fresh vegetable.

The time element in scalding. When one attempts to translate the general principles of an adequate scald into a fixed schedule of processing for each vegetable product, the problem of personal preference is immediately encountered. This is evident in the varying recommendations to be found in the literature on food freezing.

Many investigators very strongly favor steam scalding to a boiling-water scald, even for processing in the home. Others, recognizing the advantages of steam, recommend that it be used commercially, but favor water scalding for the home because it is simpler and more "foolproof."

Some workers insist that in using boiling water for the scalding medium a sufficient volume of water must be available to prevent a lowering of the temperature when the vegetable is immersed. Thus as much as 5 gallons of water per pint of vegetable may be called for.[4] Other investigators recommend 1 to 2 gallons of boiling water per pound of vegetables to be scalded. But even here there is a minor parting of the ways, for some recommend that the scalding time start when the product is first immersed, whereas others count their scalding period from the time when the water has again returned to a boil.

Personal likes and dislikes in food qualities, and the maturity, size, and variety of the vegetable will all affect the choice of a scalding time for a given product. For home processing, the amount of heat that can be directed on the scalding kettle will have a significant effect on the time required for the water to return to a boil. Since the cooking action progresses even though the water may not be boiling, it is obvious that a variable amount of scalding may be accomplished during this period following immersion of the produce. Thus it is not surprising to find that published recommendations for scalding times are not strictly in agreement with each other.

Variable recommendations in scalding vegetables. Six pamphlets on freezing, selected at random and containing directions for the homemaker or locker operator, range as follows in their recommendations for scalding times in boiling water:

For asparagus, the times range from 2 minutes to 4 minutes.

For snap beans, scalding times from 2 to 3 minutes are recommended.

For lima beans, times from 1 to 3½ minutes are suggested.

For broccoli, the recommendations range from 3 to 5 minutes.

For Brussels sprouts, 3 to 4½ minutes of scalding is proposed.

For small ears of corn on the cob, the recommendations range from 4 to 7 minutes' scalding. For large ears, the times range from 8 to 10 minutes.

For peas, recommendations as low as ¾ and as high as 2½ minutes are found.

For spinach, scalding times from 1 to 3 minutes are suggested in different bulletins.

Some booklets also give scalding times where steam is to be used, rather than boiling water. The ranges in this case are even wider. For example, the recommended times range from 2 to 8 minutes for asparagus, from 1 to 4½ minutes for lima beans, from 2 to 5½ minutes for Brussels sprouts, from 1 to 3½ minutes for peas, and from 1 to 4 minutes for spinach scalded in steam.

From a glance at even these few recommendations for the scalding of eight popular vegetables for freezing, it is evident that there is some leeway in the processing of vegetables.

Underscalding versus overscalding. There is a *minimum* scalding period below which enzyme inactivation is quite incomplete. Most, if not all of the investigators, are agreed that such a minimum processing time must be equaled or exceeded. There is, however, no such definite *maximum* scalding period above which food quality is lost or rendered unstable. As the heating period for scalding is extended, the necessary or desirable heating period for subsequent cooking is shortened. This is one reason why recommendations for the cooking of frozen vegetables may vary.

Overscalding is to be avoided. But as a general rule, overscalding is to be considered less serious than underscalding when a long storage life is desired for the frozen product.

Steam versus water scalding. Water has been termed the universal solvent. Many of the carbohydrates, proteins, minerals, and vitamins in plant products are soluble in water. Thus it is obvious that excessive exposure of these foodstuffs to the scalding action of boiling water will inevitably result in a lowering of the nutritive value of the final product.

The dissolving power of water is greatly increased by a rise in temperature. And a disorganization of the tissues, characterized by a disruption of the integrity of the cells together with an increasing permeability of the cell membranes, is also effected by exposure to high temperatures. These two facts mean that the scalding of vegetables in boiling water may have a very pronounced effect whereas the preliminary washing of the vegetables has but little effect on the nutritive materials dissolved in the tissues.

The disorganization of vegetable tissue under the influence of heat occurs whether boiling water or steam is the scalding medium. In the latter case, only a minimum of leaching of the dissolved nutrients is possible. The result is that changes in vitamin content, soluble sugars, and other quality indexes are kept at a minimum.

In water scalding, the vegetable is exposed, in some cases for as long as 10 minutes, to large volumes of boiling water. During the early period, when enzyme destruction and other desirable effects of scalding are taking place, the leaching of solids is not excessive. If, however, the scald is prolonged beyond this necessary minimum period, loss of tissue solids continues to the point where it may become appreciable. Because there is a loss in the soluble constituents during scalding in water that is not obtained in steam scalding, the latter is generally the preferred method.[7] It should be pointed out, however, that losses of dissolved solids may be very considerable during the period of cooling after scalding,[8] when the vegetable is immersed in water. Shortening this period of immersion to the minimum may afford more savings in nutritive value than merely changing from a hot-water to a steam scald.

Nutrients affected by scalding. Some food elements, such as fat-soluble vitamin A and the yellow pigment, carotene, are not affected by the leaching action of the hot water. And among the water-soluble materials considerable differences may exist in the losses encountered during the scalding operation.

For example, during a one-minute water scalding of peas as for freezing, some 6 per cent of the protein, 15 per cent of the sugar, and a similar amount of the mineral constituents were leached out, whereas the ascorbic acid loss was in the neighborhood of 35 per cent.[9] The very high solubility of ascorbic acid, coupled with the fact that vegetables constitute the principal source of this vitamin in the diet, has led to its often serving as an index of the effects of both the processing and cooking on the nutritive value of vegetable products.

The nutrients may be protected from solution losses by reducing the amount of cut surface through which leaching may occur rapidly. In *sliced* green beans,[9] 10 per cent of the protein, 27 per cent of the sugar, 26 per cent of the minerals, and 40 per cent of the ascorbic acid were lost in a 2-minute water scald. *Whole* green beans similarly processed lost only 1, 1, 10, and 9 per cent, respectively, of these nutrients.

The suitability of various scalding waters. The mere determination that a water supply is safe from a sanitary standpoint does not mean that it is suitable for the processing of foods. Assurance must be obtained that the water does not contain materials which will prove harmful to the texture, appearance, odor, flavor, nutritive value, or storage life of the processed food.

[7] D. Melnick, M. Hochberg, and B. L. Oser, Comparative study of steam and hot water blanching, *Food Research* 9, 148 (1944).

[8] E. N. Todhunter and Ruth C. Robbins, Ascorbic acid (vitamin C) content of garden-type peas preserved by the frozen-pack method, *Wash. Agr. Expt. Sta. Bull.* 408 (1941).

[9] A. G. Horner and J. Stanworth, Changes occurring during the blanching of vegetables, *J. Soc. Chem. Ind.* 61, 96 (1942).

Commercial canners have long known that water with excessive "hardness" has an undesirable effect on the texture of vegetables such as peas. The calcium in the water is taken up by the pectin materials in the skin, with the result that a toughening becomes evident. According to Miles,[10] this texture change occurs during the scalding of the peas, rather than during the washing operation. One hundred and fifty parts per million of the salts which characterize "hard" water can lower the quality grade of commercially canned peas.

The preliminary stages of processing for freezing resemble the early steps in canning of vegetables. Accordingly, it is not surprising that the frozen-food packer finds that he must also watch the characteristics of the scalding water. Excessive "hardness" may contribute a toughening effect. Excessive iron may cause a rusty discoloration on the surface of the product. "Temporary hardness" in the form of various bicarbonates may cause trouble and lower efficiency by forming scale in the boilers and similar deposits on the heat-processing equipment. Copper in the water may cause color changes and in addition may promote the oxidation of the nutrients, including ascorbic acid.

The treatment of water in the larger food-preserving establishments is an accepted practice where the water supply has some of the defects previously noted. Where the freezing of foods is carried out in the smaller plant, such as the community frozen-food locker plant, or in the home, such treatment is not generally feasible unless the need should prove to be particularly acute. A recent study[11] indicates that the nutritive value and the storage life are not adversely affected by scalding waters such as most home processors are likely to use. In many states the water supply may *average* in the high range of more than 180 p.p.m. of "hardness." Such waters, containing calcium as both temporary (bicarbonate) and permanent (sulfate) "hardness" in amounts up to 500 p.p.m. and 100 p.p.m., respectively, proved acceptable for scalding prior to the home freezing of either peas or beans. Furthermore, as much as 1 p.p.m. of iron or 0.25 p.p.m. of chlorine was not such as to pose a problem. The conclusion drawn was

[10] H. V. Miles, Correction of defects of water used for food manufacture, *Proc. Inst. Food Tech.* **1944**, 59.

[11] F. A. Lee and Joanne Whitcombe, Blanching of vegetables for freezing. Effect of different types of potable water on nutrients of peas and snap beans, *Food Research* **10**, 465 (1945).

that with infrequent and minor exceptions, such as where the extremely iron-hard waters in the Adirondack region of New York or the northern part of Minnesota are encountered, the quality of the potable water in the city or on the farm is generally suitable for scalding prior to the home freezing of vegetables.

THE PROCESSING OF FRUITS

The retention of the original color of fruit products has long claimed the attention of investigators, for not only is the appearance of the product affected by changes in color, but also such changes are accompanied by loss of flavor and nutritive values. The preservation of fresh fruit color is of prime importance in preserving fruits for freezing where "just like fresh" is the main stock in trade. Early attempts in preventing discoloration by oxidation in frozen fruit were crude and laborious. Cherries, for instance, were mixed with sugar and packed in barrels, and the barrels were rolled twice a day to change the surface and prevent discoloration of the layer exposed to the air. Cold-packed fruits so treated were acceptable to jam makers and other processors, and some fruits are still thus packed. It was not until new methods improved fruit quality that they were acceptable in consumer-size units. Consumer acceptance of some fruits has been very slow to develop because of the tendency of these foods to darken rapidly on thawing. The use of antioxidants such as ascorbic acid is not widespread even today. As a consequence apricots, peaches, and apples are found among the less popular frozen fruits for dessert use in consumer packages.

Browning and its prevention. Joslyn [12] attributes the browning of fruits to the formation of pigmented substances by decomposition of certain chemical constituents, to the reaction between some of the constituents of the fruit tissues and the oxygen of the air, and to reaction between constituents present or introduced in manufacture. It is the second factor, enzyme-catalyzed oxidation, that is largely involved in the processing of fruit by freezing.

Since color changes may occur during the preparation, processing, storage of the fruit, and thawing, measures to prevent or

[12] M. A. Joslyn, Color retention in fruit products, *Ind. Eng. Chem.* **33**, 308 (1941).

to inhibit discoloration must be taken at each step. Discoloration of surfaces exposed to air is first to occur. Speed in handling and the rapid exclusion of air are therefore of prime importance for those fruits subject to appreciable browning, such as apples, apricots, and peaches.

Various forms of special processing have been proposed to prevent oxidative discoloration in fruits. Scalding is effective, but among its objections are its deleterious effect on the delicate and volatile fruit flavors. Accordingly, the trend has been to incorporate antioxidant chemicals prior to freezing.

Antibrowning agents. A common inhibiting agent used in preventing browning during processing and storage is citric acid, which is the edible and flavorful acid of citrus fruits. Citric acid has been quite successful in preventing darkening of fruits such as peaches. Generally, they are dipped in a citric acid solution having a concentration of approximately 2 per cent. Other acids, including tartaric, are also effective as antioxidants.

Sulfuring of fruit has long been used in processing for sun drying or dehydration. The reducing properties of sulfur dioxide or sulfites have also been advantageously applied in treating fruits for freezing. MacArthur [13] recommends a sulfite dip (2 minutes in a solution containing 2800–3000 p.p.m. of sulfur dioxide or its equivalent) as being the most effective economical means of preventing browning of apple sections. In the use of sulfite the dipping or spraying step must be closely controlled and must be correlated with subsequent processing and handling. Too high a level of sulfur dioxide on the fruit will lead to a distinct and foreign flavor; too low a level will lead to discoloration of the fruit. Time, temperature, draining, holding, acidity of the product, and other factors have a contributing influence on the level of sulfur dioxide in the final frozen and thawed fruit.

Recently, ascorbic acid has been proposed [14] as a reducing agent to prevent oxidative browning of cut fruits for freezing. A concentration of 0.2 per cent of ascorbic acid in the sugar sirup is very effective in minimizing color changes both before freezing and after thawing. While this process is somewhat more expensive than other means of checking browning in fruits, it does

[13] Mary MacArthur, Freezing apples for bakers, *Food Packer* 16, 13 (1945).
[14] D. K. Tressler and C. W. DuBois, No browning of cut fruit when treated by new process (ascorbic acid treatment), *Food Industries* 16, 75 (1944).

have the unique advantage of materially improving the vitamin content of the food. It thus enriches the nutritive value while serving to maintain the other desirable qualities of the cut fruit.

Speed in processing. Air is excluded by immersion of the foodstuff in a liquid. Prefreezing treatment of the cut fruit may be simple. Commercially, spray freezing with a refrigerated sugar solution has been successful in minimizing discoloration in fruits such as apples.[15] This combines the use of a protective coat of sirup with a great reduction in holding and freezing time during which deterioration may occur. As practiced by the homemaker, the fruit may be held in a 2 to 3 per cent brine while awaiting the next processing step, or the holding period is eliminated entirely by the preparation of only a small quantity at a time. The fruit may be sliced directly into the protective sirup in the container, after which a ball of paper placed directly under the lid will keep the fruit immersed in the sirup.[16]

Sirup pack. Not only is enzymic discoloration reduced by storage at low temperatures, but also it is indirectly inhibited by sugar sirup, which serves to exclude air from the tissues. The addition of sirup to fruits for freezing also markedly improves the texture.[17] For peaches [18] as well as other products, a sirup of approximately 35 per cent sugar produces the least change in the physical texture. More concentrated solutions tend to draw the water from the tissues, leading to a shrunken condition. Weaker sirups are below the osmotic concentration of the fruit juice, and accordingly the tissues will take up water to the detriment of the texture.

A sirup, made by dissolving granulated sugar in water, may be poured over the fruit. Sirup concentrations of 30 to 60 per cent are commonly used. Although some authorities occasionally recommend concentrations as high as 65 to 70 per cent for strawberries and peaches, the 40 per cent concentration is the usual one recommended for all-round use by homemakers. It is common practice commercially to use sirups varying from 45 to 56 per cent.

[15] V. R. Greene, Modern quick-freezing methods, *Canner* **91,** 15 (1940).

[16] J. D. Winter and A. Hustrulid, What's new in freezing foods for home use, *Minn. Farm & Home Sci.* **2,** no. 3, 1 (May 1945).

[17] M. A. Joslyn and G. L. Marsh, Observations on certain changes occurring during freezing and subsequent thawing of fruits and vegetables, *Fruit Products J.* **12,** 203 (1933).

[18] J. G. Woodroof, Preserving fruits by freezing. I. Peaches, *Georgia Agr. Expt. Sta. Bull.* **163** (1930).

Well-ripened fruits, and particularly tree-ripened produce, require less sugar or a weaker sirup. From the standpoint of browning the inclusion of crystalline ascorbic acid in sirups permits the use of a lighter sirup.[19]

Sugar pack. The sugar sirup may be formed by solution of the dry sugar in the fruit juice itself, since the sugar solids in contact with the fruit a short time will, by osmosis, draw the juices from the fruits. However, because the sirup pack tends to retain better the original texture, and because it offers a more immediate and complete protection from oxidation arising from the presence of air, it is generally preferred to the use of sugar alone in frozen pack fruits.

Recommendations for the proportion of fruit to dry sugar in sugar packs vary from two pounds of fruit to one pound of sugar (2:1), to five pounds of fruit to one pound of sugar (5:1). The 2:1 pack is generally considered too sweet for most tastes. If the proportion of fruit to sugar is greater than 5:1 the color and quality may not be protected. The usual recommendation is the 3:1 pack.

Seasonal variations in fruit and personal preference determine the final choice of the proportion of fruit to sugar within the recommended range. The dry-sugar pack results in greater tissue shrinkage and a product of higher drained weight with less liquid when thawed than does the sirup pack. It is therefore better adapted to certain uses, such as pie manufacture or jam making. Whereas a 45 per cent sirup pack will harden and remain frozen, the solution of the sugar and fruit juice may remain in liquid state at 0°F.[20] Leakage in packages of fruit so treated and stored in lockers is frequent.

Unsugared pack. Very few fruits are entirely satisfactory for dessert purposes when frozen without some sweetening material. The fresh flavor, aroma, and color are not retained, and the texture becomes spongy on thawing. The addition of sugar or sugar sirup prior to freezing affords a definite protection to the ascorbic acid contained in the frozen product. Frozen strawberries may have an ascorbic acid content equal to that of orange juice and exceeding that of grapefruit juice.

[19] J. C. Bauernfeind and G. F. Siemers, Adding ascorbic acid to peaches before freezing, *Food Industries* **17**, 745 (1945).

[20] J. D. Winter and I. Noble, Frozen fruits and vegetables for home use, *Minn. Ext. Bull.* **200** (1939).

Whole ripe fruits for processing by canning or preserving or for use in the bakery trade may be frozen as they are harvested, with the advantage of prolonging the canning or preserving season. Such fruits generally must be surface-scalded before being defrosted to stop enzymic discoloration.

Other sweetening materials. Honey, corn sirup, or enzyme-converted corn sirup have been used to replace sucrose with varying results. Honey and corn sirup will give a distinctive flavor to the product if they replace more than 25 per cent of the sucrose. This flavor may or may not be objectionable, according to personal tastes. Especially does the acceptance of honey depend on personal likes and dislikes. Enzyme-converted corn sirup, such as the commercial product known as Sweetose, may replace sucrose to one half the weight with little or no change in quality.[21] Additional replacements depend on personal reactions. The converted corn sirup alone without a sucrose sirup is quite satisfactory for packing fruits such as peaches. Since the use of enzyme-converted corn sirup seems to result in plumper fruit with higher drained weight than does the use of sucrose, it may have advantages above sucrose for commercial use.[22] Co-operators in a study of home freezing in Tompkins County, N. Y., enthusiastically endorse the special sirup for freezing fruit, especially peaches. Fifty-nine per cent of the homemakers report they will continue to use it when sugar is again available in unlimited quantities. An additional 15 per cent would like to use it if cost is comparable with that of sugar.

SANITATION

Selection of high-quality fruits and vegetables and proper processing are only two of many steps in sanitary food processing. Even scalding is no cure-all. At the same time that the scalding treatment is reducing the number of contaminating microorganisms, the cells of the product are being disrupted and made more susceptible to the invasion of bacteria, yeasts, and molds. If a prolonged lapse of time occurs between scalding and freezing, if the product is not properly cooled after scalding, if the handling of the scalded product allows recontamination, the food may be

[21] J. D. Winter, Quality in frozen fruits and vegetables, *Minn. Agr. Expt. Sta. Bull.* **362** (1943).

[22] D. K. Tressler, Freezing fruit with corn syrup, *Western Canner & Packer* **32**, no. 13, 42 (1940).

more readily spoiled by bacterial action than the fresh raw produce itself. The few bacteria remaining on scalded peas will multiply with great rapidity if conditions are made favorable. From the kitchen in the home to the processing plant of the commercial freezer, a sanitary and efficient plant is a "must."

Cleanliness is essential, for in this way the sources of contamination can be removed. The water supply must be safe, and it must be adequate. Inadequate water supplies result in inadequate washing of the plant, the equipment, and the product.

The commercial processor is usually aware of the desirability of sanitary handling of foods and is eager to improve his own plant and process. It is encouraging to note that a survey of the microbial content of a number of commercially frozen fruits and vegetables over a period of 8 years showed [23] that high counts of yeasts, molds, or bacteria in frozen products were less common in the last two years reported (1935 and 1936) than they were before that time. In many cases the reduction in the number of microorganisms contaminating the frozen food was very striking.

An index of adequate sanitation. It has been suggested [24] that:

> . . . if the bacterial content of a sample of frozen vegetables is low, let us say under 80,000 per gram, you may be reasonably sure of the following things: (1) The product has been blanched at a temperature sufficiently high to kill practically all of the bacteria found on the surface of the fresh vegetable. (2) The blanched product has been quickly and adequately cooled in water free from gross contamination. (3) The blanched vegetable has been kept cool throughout the remainder of the process of preparation for freezing. (4) The plant and its equipment were maintained clean and sanitary. (5) The vegetable was packaged in clean packages. (6) The method of freezing employed was sufficiently rapid to prevent the multiplication of bacteria during this operation. (7) The vegetable has not been permitted to warm up to the thawing point at any time during storage, transportation, or marketing.
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> If the vegetable had been carelessly handled at any time during preparation for freezing, storage, transportation, or marketing, the bacterial count would have jumped up to at least 100,000 or more likely 200,000 or more per gram; and subsequent operations would not have reduced it greatly.

[23] Helen F. Smart, Microbiological studies on commercial packs of frozen fruits and vegetables, *Food Research* **4**, 293 (1939).

[24] D. K. Tressler, Bacteria, enzymes and vitamins—indices of quality in frozen vegetables, *Refrig. Eng.* **36**, 319 (1939).

The progress of freezing technology is reflected in the data just cited;[28] in 1936, four out of five vegetables tested had microbial counts well below the 80,000 per gram suggested as a goal, whereas in 17 tests on these vegetables in previous years only twice was the count within this range. Apparently the frozen-food packer is both able and willing to keep his house in order.

Chapter 4

PROCESSING FOR FREEZING: MEAT, FISH, AND DAIRY PRODUCTS

The foods of plant origin, particularly the vegetables, are treated very differently when being prepared for freezing from what they are when being prepared for immediate sale or consumption as fresh foods. Animal products, on the other hand, are generally handled quite similarly whether or not they are destined for zero storage.

The preparation of animal products for freezing is based on a few simple premises. Prolonged storage of meats even at subfreezing temperatures permits, at a very greatly reduced rate, slow changes similar to the reactions that occur at ordinary refrigerator temperatures. And, in contrast to the vegetables, the meat and eggs for freezing are not first subjected to an oxygen-expelling enzyme-inactivating bacteria-reducing heat treatment. Hence, any shortening of the period during which deteriorative changes can take place prior to freezing should prolong the storage life of the frozen food.

Many of the frozen products will be used for cooking when they are still frozen or only partially thawed. And even where the product is to be completely thawed, it is not suitable to remove part of the thawed product for consumption and to refreeze the remainder. The meats therefore are prepared and packaged for the most part in unit packages of sizes convenient for subsequent cooking.

Animal products, such as meats, shelled eggs, and milk, offer a moist surface with an abundance of soluble nutrients for microorganisms of disease and spoilage. Accordingly, these foodstuffs are particularly susceptible to undesirable microbial growths. Sanitary practices in processing for freezing here constitute a top requirement.

The chilling and aging period. The temperature of the flesh of freshly slaughtered animals will range in the neighborhood of

101 to 107°F. Obviously, the chemical and physical changes (autolysis) that continue after death of the animal will proceed more rapidly and more extensively if this temperature is only gradually lowered than if cooling is prompt. In general, therefore, the removal of the so-called "animal heat" is an immediate concern in preservation of the animal foods.

What is this "animal heat"? In the minds of many today, the heat contained in freshly slaughtered carcasses is something mysterious. They consider this heat as being entirely distinct from ordinary warmth in other products, or even in the same products if they are once warmed up after first being chilled. Around this supposition or superstition has been built the belief that refrigeration should be used only after the "animal heat" has been dissipated by "natural means."

Many years ago the meat packers came to recognize that "animal heat" was dissipated according to the usual physical laws that govern heat transfer, and that if "natural means" are good refrigeration should be better. The result of this tradition-shattering concept is evident in present-day practice of the packers of moving the warm dressed carcasses immediately into the cooler. This step has measurably prolonged the keeping period of these meats.

The old concept of a distinct form of heat energy requiring special handling in the preservation of flesh foods has now made its impact in freezing technology. The same man who today is using 34° temperature for chilling carcasses refuses to consider immediate freezing at temperatures of 0° or lower because "it will freeze the 'animal heat' in." This is in the face of the fact that if 34° will hasten dissipation of the heat, freezing temperatures will promote even more rapid cooling.

Recently a successful locker operator, who manages the largest plant in his state, stated that "turkeys and other poultry *must not* be placed in the freezer within 72 hours of slaughter, because the 'animal heat' would be frozen in them." His fears have little support in scientific fact.

The evidence indicates that in the ordinary chill room, poultry loses "animal heat" within 24 hours or less. Furthermore, it has been pointed out[1] that ice has four times the thermal conductivity and only half the specific heat of water. These combined facts

[1] W. Stiles, The scientific principles of cold storage, *J. Soc. Chem. Ind.* **40**, 112T (1921).

mean that of the two ice will cool much more rapidly. This indicates that the freezing of the surface of foods will actually *assist* rather than delay the removal of heat from the center of the mass.

Prompt versus delayed freezing. Freezing may and often should be carried out shortly after slaughtering. It has been stated [2] that rapid freezing of poultry will prevent off-flavors developing from bacterial and enzyme action in the digestive tract in undrawn birds and will check bacterial growth in the abdominal cavities of eviscerated poultry. Many others concur in the recommendation that poultry be frozen promptly after they are killed, preferably the same day. The evidence indicates [3] that juiciness, tenderness, and general palatability of broilers are the same whether the birds are frozen within 2 hours of slaughter or are held until the body temperature has dropped to the temperature of the cooler. Furthermore, as the period between slaughter and freezing is increased, the greater is the tendency for the fat in poultry to turn rancid during zero storage.[4]

Fish are very susceptible to deterioration through the action of both the external microbial agents and the internal enzymic catalysts of chemical change. Here prompt chilling and a minimum of delay in freezing are essential for the retention of freshness. Indeed, recent trends in the frozen-fish industry have been toward equipping the fishing boats with refrigerating machinery so as to enable the freezing of the fish immediately after the catch has been brought aboard.

Pork requires promptness in processing for the best quality and for the longest storage life. In the channels where pork is to be consumed fresh, the time between slaughter and final distribution through retail outlets is generally only five to seven days. For freezing, this holding period must be shortened in order to make possible prolonged zero storage over a period of months, since rancidification and other changes are hastened by prefreezing storage even at the low chill room temperatures.

During the war Argentine beef destined for England was boned immediately following slaughter, and the still warm meat was

[2] P. Mandeville, The quick freezing of poultry, *Refrig. Eng.* **34**, 149 (1937).

[3] G. F. Stewart, H. L. Hanson, Belle Lowe, and J. J. Austin, Effects of aging, freezing rate, and storage period on palatability of broilers, *Food Research* **10**, 16 (1945).

[4] W. H. Cook and W. H. White, Frozen storage of poultry. IV. Further observations on surface drying and peroxide oxygen formation, *Can. J. Research* **18, D,** 363 (1940).

frozen. The resulting product had the benefit of a high-quality rating in addition to several points of economy in its favor. In general, however, aging the beef prior to freezing is preferred for the better cuts of meat.

Aging for tenderization. For some meats, which may include poultry, mutton, and wild game, but particularly for beef, a limited period of holding under refrigerated conditions improves the tenderness of the product sufficiently to make such a practice desirable. The period of holding (aging) at 34° may range from a day or two to several weeks.

There is still considerable uncertainty over the chemical mechanism whereby the tough fibers of meat are made tenderer by the aging process. During this period of change the autolytic enzymes within the flesh proceed to hydrolyze and otherwise alter the structural components of the tissue. Apparently the collagen and elastin, proteins which characterize tough elastic connective tissue, are changed physically or chemically so that they no longer offer so much resistance to the shearing and crushing action of chewing.

The proper aging or ripening period for meats naturally is dependent to a certain extent on the original condition or grade of the carcass. In general, beef for the retail trade may hang one to two weeks at 34°F. Helser [5] recommends that lamb and mutton hang for a similar period to improve both tenderness and palatability. Such aging periods are not necessarily indicated for the freezing preservation of meat.

Using several different types of mechanical devices for the determination of tenderness of meats (Fig. 5), various investigators [6, 7] have found that freezing significantly increases tenderness. Beef that was aged at 34°F. for five days and then frozen proved to be as tender as unfrozen beef ripened for over a month.

The tenderizing action of freezing can thus take over at least a part of the functions of the aging period. Where the meat is headed for the freezer, the tenderizing period can be shortened by fully 50 per cent. The result will be evident in a longer storage

[5] M. D. Helser, *Farm Meats,* New York, Macmillan Co., 1923.

[6] R. L. Hiner and O. G. Hankins, Tenderness of beef as affected by aging with and without subsequent freezing, *Refrig. Eng.* **42,** 198 (1941).

[7] D. K. Tressler, C. Birdseye, and W. T. Murray, Tenderness of meat. I. Determination of relative tenderness of chilled and quick-frozen beef, *Ind. Eng. Chem.* **24,** 242 (1932).

life, less shrinkage arising from moisture loss in the cooler, and smaller trimming losses from the meat thus processed.

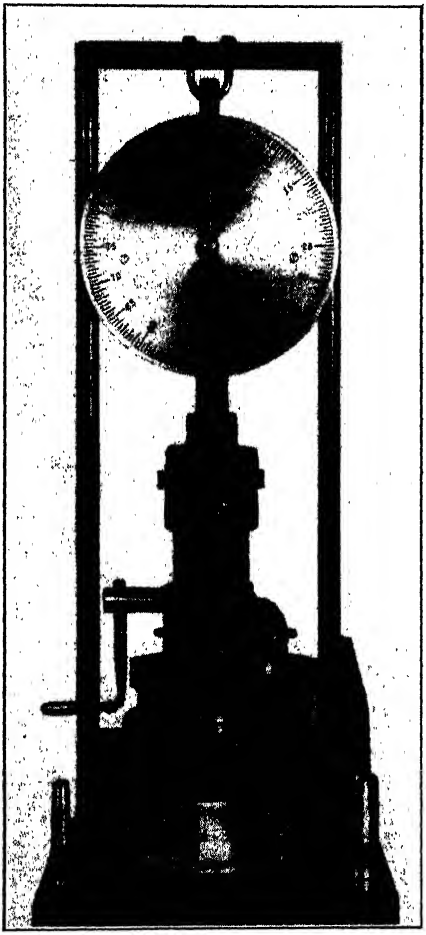


Figure 5. One of the mechanical devices for a quantitative determination of tenderness of meats. This. Warner-Bratzler shear machine registers the force required to shear through a standard cylindrical sample of the meat.

Accelerated aging of meats. As has previously been pointed out, enzyme activity is greatly influenced by temperature. Since the desirable changes associated with the aging of meat appear to be largely enzymic, it was a not unexpected finding that the holding period could be markedly shortened if the temperature of the chill room was elevated above the usual 32° to 36° range.

At higher temperatures moisture evaporates more readily, and greater shrinkage may occur if the humidity is not kept high. On the other hand, molds and bacteria thrive and multiply more rapidly under these favorable conditions of high moisture and temperature. Accordingly, under such accelerated conditions it has been necessary to find some means of holding the microorganisms in check while allowing the autolytic changes to continue within the meat tissue. Ultraviolet rays of selected wave lengths (such as 2537 angstroms) have provided this means of controlling the microbial agents that lead to whiskery mold, slimy growths, and off-odors and flavors.

The function of the ultraviolet lamps is to arrest the growth of spoilage microorganisms. The ultraviolet rays do not contribute directly to the process of tenderization. That inhibition of the development of bacteria and molds is obtained in the presence of the ultraviolet radiation seems well established. This retarding effect is evident at the usual 34° temperature as well as in the range of 50°, used in one study of accelerated meat aging.[8] There is considerable doubt, however, that under proper conditions of sanitation such extra measures need be taken to keep microbial growths within reasonable and safe limits at temperatures not exceeding 50°F. Certainly, the fact that none of the larger meat packers uses ultraviolet light in the chill and aging rooms attests to the fact that at 34°F. there should be no need for germicidal rays to maintain a sanitary plant and high-quality meat. Its value under the somewhat drastic conditions associated with accelerated aging is more evident.

Work at the Mellon Institute has suggested that very great reductions in aging time can be effected by raising the temperature to 60–65°F. One large meat retailer[9] for some time has used with success the accelerated aging of beef for three days at 60°F., the microorganisms being held in check during this period by means of ultraviolet radiation. Studies at Washington State College[8] indicate that steaks from "utility"-grade-beef short loins will be

[8] J. Sotola, J. A. McIntosh, C. C. Prouty, J. B. Dobie, M. E. Ensminger, and M. A. McGregor, The relation of ultra-violet light and temperature during aging to quality of beef, *Wash. Agr. Expt. Sta. Bull.* **431** (1943).

[9] P. B. Christensen, Modern beef chilling. Tenderizing and chill room design, control and operation, *Refrig. Eng.* **39**, 296 (1940).

somewhat more tender when aged for 6 days at 50° than when aged for a similar period at 34°F. Another study[10] on rib roasts of "U. S. Good" grade beef has shown that aging for 48 hours at 60°F. (using ultraviolet rays to prevent spoilage) followed by a similar period at 36°F. increased the tenderness of the meat somewhat over that of beef held at 36°F. for the entire 96-hour period. The surprising part of these findings is that the beneficial effect of high temperatures on meat tenderizing was only approximately 11 per cent.

Such studies as have been carried on regarding the use of ultraviolet lights in meat-aging rooms have confined their scope to retail meats destined for immediate consumption. Indeed, they have dealt with only the effect on beef alone. There is at present a growing tendency for frozen-food locker plants to install ultraviolet ray lamps in their meat-holding rooms to keep down microbial growths and to "sweeten" the air. This trend makes it particularly urgent to have more information specifically directed toward processing for freezing. For example, more is needed on the relative merits of ultraviolet radiation versus other means of assuring a sanitary plant and product. Still more important and worthy of study is the effect of the lamps on pork and poultry in the same cooler. In contrast to the distribution of fresh meat, frozen meat has as a major problem the development of rancidity during the extended period in storage. On the one hand, we have the tendency of pork and chicken fat to rancidify. On the other, we have the facts that both the ultraviolet rays themselves and the ozone which is formed in air exposed to these rays promote more rapid oxidation of fats. The likelihood of a rancidity problem, but not the actual magnitude of the problem, is evident.

MEAT CUTTING FOR FREEZING

Because frozen meat lends itself to the same cooking procedures as does fresh meat and is not packaged in containers of a fixed size as is the canned product, preservation of meat for freezing, with the exception of that frozen for the military services, has not demanded radical changes from cutting for sale over the retail meat counter. The large body of civilians using frozen meat are

[10] R. M. Griswold and M. A. Wharton, Effect of storage conditions on palatability of beef, *Food Research* **6**, 517 (1941).

the patrons of community locker plants. These families have had no opportunity to see or know of other methods and therefore have no means of comparing new methods with old. Their chief interest has been in improved locker services and improved quality of locker frozen foods. One of the suggestions made by patrons for increasing the usefulness of the locker plant to them and for improving services has been that of more personalized meat cutting.[11]

Personalized meat cutting. A survey of 250 patrons of New York State locker plants during 1945 indicated that 73 per cent of them were satisfied with the retail style of cutting as applied to meat for freezing. However, many of them had their own ideas and certain definite specifications as to how they wanted meat cut for their own use. In some locker plants meat was cut for all patrons in the same way; their suggestions were not invited. Whether a family consisted of two persons or a half dozen, cuts of the same size were made for all. It is only to be expected that some families prefer thick steaks; some like them thin. Some like Jack Spratt want no fat while others want more fat and less trimming. Coarsely ground meat pleases some; others are only satisfied if it is finely ground.

As patrons become more familiar with the freezing process and more experienced in preparing frozen foods they realize that food should fit the family rather than the family fitting the food. The style of cutting as practiced by some locker-plant meat cutters was unfamiliar to some patrons whose chief interest was in cuts they could recognize. They were in the position of one patron who said, "Bones have a way of appearing in the most baffling places to demoralize the carver." To be consulted as to how they wanted their meat cut was a real satisfaction to patrons and a service well appreciated where it existed.

Patron specifications for new methods. In the afore-mentioned study locker patrons were asked to check, in the order of importance to them, whether they would like to see new meat-cutting methods developed to do specific things as: to fit the family size better, to slice or serve with less difficulty, to eliminate bone, to give a higher proportion of certain cuts as roasts or steaks, and to suit the quality and grade of meat better. These specific ideas

[11] Nancy K. Masterman, The patron and the locker plant, *Quick Frozen Foods* 7, insert p. IV (Dec. 1944).

were suggested by patrons in the survey as desirable for incorporation in meat cutting for locker storage.

Eliminating bone was the first choice of the majority of families. Their second choice, cutting to provide a higher proportion of roasts and steaks, was closely followed by the desire for cutting to suit the grade and quality of meat. Patrons vary as to their awareness of quality. Some are very quality-conscious, as the patron who objected to all meat trimmings from a carcass being ground together. This patron wanted two grades of ground meat —first grade for the family, and a second grade for his dogs. The family who reported that at times it takes a baby beef to the locker plant, at another time a cull dairy cow, and that it should have different styles of cutting for the different animals was entirely right.

The fourth choice of locker patrons for special meat-cutting services was to have the meat cut to minimize the difficulty in slicing or serving the meat. This problem is closely associated with the elimination of the bone. Meat cutting to fit the family size better placed fifth in the desires of the patron.

Advantages of boning meat for freezing. Are bones worth the space they occupy in a locker? Some patrons think so. The idea is still quite general that the bones give flavor to the meat and that flavor would be lost were the bones removed. The housewife will need considerable education if she is to accept boneless cuts of meat. Especially will she resist the removal of bone from such cuts as steaks and chops where the bone is the distinguishing mark of the cut as the T bone, and where, manners to the contrary, the family like to chew the bone. The dog-loving patron objects to bone removal on the ground that there would be no bones for the pet were the cuts in the locker boneless. Ninety-one per cent of the patrons consulted did not want the bones removed from chops; 84 per cent would not have them removed from steaks. Boned chuck would please about 57 per cent of the families. Practically the same proportion would have the shoulder boned, and 67 per cent would not object to having the bones removed from rib cuts.

It is estimated that boning would save from 25 to 33 per cent of locker space. Filinger and Mackintosh[12] indicate that nearly one cubic foot of locker space may be saved by boning and rolling

[12] G. A. Filinger and D. L. Mackintosh, Preserving foods in frozen food lockers, *Kansas Agr. Expt. Sta. Circ.* **217** (1943).

a wholesale chuck. The saving of space in boning the rump, shoulder, and rib would be considerable.

Boning should result in better-quality meat because of the elimination of dehydration which frequently is associated with the puncture of the wrapping materials by bones. The reduction of air pockets through the possibility of fitting the wrapping material more tightly to the meat would decrease dehydration. Certainly the ease and speed of wrapping would be facilitated by the removal of bone. Boning would also result in cuts that could be sliced and served easily. Packages could better fit the family size because they would contain only edible meat. Smaller families might be better supplied with attractive and conveniently sized small cuts.

Disadvantages of boning. The cutting time required for a given carcass would undoubtedly be increased by more complete boning than is now customary. According to the Kansas experiment,[12] an additional 35 minutes was required for boning, tying, and packaging a chuck over cutting, tying, and packaging it with the bone in. The cost of boning was approximately one cent a pound. However, the patron saved storage charge on 20 pounds of bones. The bones made two quarts of soup stock which need not be stored in the locker, and in addition 0.8 cubic feet of locker space was available for other items.

The savings in dollars and cents made possible by boning would depend on the cost of the storage space. In some plants the rental is as low as $10 annually, in others as high as $25. The savings in the first instance would be negligible; in the second they would be real.

Boning requires a skilled cutter and the proper tools. With less skilled employees the waste resulting might be appreciable, at least until the skill is acquired.

Other patron suggestions for meat cutting for freezing. Naturally all freezer-locker patrons are interested in having meat cut with as little waste as is possible. Inexperienced cutters waste meat. Some patrons do not believe their present cutters are experienced enough to bone meat and would hesitate to have meat boned unless they know the operator is well trained and thoroughly competent.

Some patrons prefer to have the pieces of cut chicken which contain considerable bone for soup stock rather than having them occupy valuable locker space. The amount of bone in broilers or fryers cut in half may be reduced by removing the neck with a section of the backbone along the entire length of the bird in an inch-wide strip from head to tail. The halves then fit together flatly, eliminating air spaces and making a more compact package.

The opportunity to have less common cuts such as double pork chops with a pocket for stuffing, or specially trimmed cuts, would be appreciated by certain locker renters. Though the preferences of a family may be pretty well standardized on the size and shape of cuts in general, there are particular occasions for which they would prefer a departure from their normal requests. For convenience in use and as a means of increasing the storage life, some patrons would like the sides of bacon divided and packaged in one- or two-pound portions that may be removed from the locker and sliced as needed. They would like the special service of having whole hams that have been stored in the locker cut in half or sliced when needed.

Size to fit the family. Homemakers learn by experience the size of the cut of meat to fit their particular family. Generally they expect some cuts such as roasts to serve more than one meal. This habit, established with fresh cuts, has been carried over into their use of frozen meat.

PROCESSING OF SPECIAL ANIMAL PRODUCTS

In many phases of slaughtering, chilling, and handling, various animal products, particularly the warm-blooded flesh foods, have many basic similarities. These have enabled a limited discussion of many animal products collectively as a group, similar to the general discussion of vegetables in the previous chapter. However, the term "animal products" is quite all-inclusive, and many special food items in the list are not readily fitted into the more general discussion of principles in processing for freezing. Some of these will be taken up separately in order that we may point out those principles and techniques which have been applied to particular products.

Fish. There are several different ways in which fish are prepared for freezing. Perhaps the most familiar to the consumer is the fillet. Lemon[13] considers that fish weighing from two to four

[13] J. M. Lemon, Technical tips on fish freezing in the locker plant, *Food Freezing* 1, 48 (1945).

pounds should be filleted; those larger than four pounds should be prepared as steaks or as sectioned chunks; and fish smaller than two pounds in weight are best prepared as "pan-dressed" fish, from which the viscera, head, tail, and fins have been removed.

The different styles of preparing fish for freezing pose varying problems in terms of packaging and processing, as well as in the storage life of the frozen product. The fillet, exposing as it does a very large cut surface, offers the greatest opportunity for oxidation, desiccation, and drip formation on thawing.

Processing by brining. For some species of fish, special processing in brine may be indicated for minimizing leakage. In other species, particularly those having a high fat content, this same processing may result in a lowering of quality owing to the catalytic effect on fat oxidation and rancidification. Accordingly, there is some reason for avoiding blanket recommendations.

There is a considerable amount of drip formation from fresh fish fillets, and freezing generally increases the tendency of the tissues to lose the juices on subsequent holding at normal refrigerator temperatures. Thus unfrozen flounder fillets may lose 4 per cent of their weight as drip in a 24-hour period, whereas the frozen and thawed fillets may lose 10 to 15 per cent of their weight in a similar period.[14] This tendency toward leakage of tissue fluid is largely eliminated by dipping the fillet in a cold brine made with purified common salt.[15] The evidence indicates that purity of the salt is important, since some of the seemingly minor impurities present in technical grades of salt promote deterioration of the fish during frozen storage.

The principle involved in the brine-immersion process appears to be the formation of a "protein skin" over the surface of the fillet. The globulin proteins are soluble in dilute neutral salt solutions. Apparently dipping the fillets results in the dissolving (peptization) of these proteins, which then form a protective film over the cut surface.[14] This could thus serve to minimize drip formation by actually sealing in the flesh.

Rancidity. The brine treatment must be used with discretion. Fatty fish, such as the herring, are subject to fat rancidity during

[14] H. L. A. Tarr and P. A. Sunderland, Drip in unfrozen and frozen fillets controlled by brining, *Fisheries Research Board Can., Progress Repts. Pacific Coast Stas.* **45**, 19 (Sept. 1940).

[15] D. K. Tressler, Chemical problems of the quick-freezing industry, *Ind. Eng. Chem.* **24**, 682 (1932).

storage, and this change is accelerated by salt. For prolonged storage of frozen fish having a relatively high fat content, salt is to be avoided in the processing. The darkening ("rusting") of the flesh and the appearance of undesirable flavors in frozen salted herring, salmon, or mackerel is directly traceable to oxidation of the fatty elements in the tissues.

The time element. Holding of the fish prior to processing and freezing is detrimental to the maintenance of top quality. Bacteria thrive on the excellent growth media offered by exudates from the flesh of fish. Enzymes of autolysis rapidly carry the process of decomposition to an undesirable level, even at near-freezing temperatures. Furthermore, there is evidence [16] that, as the period of storage prior to freezing increases, the greater is the tendency for protein denaturation, a structural change characterized by a lowered solubility of the protein. Denatured proteins have a lowered ability to absorb and hold the tissue juices.

Poultry. "Bloom" is the somewhat intangible yet very important quality which in poultry refers to the over-all fresh appearance of the surface of the flesh. In processing birds for freezing, the handling may have a pronounced effect on the bloom, and hence on the marketability, of the product.

The initial color and quality of the bird play a role in determining the loss of bloom that may subsequently occur,[17] the light-colored "Milkfed" grades undergoing the least change under standard conditions.

Considerable opportunity presents itself for loss of bloom in the scalding of poultry prior to picking and in the use of mechanical pickers. High-temperature scalding (for example, 15 seconds at 150°F.) permits a rapid and complete picking operation by the friction and suction action of the rubber fingers of the picking machine. However, it leads to a considerable loss of bloom, with some skinning and discoloration. A longer scald at a maximum of 130°F. leads to a slower operation with more hand finishing, but leaves the flesh in a desirable condition. Accordingly, the milder treatment is to be recommended.

[16] W. A. Riddell, H. N. Brocklesby, and L. I. Pugsley, Frozen-fish research. Chemical and biochemical studies of halibut, *Ice and Cold Storage* **40,** 189 (1937).

[17] W. H. Cook, Frozen storage of poultry. II. Bloom, *Food Research* **4,** 419 (1939).

Frozen poultry may be prepared in such varying stages as "New York dressed" (undrawn), as drawn birds, as steamed and boned chicken, or as chicken à la king and other prepared dishes. Frozen undrawn birds still predominate, although the trend continues toward evisceration prior to freezing.

It now seems well established that, under comparable conditions, undrawn poultry has less tendency to develop rancidity during prolonged frozen storage than drawn birds. This is understandable when one realizes that the abdominal fat of the bird, as well as the fat in the sebacious glands in the skin, is readily oxidized. However, this slight protection from rancidity in undrawn birds is offset by a greater tendency to develop off-flavors and odors if the time in the near-freezing range is not kept to an absolute minimum. Undrawn poultry must be frozen as soon as possible after slaughter. After thawing, the birds should be immediately eviscerated if tainted quality is to be avoided. Drawn birds have a somewhat greater margin of safety in both the prefreezing and postthawing periods and generally have a higher consumer appeal.

Eggs. Frozen eggs are available as whites, as yolks, and as mixed whole eggs. When egg white freezes, the quality of the product remains unimpaired. Frozen and thawed egg white has the desirable whipping properties of the fresh material. Consequently it finds extensive use as an ingredient in white cakes, meringues and icings, biscuits, cookies, candies, marshmallows, ice cream, and pies.[18]

When egg yolk freezes, the solids precipitate as gummy particles. The yolk proteins are partially denatured, and the colloidal structure of the fat emulsion in the egg is irreversibly changed. Lecithin, the fatty emulsifying agent in the yolk, separates and coagulates when the egg yolk alone is frozen and thawed.[19] The lumpy character of the thawed yolk is an undesirable quality which generally must be avoided. Proper processing of the yolk enables freezing preservation to be successful for this product.

The common principle used in preventing coagulation of the yolk solids during freezing is to lower the freezing point of the mixture. Glycerine, sugar, salt, and honey have been used with

[18] J. A. LeClerc and L. H. Bailey, Fresh, frozen and dried eggs and egg products (their uses in baking and for other purposes), *Cereal Chem.* **17**, 279 (1940).

[19] O. Urbain and J. Miller, Relative merits of sucrose, dextrose, and levulose as used in the preservation of eggs by freezing, *Ind. Eng. Chem.* **22**, 355 (1930).

success as ingredients to be mixed with the yolk prior to freezing. In general, the salt concentration used is about 5 to 10 per cent of the weight of the yolks. Five per cent of glycerine is a common level for glycerine yolks. Where sugar is used, approximately 10 per cent is added. Corn sugar (dextrose, or glucose) is much more effective than cane sugar (sucrose) in eliminating the undesirable coagulation of egg lecithin.[19] Hydrolyzed sucrose (invert sugar) is also a more effective anticoagulant.

Naturally the ultimate use of the product will be a determining factor in the choice of sugar versus salt as an agent for preserving the smooth qualities in frozen and thawed egg yolks. LeClerc and Bailey[18] indicate some of the many uses of frozen egg yolks in the food industry. Any of the processed yolks may be used in mayonnaise or salad dressings, which constitute nearly the only outlets for salt yolks. Plain yolks, sugar yolks, or glycerine yolks may be used in making cookies, biscuits, dark cake, and doughnuts. In addition, the plain yolks and sugar yolks are adapted to use in custards and ice cream. Because of the flavor imparted by the processed yolks, only plain yolks are suited to the manufacture of noodles.

Sanitary-plant practices are particularly important in the frozen-egg industry. In the preparation of eggs for freezing, they are chilled and then candled to eliminate the cracked and the more readily detectable spoiled eggs. The eggs are then broken, and any with an off-odor or other evidence of deterioration are immediately rejected. Considerable precaution is taken to avoid letting any trace of the bad eggs come in contact with the shelled eggs for freezing. Cracked eggs and leakers are never used even though they show no evidence of decomposition, since such eggs usually contribute a high bacterial count to the egg batter.[20]

If the egg passes the test of smelling, it is added to the batch ready for processing, or the whites are separated from the yolks if these two are to be frozen separately. The whites are then ready for freezing. For both whole eggs and egg yolks, the yolk membrane is first broken by churning. This leaves the mass homogeneous, and also affords the conditions necessary for addition of the protective agent (salt, sugar, or glycerine) to the yolk.

[20] R. Schneiter, M. T. Bartram, and H. A. Lepper, Bacteriological and physical changes occurring in frozen eggs. Influence of defrosting and prolonged storage on bacterial count and on odor, *J. Assoc. Official Agr. Chem.* **26,** 172 (1943).

The egg products are generally placed in 30-pound containers. These containers are immediately moved to the freezing chamber. In a well-run plant, only a few minutes elapse between the breaking of the egg and its arrival at the freezer.

Milk Products. Frozen cream has long been a standard product for use in ice-cream manufacture. Frozen milk, on the other hand, has found a much more limited use. Recently, it served successfully as a source of fluid milk for patients on Army and Navy hospital ships because of its superiority to dried milk in freshness of flavor.

Frozen dairy products need the same rigid control in processing that the fresh milk or cream require. Again sanitation cannot be overemphasized. And, as with the fresh product, contamination with copper must be scrupulously avoided, since minute traces of this metal catalyze the oxidation which produces an undesirable off-flavor in milk or cream. Since freezing does not completely destroy harmful bacteria, nor rid the dairy product of spoilage microorganisms, pasteurization is generally carried out prior to freezing.

The unique physical and chemical make-up of milk and cream, containing as they do a sparingly soluble casein protein and an insoluble butterfat, poses a problem to the processor. Freezing alters the very fine colloidal particles, and under many processing conditions either or both of the insoluble fractions may separate on thawing. The phenomenon of "oiling off," wherein the butterfat separates and rises in flocs by a coalescence of the fine fat globules, is familiar to most families in the North who have found on occasion that the milk left on the doorstep had frozen. Precipitation of the caseinate also occurs under some conditions encountered during freezing and storage.

High-fat creams tend to "oil off" more than products with a lower fat content. And many conditions associated with handling of the milk prior to freezing appear to play a role in the stability [21] and flavor [22] of the product. Homogenization, which is a physical process that serves to reduce greatly the size of the fat globule, partially protects the emulsified fat during the freezing and thaw-

[21] R. W. Bell and C. F. Sanders, The influence of milk-fat globule size and cream temperatures on the stability of the frozen cream emulsion, *J. Dairy Sci.* **28**, 581 (1945).

[22] G. M. Trout and M. V. Scheid, The influence of several factors on the flavor of frozen sweet cream, *J. Dairy Sci.* **26**, 609 (1943).

ing cycle. More effective in preventing the separation of fat from frozen cream is the addition of sugar[23] which leads to the formation of smaller ice crystals[24] and lessens the tendency for coalescence of the butterfat particles.

It has been stated[25] that condensed pasteurized fresh whole milk can be frozen without adversely affecting the "body" or flavor. A 3-to-1 concentration is common and is economical in its requirements for refrigerated storage space.

Sausage. Ground meats offer a greater exposed surface and hence are more readily subject to lowering of quality through oxidation and bacterial invasion than the retail cuts of meat.

Desiccation removes the thin moisture film that may protect some of the fat and accordingly tends to hasten further onset of rancidity. This oxidation of the fat in frozen storage is also more rapid in the presence of salt. It is well known that seasoned sausage loses color and develops rancid odors and flavors in a matter of weeks, even at 0°F., whereas the ground pork itself may be safely stored for several months. It has been shown[26] that the catalytic material in the seasoning is common salt and not the various spices that may be present. Cooked sausage, in which the enzymes have been destroyed, is not affected by the presence of added salt.

In order to maintain best quality during frozen storage, sausage should not contain added salt as an ingredient. Rather, the salt should be incorporated immediately before use of the product. Salted butter also has a shortened storage life in the freezer.

[23] G. M. Trout and M. V. Scheid, The stability of the fat emulsion of frozen cream, *J. Dairy Sci.* **26**, 619 (1943).

[24] F. J. Doan and F. B. Baldwin, Jr., Observations on the freezing of milk and cream. II. The destruction of the fat emulsion in frozen cream, *J. Dairy Sci.* **19**, 225 (1936).

[25] B. H. Webb and S. A. Hall, Some physical effects of freezing upon milk and cream, *J. Dairy Sci.* **18**, 275 (1935).

[26] C. W. DuBois and D. K. Tressler, Seasonings, their effect on maintenance of quality in storage of frozen ground pork and beef, *Proc. Inst. Food Tech.* **1943**, 202.

Chapter 5

PACKAGING FOR FREEZING

Although invariably used in conjunction with some other means of effecting preservation—such as freezing—packaging is a physical means of extending the storage life of foods. With no protective wrap, most frozen foods would become unmarketable or unpalatable in a few weeks' time. With proper care in selection and use of packaging materials, these same foodstuffs may be satisfactorily held for many months in zero storage. Packaging cannot assume complete responsibility for the maintenance of quality of frozen foods, but it must be designed to overcome the conditions of low-temperature storage which desiccate (dehydrate, dry) foods. The success or failure of food freezing may hinge on the package itself.

All too often zero storage itself is blamed for poor food products that are actually the result of faulty packaging. Recently the U. S. Department of Agriculture defined[1] "fresh hard-chilled poultry" as stock that has been in zero storage for less than 60 days and "does not have the appearance of cold-storage poultry." Storage poultry was a term applied to birds in frozen storage for a longer period so that they "have developed a cold-storage look." It is unfortunate that the desiccated appearance of such foods has come to be associated with "cold-storage" or freezing rather than with poor packaging materials or techniques.

The functions of packaging for freezing. Packaging materials should perform several functions other than merely "containing" the food product. They may serve to exclude or minimize the contact of the food with air, thus tending to lessen undesirable oxidation reactions. The wrap should protect the food from dirt, insects, and bacterial and mold contamination before and during zero storage, as well as during thawing and

[1] Anonymous, Poultry primer, *Consumer Guide* **XII**, no. 2, 9 (Feb. 1946).

preparation for cooking. It thus is important in ensuring sanitation.

Moisture vaporproofness an essential. The package may—indeed, it must—provide a barrier against water vapor. Exchange of moisture from food to the surrounding air within the container and from this air to the air of the storage room is the result of the natural tendency of vapor pressures to equalize. This moisture is deposited in the form of frost on the cooling surface. As the margin of difference between the temperature of the air of the storage room and the temperature of the refrigerant is increased, the vapor-pressure difference becomes greater. This not only accelerates the deposition of frost on the freezing coils, but also causes an increasing separation of moisture from the food. Container materials must resist this exchange of moisture. In addition, control of temperature differential and storage-room humidity are important in making the best of materials effective. Low moisture-vapor transmission means little desiccation. It is the surface drying of frozen foods which is responsible for the bleached chalky mottled appearance somewhat misnamed "freezer burn."[2] Packaging material that permits the passage of moisture vapor also permits the absorption of oxygen from the air and the absorption of odors and flavors as well.

Additional functions of the packaging materials. It is not enough that the packaging materials perform the various functions just mentioned. In addition the materials must be satisfactory with respect to:

1. Price. This is the first consideration of businessman and housewife alike and too often the sole consideration. There are locker plants today where the meat is merely wrapped in a single thickness of plain butcher paper before being placed in zero storage!

2. Appearance. The large packer of frozen foods needs no reminder of its importance, and the locker operator and the freezer patron, without access to a more scientific evaluation of the packaging material, must often rely on price and appearance in selecting the cartons or papers. Only the experience in trial and use

[2] D. K. Tressler, Freezer burn on refrigerated poultry, *Ice and Refrig.* **89**, 373 (1935).

can substitute for laboratory testing of the other desirable features of a frozen-food package.

3. Ease of handling. The simplicity in wrapping various foods and the ease and efficiency of sealing the package can be expressed in both minutes and money. Wrapping papers must be pliable and easily manipulated. Homemakers require a container that is convenient to use and easily and quickly filled and sealed. Industry requires a package that may be set up, filled, and sealed automatically if the cost of production is to compete with costs of other processed foods.

Courtesy H. J. Heinz Co.

Figure 6. Ice occupies more space than water. Those living in the northern states will have recognized from scenes such as this that space for expansion is needed in packaging foods for freezing.

4. Waterproofness. Most products to be frozen are moist, and some are liquid. Fruits are packed in sirup or in sugar which will draw liquid from the tissues to create a sirup. Vegetables are occasionally brine-packed and in any case are scalded and cooled in water immediately before packaging. Meat and fish may exhibit some "drip" of tissue fluids both before freezing is completed and after thawing begins. The wet-burst strength, the ability of a material to withstand pressure when wet, will govern the suitability of many papers to such products. But for liquid packs, truly waterproof materials, fashioned into a leakproof design, are necessary. Consumers of commercially frozen food and home processors alike demand a leakproof container. The leakage problem of nonmetal containers for fruits is yet unsolved. It is one of the most frequently encountered problems in the storage of fruits in locker plants and home units. Sirup is heavy and freezes slowly. In many instances the liquid never freezes entirely solid. Package liners may burst at the seams, since a 10 per cent expansion in volume accompanies the change of water to ice (Fig. 6). The sealing is often incomplete or weak owing to the presence of moisture or the use of too hot a sealing device.

5. *Greaseproofness.* This quality is of minor significance for fruits and vegetables, but important for fatty animal products. A greaseproof paper will offer the additional advantage of minimizing loss of volatile essential oils which characterize the flavor or odor of many foodstuffs.

6. *Physical toughness.* Criteria to be assessed are: the ability to withstand abuse in handling, sufficient stacking strength in warehouse and truck, resistance to puncture (of particular importance where protruding bones, stems, fins, and the like are encountered), and ability to stand temperatures ranging from +100° to —60°F. without getting brittle or cracking.

7. *Physical inertness.* The package should, insofar as possible, permit or cause no avoidable changes in flavor, odor, or color. Fish, smoked meats, and strong-flavored products are stored side by side with other foods. Unless extreme care is taken, odors develop in aging rooms in locker plants, and in the locker rooms themselves. The more delicately flavored foods such as poultry are seriously affected by plant odors. The quality of frozen foods has been low in those community locker plants where packaging materials have been inadequate. Packaging material must not impart an odor or flavor of its own to the product. The adhesive used in laminated papers and sealing tapes must be odorless.

8. *Economy in space.* Storage space is a concern whether the zero storage is in the warehouse, the locker plant, the retail store, or the home. Storage space for the container itself must be considered by its distributors.

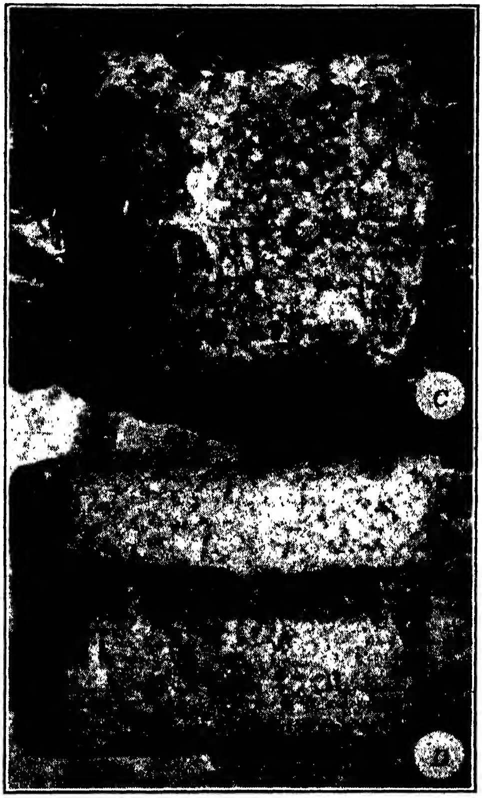
Adapting the package to the food. In frozen-food packaging, these requirements are often not satisfied in a single paper or carton design. Round unlined containers are more nearly liquid-tight than are the lined ones but they are wasteful of space. Square unlined containers must be sealed, and a perfect seal is difficult. Packages may not be liquid-tight when inverted. Glass jars of the type used for canning are likely to break unless filled and handled with care. They do not stack well in the freezer and are cold and slippery to handle. A new glass jar, designed especially for freezing, features no shoulder to retard removal of contents, slightly tapered sides with nonslip stippled ribs. The one-piece reusable metal cap is recessed so that jars stack easily. Tin

Courtesy Food Freezing

Figure 7. Chops wrapped by drugstore method. *A*. Cellophane wrap removed. Note the glazed surface, fresh appearance of fat and lean. *B*. Locker-paper wrap removed. Note dehydration of fat and lean; greater dehydration of meat in center receiving no protection from the folded-over ends of the paper.

cans, long outstanding for food packaging, are successfully used for freezing by homemakers and research workers.

Cellophane for frozen-food packaging combines such features as cleanliness, vaporproofness, sealing ease, and greaseproofness. However, the cellophane-wrapped food is improved by an outer wrap or paperboard carton, which imparts to the package an ability to withstand abuse not inherent in the cellophane alone. For meats cellophane may be covered with stockinette, a wide-mesh knit cloth which offers protection from abusive handling and



Courtesy Food Freezing

Figure 8. Ground beef wrapped by the drugstore method. *C*. Cellophane wrap removed. Note glazing and brighter color. Frost is held in air pockets. *D*. Locker-paper wrap removed. Note dehydration, chalky appearance, and absence of glazing. Note better appearance of meat beneath locked fold of the wrap. In this instance the frost has been lost through the paper.

helps exclude air by holding the cellophane against the meat. Laminated wrapping papers, in which various combinations of paper, metal foil, glassine, cellophane, and rubber latex sheets are bonded together, are now common. These enable the various packaging specifications to be met by a combination of materials with different desirable characteristics.

The so-called requirements do not carry equal weight under varying circumstances. For fruits packed in sirup waterproofness is of prime importance; for obvious reasons leaky cartons must be avoided. For meats and particularly for poultry moisture vaporproofness is of great concern, since "freezer burn" and its accompanying chemical and physical changes may make the product unmarketable or unpalatable.

The effect of drying out on frozen foods is varied. Appearance may be seriously affected. Pocklike marks appear on poultry owing to uneven desiccation, particularly around the feather follicles. Meats lose their "bloom" or fresh moist appearance, and there is usually a bleaching of the color of the surface flesh (Figs. 7 and 8). Even in vegetables, such as peas, there is some color impairment as dehydration progresses. Flavor is also changed. In meats and poultry, surface drying exposes more of the fat to the air [2] with the result that rancidity progresses at a more rapid rate than in properly packaged produce. Even texture is affected by desiccation during zero storage. There is a definite toughening of the skin in peas showing extensive desiccation. The proteins of the foods dry out and are altered so that they do not readily take up water again. This effect is not restricted to the skin or surface layers. For example, severe freezer burn in poultry [3] may cause the loss of more than a fourth of the moisture originally present in the muscle tissue.

Evaluating moisture-vapor transmission. Moisture-vaporproof materials are not detectable by mere appearance, nor are they restricted to a single type of material. Indeed, cellophane may be completely permeable to water vapor or may be a very effective barrier, depending on the presence or character of a resinous film on the surface of the cellophane. There are many "cellophanes," and only those having the letter *M* in the code designation are effective vaporproof packaging materials.[4]

What is an adequate packaging material from the standpoint of vaporproofness? Unfortunately this question is clouded by vary-

[3] W. H. Cook, Surface-drying of frozen poultry during storage, *Food Research* 4, 407 (1939).

[4] In the code for classifying various cellophanes, *M* indicates that the paper has a low moisture-vapor transmission rate. *S* indicates that a heat-sealing compound is present on the surface. *A* indicates that a special adhesive bonding has been added to insure the retention of the varnish films when the cellophane is to be in contact with water. *T* is the code designation for transparent cellophane films.

ing terminology and the use of many different test conditions in different laboratories. At least three well-known tests are in use—the TAPPI [5] method, which determines the vapor transmission at 73°F. and 50 per cent relative humidity (R.H., the ratio of the vapor present to the maximum the air can hold), expressing the result as either grams per square meter per 24 hours or ounces per square yard per 24 hours; the GFMVT [6] test at the different environmental conditions of 100°F. and 95 per cent R.H. and the still different unit of measuring transmission rates as grams per 100 square inches per 24 hours; and the procedure recommended by DuBois and Tressler.[7]

The latter investigators use test conditions more nearly approximating freezer storage practice. They consider a wrap as being adequate for preventing desiccation of meat if the transmission of moisture vapor at 5°F. and 50 per cent R.H. is below 3 grams per square meter per 24 hours. Under test conditions, moisture-vaporproof cellophane lost 0.1 to 0.4, special coated parchment lost 0.4, waxed parchment was unsatisfactory, losing 5 to 7, and uncoated parchment lost 30.5 grams. These figures mean that meats wrapped in waxed paper, parchment, and similar materials may lose from 1.5 to 5 per cent of their weight in 6 months of frozen storage. These meats will show a desiccated appearance. Evidence of some rancidity will also be probable in frozen pork under these conditions. If vaporproof materials are used this moisture loss is reduced to less than 0.2 per cent in a 6-month period.

It should be noted that waxing improved the parchment, but insufficiently. For moisture-vapor transmission waxed paper was as good as waxed parchment. The parchment was better than paper for waterproofness, however. Neither the waxed paper nor parchment was good from the standpoints of heat-sealing qualities and resistance to bloodstain; they were not greaseproof, not satisfactorily waterproof, and often cracked at temperatures of 0°F. Creasing also interferes with their efficiency [8] by breaking the wax layer.

5 Technical Association of the Pulp and Paper Industry.

6 General Foods Moisture-Vapor Transmission Test.

7 C. W. DuBois and D. K. Tressler, Moisture-vapor proofness of wrapping materials used on frozen foods, *Paper Trade J.* **109**, 15 (1939).

8 W. Rabak, Some observations on the materials employed in packaging frozen foods, *Proc. Inst. Food Tech.* **1940**, 193.

Other barriers to moisture loss. There are other "packaging" devices for retarding the removal of moisture from food during zero storage. These include the use of fats, of water in the form of an ice glaze, and of brine or sirup packs. Dipping poultry in water before freezing reduces the progress of freezer burn,[2] but the thin ice layer will need renewing after several weeks' storage. Glazing is more common for fish than for other frozen foods. In commercial practice frozen whole fish and sometimes dressed fish are sprayed or dipped in cold water to form a protective layer of ice on the outside of the fish. This ice layer effectively seals the fish, preventing access of oxygen from the air. Any evaporation which takes place comes from the ice glaze and not from the fish itself. As ice is lost through evaporation during the storage period, the glaze must be renewed from time to time. Glazing as practiced commercially requires special equipment and experience. Some locker plants are equipped to do the work. Rather than renewing the glaze at intervals it would be more convenient for locker storage to wrap the glazed fish in moisture-vaporproof paper to prevent the loss of the ice layer. Care is to be taken to avoid cracking of this brittle ice film.

A thin coating of fat is effective in preventing surface drying of poultry and meats. When meats are treated in this manner, rancidity may be a greater problem than desiccation. As in the case of the ice glaze, cracking of the protective coating must be avoided through proper selection of the fat. Beef tallow, for example, is unsuitable because of its brittleness at low temperatures.

Many fruits are packed in sirup before freezing. In addition to preserving such quality characters as flavor, the sirup prevents the drying of the fruit even though appreciable moisture may be lost from the package. Some investigators recommend that various vegetables be packed in a weak brine. Although such recommendations are generally based on an improved texture for the frozen product, desiccation and its accompanying quality changes are also avoided by the brine-pack technique. However, because of other considerations, few frozen-pack vegetables, whether in the home or commercial plant, are processed in this manner.

The canning procedure of packing with brine was followed in many of the early experiments with the freezing of vegetables. The brine pack continued to be recommended for home processors after it had been abandoned by commercial packers who found brine packs less economical and no more satisfactory than dry packs. Less refrigeration was required to freeze a given weight of dry-packed vegetables; less expensive containers could be used; and the cost of transportation was less for dry packs than for the heavier brine pack.

The advocates of brine pack for home use gave as its advantages: the protection from desiccation where containers were not moisture-vaporproof; keeping the product cool when en route to the locker plant; and delayed thawing on its removal from the plant. They held that the shape and texture of some vegetables—especially broccoli, asparagus, and cauliflower—were better when brine was used. The recognized disadvantages were that some vegetables toughen when brine is added; the cost of processing is increased by the increased weight of the package; cartons are very subject to leakage, and breakage is frequent when glass is used; vegetables must be thawed before cooking to insure even heating.

The use of the brine pack has now been largely discontinued by the locker patron and the home-freezer user, although directions furnished by some locker plants still call for the use of brine.

Factors influencing evaporation of moisture. In practice, the removal of moisture vapor is affected by several variable conditions in the freezer.

The rate of evaporation varies directly with storage temperature. Air at 0°F. and a relative humidity of 80 per cent has nearly three times the drying action of air at —20°F. and 80 per cent R.H. Peas in paperboard packages for 20 months have been shown [9] to lose twice as much weight at 15°F. as at 0°F.

The rate of evaporation varies inversely with relative humidity. Moisture vapor flows much faster from a 100 per cent R.H. air film (at the surface of the food) to air at 50 per cent R.H. than from the same 100 per cent R.H. film to a 90 per cent R.H. atmosphere. Naturally this diffusion of water vapor tends to raise the humidity of the room toward 100 per cent. However, this tendency is offset by the cooling coils, which condense the moisture, owing to a lower vapor pressure at the colder temperature adjacent to the refrigerated coils. For poultry relative humidities of less than 95 per cent around the foodstuff are unsatisfactory,[3]

[9] W. Rabak, Some effects of storage temperatures and package types on weight losses and quality of frozen peas, *Western Canner & Packer* **33,** 52 (1941).

2 to 3 months in frozen storage leading to definite evidence of surface drying. This means in practice that vaporproof packaging is necessary for extended zero storage.

The rate of evaporation from unwrapped foods or from packages which are only partially moisture vaporproof increases with air circulation. The air film of high relative humidity immediately surrounding the frozen food or penetrating the wrapping material will be continually "wiped off" by a stream of circulating air. This will result in a more rapid transfer of moisture from the product to the air film.

Finally, the efficiency of sealing affects moisture-vapor transmission. It has been reported [8] that sealed moisture-resistant but not impermeable wraps, such as heavy waxed paper, are as effective for reducing surface marking of frozen poultry as unsealed but otherwise impermeable foil liner. For a year's storage in the freezer, poultry needs both a good paper and a good seal to avoid surface drying.

Principles for best results in packaging. There are a number of implications to be gathered from these generalizations. The locker-room temperature should be kept as low as is economically possible, with 0°F. as the upper rather than the lower limit. Every attempt should be made to maintain a high relative humidity around the product. This means maintaining a low temperature differential between the frozen food, the room, and the cooling coils or plates. With the storage room at 0°F., the relative humidity may be as low as 65 per cent when the coil surface is at —10°F.[10] If the latter is at −20°F., the relative humidity may be lowered to the neighborhood of 30 per cent.

The water- and greaseproofness and other characteristics and, above all, the moisture-vapor transmission (MVT) rating of the paper should be closely scrutinized before the paper is accepted for packaging frozen foodstuffs. It is unfortunate that so much confusion exists in getting general agreement as to what test conditions to employ and what MVT units to use for expressing the vaporproof qualities of a packaging material. This makes it difficult for a small packer, the locker operator, or the homemaker to select on the basis of MVT characteristics, particularly since many dealers do not reveal in their specifications the vapor transmission rates for their product. It is to be hoped that the future will see

10 W. H. Martin, Humidity and its control, *Ice and Refrig.* **96**, 515 (1939).

each manufacturer marking the packaging material with its MVT rating, based on a single standard test and unit of measure.

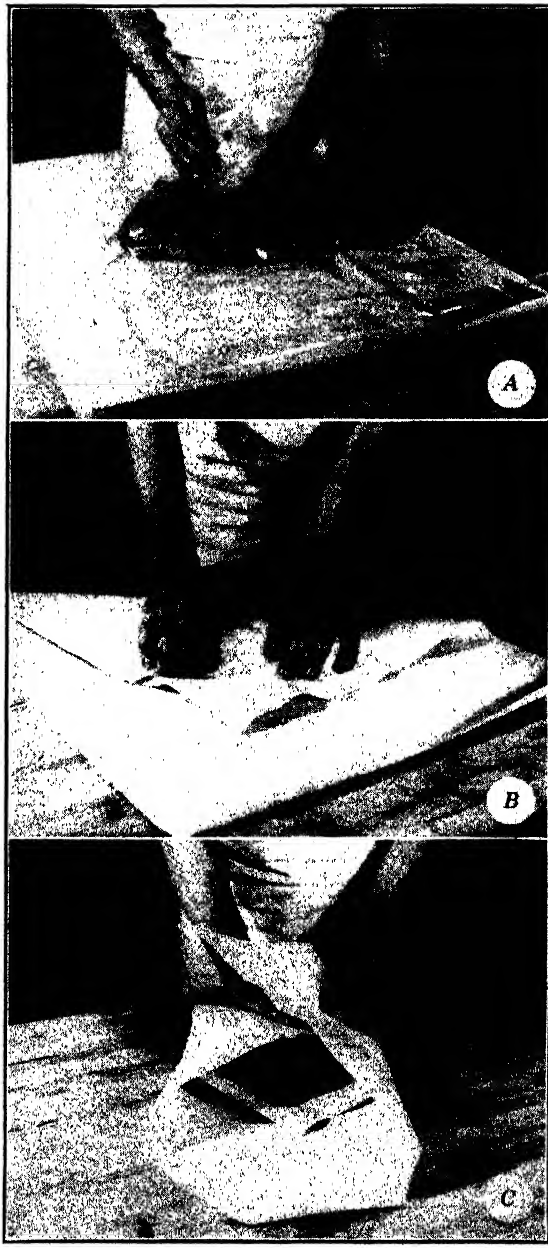
The entire burden of protection cannot be placed on the wrapping material alone. The wrapping technique is important. Elimination of oxygen from the container to prevent oxidation means that food must be tightly wrapped, and the packages must be made as airtight as possible.

Courtesy Food Freezing

Figure 9. An example of "cavity-ice" formation in a package of frozen snap beans. The side on which the ice crystals have built up faced the refrigerated plate of the freezer. Note the desiccated appearance of the beans.

Desiccation takes place in crevices and air pockets. A completely moisture vaporproof wrap will prevent a weight loss from the *package,* but cannot protect *food* from the loss of moisture if large cavities exist within the carton. This "internal" drying within the package is evidenced by a heavy deposit of frost on the inner surface of the vapor barrier and around the food particles ("cavity ice"). Christensen [11] cites a simple demonstration where a frozen apple was sealed in a standard moisture-vapor-

[11] P. B. Christensen, The warehousing of frozen foods, *Food Freezing* 1, 25 (1945).


A
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C

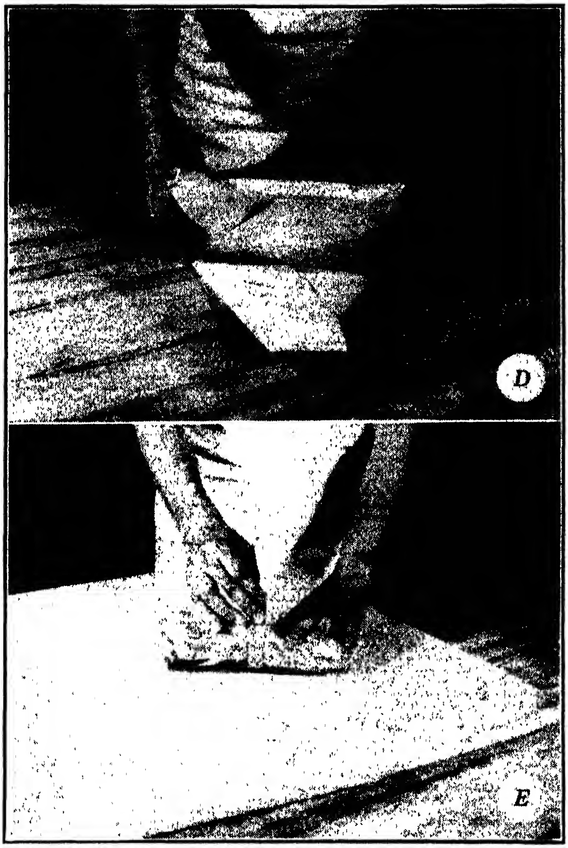


Figure 10. The butcher's wrap. In this instance an outer wrap is being applied to meat already wrapped in cellophane by the butcher's method (*A*). Note that the meat is placed on the diagonal of a large sheet of paper (*B*). The series of folds (*C, D, E*) covers the meat. This folding requires careful execution to exclude air and keep meat perfectly flat.

proof package and stored in a freezer which was subjected to frequent temperature changes. Although the package did not change weight, the apple became very desiccated. The moisture from the fruit was evident as a snow within the package.

Temperature fluctuation is the principal cause of this transfer of moisture from the food to the surrounding air space. As the air in the pocket warms, it picks up additional moisture from the food. When the temperature in the freezer again drops and cools the air in the package, moisture will be deposited as frost on the


A
B
C

Figure 11. The drugstore wrap. Note the meat is placed in the center of a sheet of paper large enough to permit the locked folds in *C*. Forming this fold draws the paper tight to the meat. Note the folding of the ends in *D* to eliminate air pockets at the corners and the sealing of the ends in *E*. Pressure-sensitive tape holds the wrapper.

wrap and contents of the package. Radiation also plays a significant role in these temperature changes.[12] The surface that is cooled most rapidly under these conditions will be first to accumulate a layer of frost. Under some circumstances in zero storage, the ice leaving the food may build up exclusively on one wall of the air pocket within the carton (Fig. 9). In order to prevent or to minimize the desiccation effect of pockets and crevices within the package, special folding of the paper and sealing with heat or tape is recommended. Cartons should be filled with space for expansion carefully estimated so that the carton is full after freezing with no excess air space.

Wrapping methods. The community locker plant has been the largest processor of frozen meat for civilian use. Two methods of meat wrapping have been in general use in locker plants: the butcher's wrap and the confectioner's or drugstore wrap (Figs. 10 and 11). The drugstore wrap requires less paper. It is well adapted to products that should be kept flat, as steaks and sliced meat. As the interlocking folds draw the paper tight to the meat and all edges are sealed, there is less opportunity for air pockets and moisture-vapor transmission at the seams than in the butcher type where more of an effort is necessary to secure a tight wrap, and edges are unsealed. However, if the wrapping is done carefully, the butcher style, with its several thicknesses of paper, may be more efficient from the standpoint of protection than is the druggist type with its one thickness, particularly where wrapping materials possessing high moisture-vapor transmission rates are used.[13]

The evidence leaves no doubt but that proper packaging can extend the storage life of frozen food. But it cannot offset faulty handling of the product. Good produce, prompt processing, and proper storage must go along with quality packaging.

[12] C. I. Sayles, W. A. Gortner, and Frances Volz, Frozen Food packaging: A preliminary study of cavity ice, *Food Freezing* 1, 430 (1946).

[13] Nancy K. Masterman and K. Winsor, The moisture losses in stored frozen meats vary with packaging material, wrapping method, *Food Freezing* 1, 143 (1946). *Cf.* also J. D. Winter, Cellulose sponge tests for moisture loss in wrapping material at 0°F., *ibid.*, 1, 480 (1946).

Chapter 6

FREEZING RATES AND FOOD QUALITY

One of the most controversial subjects in food freezing is the effect of the rate of freezing on food quality. Many firmly believe or actively promote the idea that "quick freezing" is essential for a high-grade product. Others feel that such a position is open to attack and hold that a few, many, or even most slow-frozen products are, to the consumer, indistinguishable from those frozen at more rapid rates. In certain cases, slow freezing has even been recommended over quick freezing.

Woolrich [1] points out that "many have a mistaken idea that very rapid freezing is equally desirable for all perishable foods that require preservation by cold. The need of rapid freezing is much more pronounced for some perishables than for others. Furthermore, the colloidal composition of some products is such that even slow freezing affects the structure but slightly. With most foods that are to be cooked as soon as defrosted, slow freezing is as satisfactory as quick freezing."

As with most phases of food preservation, broad generalizations are often dangerous and misleading. Certainly, the rate of freezing can be shown to induce certain physical and physicochemical changes in the foodstuff. The question then should center on whether these changes are significant from a quality standpoint.

Terminology. What is "quick freezing"? Even here we find a general lack of clarity and agreement bordering on confusion. Some define the term on the basis of the observed ice formation in the frozen product. Thus fast freezing of animal tissues has been referred to [2] as intrafiber freezing and slow freezing as a condition where ice formation is largely extrafiber. This classi-

[1] W. R. Woolrich, The romance and engineering of food preservation, *Science* **99**, 107 (1944).

[2] C. H. Koonz and J. M. Ramsbottom, A method for studying the histological structure of frozen products. I. Poultry, *Food Research* **4**, 117 (1939).

fication has been extended to both animal and plant tissues by reference to "intracellular" and "extracellular" freezing.

Woodroof [3] has defined quick freezing, at least for plant materials, as a condition where the travel of the ice zone through the food progresses at a rate of 0.3 centimeter per minute or faster. Most freezing conditions encountered in home units or community locker plants will, under this standard, fall in the category of slow freezing. And such common commercial processes as the freezing of boxed poultry cannot begin to approach this drastic proposed requirement.

It has been suggested [4] that quick freezing be defined as that condition where solidification (the "zone of maximum crystal formation," 32° to 25°F.) is passed through in 30 minutes or less. Products passing through this temperature range within an hour have also been termed [5] "quick-frozen."

Eickelberg [6] defines quick freezing as "the obtaining of the most desirable texture and frozen condition of product, and the retaining of natural color, turgidity, and acceptable appearance as rapidly as economic operations will permit." This "definition" fails to recognize that what is "economic" for the large packer may not be so for the locker operator, and that the most desirable rate for asparagus may not be most desirable for peaches. However, such phraseology does bring out what others are reluctant to conclude, namely, that "quick" is a relative term not capable of precise definition.

THE FREEZING RATE VERSUS FOOD QUALITY

The advantages of a rapid freezing rate have been summarized [7] as being fourfold: (1) The minimizing of destruction of the intact cells by favoring the formation of smaller ice crystals, (2) a shortening of the period of solidification during which diffusion and osmosis can alter the water and soluble solids relationships in the

[3] J. G. Woodroof, Microscopic studies of frozen fruits and vegetables, *Georgia Agr. Expt. Sta. Bull.* **201** (1938).

[4] Mary E. Pennington, Fifty years of refrigeration in the egg and poultry industry, *Ice and Refrig.* **101,** 45 (1941).

[5] P. J. Frost and N. M. Carter, The complete freezing of fish flesh, *Fisheries Research Board Can., Progress Repts. Pacific Coast Stas.* **62,** 21 (Mar. 1945).

[6] E. W. Eickelberg, Effect of the rate of freezing on the texture of peas, *Canning Age* **19,** 512 (1938).

[7] D. K. Tressler, Chemical problems of the quick-freezing industry, *Ind. Eng. Chem.* **24,** 682 (1932).

tissues, (3) the arresting of the growth of microorganisms of spoilage by a rapid lowering of the temperature, and (4) the retention of quality through a greatly slowed enzyme action. Some of these advantages result from quick chilling as well as from quick freezing. And the list omits the major reason for the commercial quick freezing of foods—economy in production on a large scale.

To explore more carefully the evidence for quality retention as a function of freezing rate, the data on various classes of frozen foods are discussed in the following paragraphs.

Meat and Poultry. The effect of freezing rate on animal tissues centers largely on the tenderness and leakage of juices on thawing (drip).

Drip. As far as drip is concerned, the scientific data can be selected to prove any contention desired. Much of this is the result of different techniques of determining drip or different ways of expressing results. For example, it has been shown [8] that for smaller cuts of meat, such as individual steaks, the slow-frozen products will lose more fluid on being defrosted, since the relatively large cut surface enables fluid to be lost before the muscle fibers can absorb the thawed liquid, which may be largely extracellular. In such cases the freezing temperature unquestionably assumes a greater importance through its influence on drip formation than in larger cuts of meat, where the tissues have more opportunity to reabsorb the water even though extrafiber ("slow") freezing had occurred.

Where small plugs of the frozen meat were thawed,[9] or where minced tissue was used [10] giving an artificially high ratio of cut-surface area to volume of the meat, the greater amount of drip in the slow-frozen products was readily demonstrable, although Empey [11] was unable to detect an effect of rate of freezing in the drip from beef muscle when the freezing times for the meats ranged from 1 minute to 8 hours. The intact roasts, however,

[8] J. M. Ramsbottom and C. H. Koonz, Freezing temperature as related to drip of frozen-defrosted beef, *Food Research* **4,** 425 (1939).

[9] C. W. DuBois, D. K. Tressler, and Faith Fenton, Influence of rate of freezing and temperature of storage on quality of frozen meat, *Proc. Inst. Food Tech.* **1940,** 167.

[10] C. H. Koonz and J. M. Ramsbottom, Susceptibility of frozen-defrosted poultry meat to drip, *Food Research* **4,** 485 (1939).

[11] W. Empey, Studies on the refrigeration of meat. Conditions determining the amount of "drip" from frozen and thawed muscle, *J. Soc. Chem. Ind.* **52,** 230T (1933).

showed little drip, and the variations between duplicate roasts were as great as the variation in drip between the rapidly and slowly frozen roasts. Similarly, frozen whole chickens do not drip appreciably on thawing, regardless of the freezing rate.[10]

A number of conditions other than freezing rate and cut surface play a role in determining the extent to which the tissue fluids will leak on thawing of frozen meats. And marked differences are observed [11] in the extent of dripping from different portions of the same carcass or from similar parts of different carcasses, frozen and thawed under similar conditions. Perhaps this accounts for the varying emphasis that investigators place on the importance of this phenomenon. It has been observed [11, 12] that drip from frozen beef is related to the acidity, or pH, of the tissue, and is absent from slowly frozen tissue at pH 6.4. This suggested that drip was not due merely to the size of the ice crystals formed on freezing, since large crystals were always produced by slow freezing regardless of pH. Only in the slightly more acid isoelectric region of pH 5.2 did the production of smaller crystals by quick freezing lower the quantity of drip.

Tenderness. There is general agreement that the freezing of meat does effect some tenderizing, although the improvement is slight under many conditions. There is some evidence [13] that rapid freezing effects a greater tenderization because the ice crystals are formed within the muscle fibers, causing a disintegration of the fiber with an accompanying increase in tenderness. The histological appearance of the muscle fibers supports this contention. In the study cited the degree of tenderizing effected by a very rapid freezing rate was quite appreciable, and nearly every fiber appeared to be ruptured and split longitudinally into sections. However, defrosted muscle has a normal appearance in microscopic examination, regardless of freezing rate.

Palatability. In one study comparing the eating quality of rib roasts of beef frozen under ten different conditions, it was concluded [9] that the more rapidly the meat was frozen, the better was its all-round quality. However, the palatability of the roasts also showed that slow freezing produces acceptable meats, since the

[12] L. Sair and W. H. Cook, Relation of *pH* to drip formation in meat, *Can. J. Research* **16, D,** 255 (1938).

[13] R. L. Hiner, L. L. Madsen, and O. G. Hankins, Histological characteristics, tenderness, and drip losses of beef in relation to temperature of freezing, *Food Research* **10,** 312 (1945).

roast frozen at the slowest rate "ranked almost as high as the check roast which had not been frozen." Certainly this work would seem to minimize the significance to the consumer of the tenderizing action ascribed to freezing, regardless of freezing rate.

The freezing rate over a practical range does not affect the cooking shrinkage of frozen poultry.[10] It seems well established that for broilers [14] and roasting chickens [15] frozen under a variety of conditions and including fast and slow rates of freezing casual examination or actual taste tests do not reveal differences between "quick-frozen" poultry and the slower-frozen products. Differences in the histological picture of the muscle tissue can be readily shown in the frozen birds, but after thawing, irrespective of the rate of freezing of the bird, the fibers "have remarkable capacities to reabsorb or appropriate the 'frozen out' or displaced water." [10]

It has been claimed [16] that freezing rate is important in the maintenance of "bloom," or fresh appearance of poultry. This report refers to a "dark color which results from slow freezing." There is no citation to published data, and the work of other investigators does not confirm the observation unless slow freezing is intended to refer to a freezing period exceeding 48 hours.[4]

With a lower freezing temperature and hence a faster rate of cooling tenderness appears to be somewhat improved. As far as the authors are aware, there are no satisfactory data to indicate that freezing, regardless of its rapidity, has an important effect on other palatability criteria in meats. Appearance, odor, and taste seem to be unaffected. The nutritive value would be a consideration only insofar as a very minor fraction of the protein and mineral nutrients accompany the fluids that may drip from the thawed meat. In many instances these juices would go into gravy, thus saving these nutrients and flavor. A review of the literature dealing with quick-freezing meat points to the conclusion that there is no need for extremely rapid freezing from the quality standpoint.

[14] G. F. Stewart, H. L. Hanson, Belle Lowe, and J. J. Austin, Effects of aging, freezing rate, and storage period on palatability of broilers, *Food Research* **10,** 16 (1945).

[15] C. W. DuBois, D., K. Tressler, and Faith Fenton, The effect of the rate of freezing and temperature of storage on the quality of frozen poultry, *Refrig. Eng.* **44,** 93 (1942).

[16] H. J. Reynolds, Some methods of protecting stored frozen poultry, *Proc. Inst. Food Tech.* **1940,** 189.

Fruits. It has been claimed that fast freezing is not necessary for fruits and berries that absorb sugar strongly. Indeed, there are data to indicate that the advantage may occasionally be with slow freezing. Some workers [17, 18] report that slowly frozen strawberries hold up much better after thawing and have a better texture than faster-frozen strawberries. Studies of peaches have resulted in the conclusion [19] by workers at the U. S. Department of Agriculture that slow freezing leads to the best preservation of color, a rapid lowering of the temperature being more favorable to more rapid deterioration of the fruit. Certainly many fruits, not having the supporting membranes and fibers of meat or vegetable products, are observed to lose firmness and partially collapse even when frozen at very low temperatures. Some [3] claim that a short interval between formation of the first ice crystals and the complete freezing of the fruit is essential for the maintenance of texture, palatability, and satisfactory superficial appearance.

Vegetables. A number of workers in the field are of the conviction that quick freezing improves the quality of frozen vegetables. Some report a greater loss of soluble matter—and, hence, nutritive constituents—during the thawing and cooking of slow-frozen peas as compared with those frozen quickly. Others [6] conclude that quick-frozen peas have fewer ruptured cells, are superior in color and flavor, have a reduced loss of plant juices, and have a more desirable texture compared to the slow-frozen product.

A number of investigators report that slow freezing, such as at 0°F., is satisfactory for vegetables.[17, 20, 21] This claim is particularly made for starchy vegetables.[3] There is little question but that freezing does "tenderize" or soften vegetable tissues. This is reflected in the shorter cooking time recommended for the frozen as against the fresh product. A small difference in the

[17] M. A. Joslyn and G. L. Marsh, Observations on the effect of rate of freezing on the texture of certain fruits and vegetables, *Fruit Products J.* **11**, 327 (1932).

[18] Anonymous, Ordinary cold storage temperature successful for frozen pack method, *Fruit Products J.* **12**, 227 (1932).

[19] J. S. Caldwell, J. M. Lutz, H. H. Moon, and A. T. Myers, Varietal adaptability of peaches to freezing in small consumer packages, *Fruit Products J.* **12**, 366 (1933).

[20] H. H. Plagge, Fruits and vegetables—studies relating to their freezing and storage, *Ice and Refrig.* **94**, 220 (1938).

[21] H. C. Diehl and J. A. Berry, Relation of scalding practice and storage temperature to quality retention in frozen pack peas, *Proc. Am. Soc. Hort. Sci.* **30**, 496 (1933).

softening of tissues effected by varying the freezing rate could easily be ascribed to, or corrected by, a slight change in cooking time or temperature. Perhaps herein lies the explanation for apparently contradictory statements from various investigators in the frozen-food field.

The nutritive value and acceptability of slow-frozen vegetables. If reports of greater tissue disruption and loss of dissolved solids on cooking of slow-frozen peas could be confirmed, the implications from the standpoint of nutrition alone would cast doubt on the acceptability of many home-freezer cabinets. A recent study [22] using peas and green beans as representative of starchy and non-starchy vegetables sheds additional light on the problem of what constitutes a desirable rate of freezing for vegetables. The freezing rates of these two products were varied over a range including rates far faster and far slower than would be encountered under operating conditions either in commercial practice or in the individual freezer locker. The eating quality, appearance, and vitamin values of the products were determined.

As was expected from the work of other investigators, the freezing rate was found to have a pronounced effect on the appearance of the vegetable tissues when the frozen cut sections were viewed (although the external appearance was not altered by changing the freezing rate). In Figs. 12 and 14, the slower-freezing rates can be seen to favor the formation of large ice crystals, appearing as veins of extracellular ice surrounding the partially dehydrated and shrunken tissue solids. The fleshy membranes in the quick-frozen bean are seen as thin fiberlike structures in the slow-frozen product.

The migration of cellular fluids which resulted in the large veins of ice was largely if not completely reversible. This observation is significant in assessing the importance of the freezing rate. Figures 13 and 15 readily show the complete manner in which the defrosted tissues have reabsorbed the thawed fluids, returning to their natural appearance. To all appearances, the quick-frozen and slow-frozen products are identical within a few minutes after thawing. The heating of the tissues in cooking would constitute an additional equalizing factor, although no photomicrographs of the cooked vegetables were taken in this study.

22 F. A. Lee, W. A. Gortner, and Joanne Whitcombe, Effect of freezing rate on vegetables. Appearance, palatability, and vitamin content of peas and snap beans, *Ind. Eng. Chem.* **38**, 341 (1946).

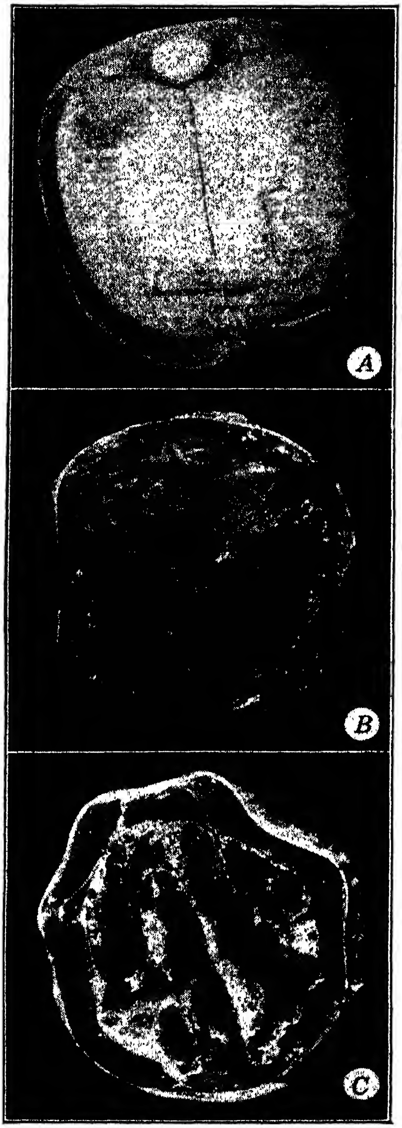


Figure 12. Photomicrographs of cross sections of frozen peas. *A.* Less than 1 minute in freezing zone. *B.* 2–4 hours in freezing zone. *C.* 48–50 hours in freezing zone.

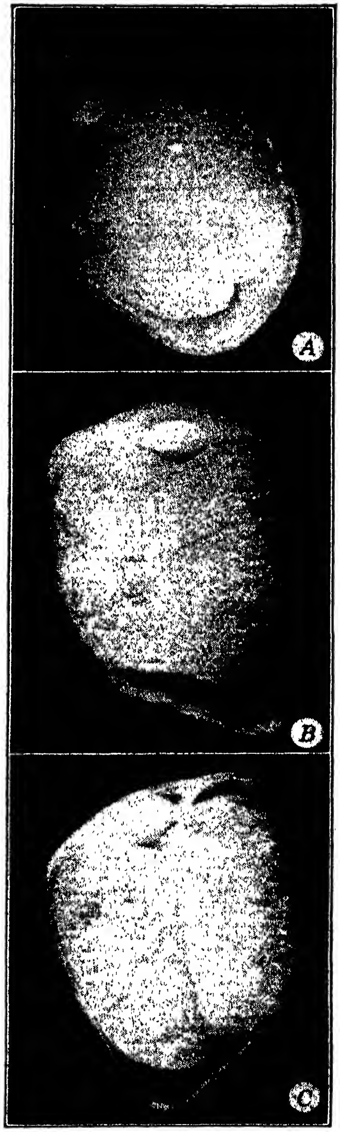


Figure 13. Photomicrographs of cross sections of thawed peas. The samples correspond to those frozen at 3 greatly different rates as noted in Figure 12.

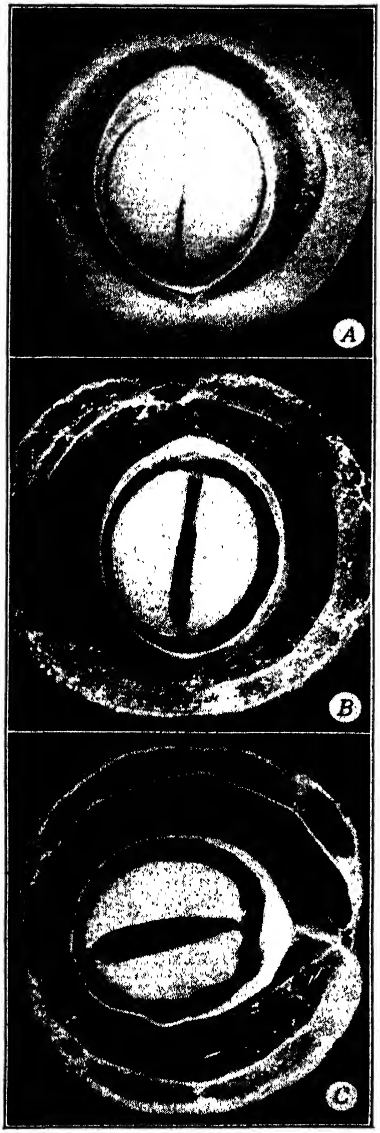


Figure 14. Photomicrographs of cross sections of frozen green beans. *A*. Less than 1 minute in freezing zone; *B*. 8 hours in freezing zone; *C*. 46 hours in freezing zone.

Figure 15. Photomicrographs of cross sections of thawed beans. The samples correspond to those frozen at 3 greatly different rates as noted in Figure 14.

Shortly after freezing, and again after a 6 months' period in zero storage, these products were analyzed for their content of thiamine, ascorbic acid, and carotene. Both before and after cooking, the nutritive values of the vegetables frozen at five widely varying rates were the same. None of the vitamins tended to disappear more rapidly during freezing under a particular freezing condition. None tended to decrease more rapidly during storage following a given freezing process. None tended, during cooking, to disappear or leach out more rapidly from the slow-frozen than from the quick-frozen peas or beans. Indeed an unduly large volume of cooking water was deliberately used in one of the cooking tests in an attempt to exaggerate losses due to solution of nutrients in the cooking water—and no differences ascribable to freezing rates were found.

The final test—and the ultimate one, that of appearance, odor, flavor, texture—was equally negative. The slow-frozen vegetables were as acceptable to the palate as the fast-frozen ones.

It is difficult to reconcile these data with statements that have crept into the literature, such as [6] "When slow-frozen products are thawed, an extensive change takes place. The liquid in the ruptured cells, mineral salts, natural sugars, and other substances which give the pea its favor leak away. There is nothing left but a flabby tasteless unattractive mass of vegetable matter." No data and no descriptions of the experiment were presented or cited in support of this statement.

Realizing the danger of too broad generalizations, one must emphasize that the data just cited [22] do not discount the possible beneficial effect of a very rapid rate of freezing for certain vegetable materials such as asparagus.[23] They do, however, minimize the importance of freezing rate for such products in general. The locker operator and the owner of a home locker may be assured that their freezing equipment is adequate for the processing of quality frozen vegetables if the freezing can be completed within 24 hours.

Dairy Products. There is some evidence that rapid freezing of milk or cream, in contrast to slow freezing, minimizes separation of the chemical components into different parts of the frozen mass. Although fast freezing is more effective in stabilizing the

[23] M. Joslyn and S. Kilner, Effect of rate and extent of freezing on texture of asparagus, *Quick Frozen Foods* 4, 14 (1942).

fat emulsion,[24] it does not entirely prevent the separation of fat ("oiling off") of the cream. It is doubtful whether the coalescence of the butterfat in frozen and thawed cream can be prevented by varying the manner and rate of freezing within practical limits, although it has been claimed that the freezing of milk products in liquid air will permit subsequent total reversibility.

Fish. There is good evidence that the rate of drip from frozen flounder [25] and haddock muscle [26] decreases with an increased rate of freezing, the amount of drip being closely related to the time spent in the zone of 23° to 30°F. For pink salmon [25] there is little difference in the drip from slow-frozen, quick-frozen, and unfrozen fish. The amount of drip from this species of salmon is only a fraction of that occurring in halibut and flounder.

Since drip can be largely prevented by a brief treatment with cold salt solution (see Chapter 4), the importance of the leakage of fluid from thawed fish may be somewhat overrated. However, it does seem evident that rapidly frozen fish have a higher taste-panel acceptance than very slowly frozen ones.

It has been reported [26] that the proteins even in slow-frozen fish muscle (7 hours in the range of 23° to 30°) are not physically altered or denatured during the freezing process, which suggests that drip formation may result from structural changes brought about by large ice crystals. There is evidence [27] that the proteins of frozen fish may be partially denatured at low temperatures, although the holding period prior to freezing and the time–temperature conditions in frozen storage appear to play a more significant role than the actual freezing conditions.[28] As the storage period of the muscle juice before freezing increases, the tendency is for denaturation to be greater. In any case, the denaturation of the protein of fish muscle in the frozen state is not nearly so extensive, so rapid, nor so clear-cut, as is the change induced by heat.

[24] G. M. Trout and M. V. Scheid, The stability of the fat emulsion of frozen cream, *J. Dairy Sci.* **26,** 619 (1943).

[25] H. L. A. Tarr and P. A. Sunderland, Drip in unfrozen and frozen fillets controlled by brining, *Fisheries Research Board Can., Progress Repts. Pacific Coast Stas.* **45,** 19 (1940).

[26] G. A. Reay, The influence of freezing temperatures on haddock's muscle. II., *J. Soc. Chem. Ind.* **53,** 413T (1934).

[27] G. A. Reay, The influence of freezing temperatures on haddock's muscle. I., *J. Soc. Chem. Ind.* **52,** 265T (1933).

[28] W. A. Riddell, H. N. Brocklesby, and L. I. Pugsley, Frozen-fish research. Chemical and biochemical studies of halibut, *Ice and Cold Storage* **40,** 189 (1937).

Such denaturation as may occur is not harmful from the standpoint of nutritive value. The effect on drip is the important consideration and may constitute a problem in fish fillets, which offer a very large exposed cut surface in proportion to the actual volume. Indeed, if freezing rate is important in maintaining high quality in certain frozen products, fish is one such product.

It has been stated [29] that, after cooking, properly frozen fish is difficult to distinguish from unfrozen samples, the differences often being less than might be expected from different fresh fish. The frozen product is definitely to be preferred to unfrozen fish which must be shipped to distant consumer markets, with consequent deterioration en route.

General. There is some belief that freezing at very low temperatures will extract heat from food so rapidly that there is an absence of ice-crystal formation and no destruction of tissues, the cells being left intact. Examination of fast-frozen tissue under high magnification [13] shows the reverse to be true—that is, fast freezing shatters the cell membrane owing to the expansion of the intracellular ice. Misinterpretations may arise from the fact that in the thawed product the cells appear once more to be intact.

A simple demonstration of the effect of slow freezing on water relationships within the foodstuff can be made, using an untreated cellophane bag to represent the cell membrane. If such a bag containing a sugar solution is immersed in the same solution and the outer liquid frozen (as would be the case in slow freezing), water passes from the inner to the outer solution as freezing progresses. Thus does water tend to pass from within the cell to the outer extracellular space, where it becomes frozen. Such a process, known as osmosis, leads to a distribution of ice such as is seen in Fig. 14*c*.

To summarize the best information now at our disposal, it would seem that too much emphasis has been placed in the minds of the public on "quick freezing" and not enough on "quick to the freezer" and "quick cooling," without which high-quality food is sure to be affected adversely. Without "quick freezing" (a loosely used and much abused term) high quality can still be achieved. With all foodstuffs adaptable to freezing, a rapid freezing rate

[29] O. C. Young, The quality of fresh, frozen and stored halibut as determined by a tasting panel, *Fisheries Research Board Can., Progress Repts. Pacific Coast Stas.* **37,** 12 (1938).

will prove satisfactory. With most if not all of these foodstuffs, a moderate rate of freezing will prove satisfactory. With a few foodstuffs, particularly where a large cut surface is exposed, a slow freezing rate may prove somewhat less than satisfactory.

In appearance, odor, flavor, and nutritive value, the home-frozen product can usually vie with the quick-frozen food in commerce as being a quality item.

Chapter 7

THE STORAGE OF FROZEN FOOD

Successful food preservation requires that chemical change be controlled. Foods are composed of many complex compounds, with widely varying properties. They are thus subject to a diversity of chemical reactions producing many deep-seated changes. The inhibition of these reactions, which would otherwise alter the physical and chemical make-up which characterizes each food, is the usual objective in food processing.

The speed at which chemical reactions take place is dependent on temperature. Many of the chemical changes which are involved in the deterioration of foods are nearly completely inhibited at freezing temperatures. Other reactions are greatly slowed at these temperatures. Some chemical reactions, particularly those catalyzed by enzymes in the foodstuff, may continue to the extent that an auxiliary preservation aid, such as scalding (Chapter 3), may be necessary.

In general, the rate of chemical reaction, including enzyme activity, is approximately doubled for every 18°F. rise in temperature in the range above freezing. According to this, one would predict that in moving fresh produce from the kitchen table to the refrigerator the general progress of food spoilage is retarded fourfold. In moving these foodstuffs from the refrigerator to the freezer, the tendency toward a deterioration in quality should again be retarded fourfold. These crude computations suggest that the frozen food will have a storage life some 16 times that of produce without the benefit of refrigeration. Actually, the figures are *far more favorable* to freezing as a means of preserving perishable foods! Two complicating factors have not been taken into account in this line of reasoning: one is the effect of freezing on enzyme activity; the other is the effect of freezing temperatures on microbial growth.

Enzyme activity in the freezing range. The assumption of a twofold reduction in the rate of enzyme action when the temperature is lowered 18°F. is often applicable when the reaction mixture is in the *liquid* state. Between 68° and 20°F., the sugar-hydrolyzing enzyme, invertase, roughly followed this rule-of-thumb measure of activity.[1] When the supercooled solution at 20°F. was allowed to freeze, the enzyme activity *at the same temperature* was only 27 per cent of the activity in the liquid state! The enzymes, lipase and trypsin, which split fats and proteins, also show a break in the relationship of rate of reaction to temperature in passing through the freezing point.[2]

These studies make it clearly evident that one cannot calculate the extent of enzyme action in foods at subfreezing temperatures when the measurements of the enzyme activity were based on liquid mixtures at higher temperatures. The enzymes are not inactivated at very low temperatures (for example, lipase has appreciable activity even at temperatures as low as −13°F.), and, when the frozen samples are thawed, a normal rate of enzyme-catalyzed hydrolysis is exhibited unless the product has been scalded. However, subfreezing temperatures for the storage of foods are very effective in inhibiting such undesirable changes. For these hydrolytic enzymes, a unit lowering of the temperature below freezing is several times as effective as a similar decrease in the range above 32°F. Accordingly, the storage life of food in the freezer at 0° as compared with that of produce left at room temperature is, as far as enzymic effects are concerned, far more in favor of zero storage than noted in our earlier calculation.

Freezing and microbial growth. The growth of bacteria, yeasts, and molds is also dependent on temperature. But, whereas many of the nonmicrobial changes in foods are only slowed by lowering the temperature to 15°F., the microorganisms responsible in no small degree for true food spoilage are completely checked. The food is now frozen hard, and in this solid medium bacteria are immobilized and incapable of growth or reproduction.

In the refrigerator food quality can be affected both by straight chemical change and by many reactions induced through the

[1] Z. I. Kertesz, Note on invertase activity in identical mixtures in the liquid and frozen state, *J. Am. Chem. Soc.* **64**, 2577 (1942).

[2] I. Sizer and E. Josephson, Kinetics as a function of temperature of lipase, trypsin, and invertase activity from −70 to 50°C. (−94 to 122°F.), *Food Research* **7**, 200 (1942).

growth and metabolic activity of microorganisms. In the freezer this deterioration can be entirely restricted to the reactions which characterize the response of food to its physicochemical environment, uncomplicated by microbial action. Accordingly, by sufficiently lowering storage temperatures, one can completely eliminate the deteriorative action of a major spoilage agent. The result is a degree of preservation far more than that predicted from the temperature effect on chemical reactions in the range above freezing.

Freezing destroys some parasites. Pork infected with trichinae (*Trichinella spiralis*) is not detectable by the usual meat-inspection methods. Such pork may transmit to the incautious consumer the disease known as trichinosis. Because of the danger presented by the possible presence of trichinae, pork is rarely consumed unless it is first thoroughly cooked or cured, both of these procedures being effective means of destroying the parasitic organism.

In 1916 Ransom[3] found that trichinae in pork are killed when exposed to temperatures of 5°F. for ten days. He recommended that infected meat be held 20 days at 0° to ensure complete destruction of the parasites. Augustine[4] found that the organisms were destroyed 24 hours after reaching 0°F. The effectiveness of freezing as a means of rendering trichinae-infected pork safe has been recognized by the Government in establishing regulations on pork products in interstate commerce. Uncooked uncured pork products which are likely to be eaten without first being cooked by the consumer must be frozen to destroy any live trichinae, according to regulations of the U. S. Department of Agriculture's Bureau of Animal Industry. The Federal Meat Inspection Regulations as amended on March 24, 1945, state that "all parts of the muscle tissue of pork or product containing such tissue shall be subjected continuously to a temperature not higher than one of those specified" in Table 5, noting that the duration of the refrigeration at the specified temperature will be dependent on the thickness of the meat or inside dimensions of the container.

[3] B. H. Ransom, Effects of refrigeration upon the larvae of *Trichinella spiralis*, *J. Agr. Research* **5**, 819 (1916).

[4] D. L. Augustine, Effects of low temperatures upon encysted *Trichinella spiralis*, *Am. J. Hyg.* **17**, 697 (1933).

TABLE 5. REQUIRED PERIOD OF FREEZING PORK AT VARIOUS TEMPERATURES TO DESTROY TRICHINAE

Temperature, °F.	Group 1, days	Group 2, days
5	20	30
−10	10	20
−20	6	12

Source: Federal Meat Inspection Regulations (see text).

The regulations go on to say that

Group 1 comprises products in separate pieces not exceeding 6 inches in thickness, or arranged on separate racks with the layers not exceeding 6 inches in depth, or stored in crates or boxes not exceeding 6 inches in depth, or stored as solidly frozen blocks not exceeding 6 inches in thickness.

Group 2 comprises products in pieces, layers, or within containers the thickness of which exceeds 6 inches but not 27 inches, and product in containers including tierces, barrels, kegs, and cartons having a thickness not exceeding 27 inches.

The product undergoing such refrigeration or the containers thereof shall be so spaced while in the freezer as will insure a free circulation of air between the pieces of meat, layers, blocks, boxes, barrels, and tierces in order that the temperature of the meat throughout will be promptly reduced to not higher than 5°F., −10°F., or −20°F., as the case may be.

TEMPERATURE LEVELS FOR FROZEN FOODS

Since the growth of microbial agents of spoilage and disease can be stopped by maintaining temperatures below 15°F., that figure seems a logical upper limit at which to fix the recommended storage temperature for any frozen food. From the standpoint of inhibiting the progress of chemical reactions within the foods, there would be no lower limit for a desirable storage temperature. However, reasons of economy dictate that frozen-food storage be at the highest temperature at which a satisfactory storage life can be assured.

This dictum requires not only a definition of "satisfactory" from the standpoint of storage time but also an agreement as to what is "satisfactory" from the standpoint of food quality. As a general recommendation, subject to the usual exceptions of any generalization, 0°F. has been chosen by the great majority of investigators as being desirable for the storage of frozen foods. This choice represents a happy compromise in the defining of "satisfactory" for time and for quality of the many foods to be preserved by freezing.

The effects of prolonged storage of foods in the freezing range are varied. In some instances, such as butter or fatty foods, the odor may become unpleasant by a process such as rancidity. In other foods, such as peaches, the appearance or color may become altered by the process of oxidation. In some products, such as fish, off-flavors may develop by both physical and chemical processes. In other cases, such as asparagus, the texture may become undesirable. And in many cases, the nutritive value of the fruit or vegetable may be affected by processes of hydrolysis and oxidation. All these criteria that go into food quality—odor, appearance, flavor, texture, and nutritive value—are important in the defining of "satisfactory" food storage.

Naturally, all foods are not equally susceptible to a given type of deteriorative change. Nor are all changes equally affected by a given environmental temperature. Nutritive value may be seriously impaired while the factors that are concerned in general palatability are satisfactorily retained. Rancidity may progress rapidly in one food while being held in check in another fatty product. Thus the relatively recent establishment of 0°F. as a generally acceptable storage temperature involved many complications, of which the effect of the nature and composition of the food was foremost.

Time-temperature relationships in frozen-food storage. The higher the temperature, the shorter is the safe period for storing foods in the freezer. There is, however, considerable confusion and disagreement as to the maximum time for storing properly processed food at any given temperature in the subfreezing range. Some of the variability is undoubtedly caused by different starting materials; such factors as variety, maturity, speed, and care of handling, and perhaps even the feeding or fertilizing treatment, insofar as it affects the physical or chemical composition of the product, may contribute toward a differing in response or stability to freezing storage.

The storage of frozen fruits and vegetables. For fruits and vegetables a considerable number of investigations have indicated that the vitamin content is lowered more rapidly as the storage temperature is raised.

Vitamin A values (principally as β-carotene) of these plant products may drop significantly in 6 months at 15° but be satisfactory for a 3-month period. Even at 0° as much as 25 per cent of the provitamin may be lost[5] during storage of frozen peas from one season to the next.

Ascorbic acid (vitamin C) is one of the more important and one of the least stable of the nutrients in frozen fruits and vegetables. As such it is often used as an index of the suitability of the storage conditions. In Table 6 are given some data recalculated from the literature to illustrate what happens to the antiscorbutic vitamin during frozen storage. If one arbitrarily takes a 25 per cent destruction of ascorbic acid as being a desirable maximum during the storage life of a frozen vegetable, the experimental data serve to illustrate several points.

There is considerable variability among different vegetables as far as vitamin stability is concerned. Even for a single frozen vegetable, different investigators or the same investigators at different times may find discrepancies of several months in the storage life of the product as measured by vitamin destruction. But of greater significance is the unquestioned fact that the storage life must be drastically shortened if temperatures much above 0°F. are maintained. At the upper temperature limit for safe storage from the standpoint of complete inhibition of microbial growth, the nutritive value of the product remains comparable to the freshly frozen vegetable for only a month or two. Even at 10° the recommended storage period would be less than 6 months. Not until the storage temperature is lowered to 0°F. or less can one state that the high nutritive properties of frozen vegetables will be retained from one harvest to the next.

It should be emphasized that the deterioration in quality when the storage temperature is too high is not restricted to the vitamins. For example, frozen peas will lose their desirable bright green

[5] C. R. Stimson, D. K. Tressler, and L. A. Maynard, Carotene (vitamin A) content of fresh and frosted peas, *Food Research* 4, 475 (1939).

color and acquire a yellow to brown tinge at temperatures above 15°F.,[6] owing to a slow destruction of chlorophyll, the characteristic pigment of green vegetables and other plants. This change is not evident when the storage temperature is maintained at 0° or

TABLE 6. ASCORBIC ACID LOSSES FROM SOME FROZEN VEGETABLES AS A FUNCTION OF STORAGE TIME AND TEMPERATURE

Product	Months in Storage before ¼ of Vitamin C Is Lost			Reference
	0°F.	10°F.	16°F.	
Asparagus	9	5	5	*
Beans, green	over 6	1	1	*
Beans, green	6	3	..	†
Beans, green	12	2	..	‡
Beans, lima	over 6	over 6	3	†
Beans, wax	over 6	4	1	*
Broccoli	over 6	4	1	†
Brussels sprouts	10	3	1	*
Cauliflower	over 6	2	2	*
Corn	over 6	6	2	†
Peas	over 9	6	1	†
Peas	over 12	8	..	‡
Spinach	8	4	1	†

* R. R. Jenkins, D. K. Tressler, J. Moyer, and J. McIntosh, *Refrig. Eng.* **39**, 381 (1940).

† R. R. Jenkins, D. K. Tressler, and G. A. Fitzgerald, *Ice and Cold Storage* **41**, 100 (1938).

‡ W. A. Gortner, Faith Fenton, Frances Volz, and Ella Gleim, *Ind. Eng. Chem.* **40**, 1423 (1948).

less. A similar story could be cited for the other quality characteristics of fruits and vegetables.

The storage of frozen animal products. Does this generalization on the storage life of frozen vegetables also apply to meats and poultry? Considerable data in the literature bear on this point, but perhaps with somewhat less decisiveness. Carotene and ascor-

[6] H. Campbell, Undesirable color change in frozen peas stored at insufficiently low temperatures, *Food Research* **2**, 55 (1937).

bic acid are the vitamin factors most likely to change during storage, but neither is present in animal tissues in a quantity such as to make it a major nutrient in these products at any stage. Accordingly, our measures for deterioration in quality of animal

TABLE 7. QUALITY RETENTION IN SOME FROZEN MEATS AS A FUNCTION OF STORAGE TIME AND TEMPERATURE

Product	Months in Storage with Quality Retained			Reference
	0°F.	10°F.	15°F.	
Beef	15	4	3	*
Fish	....	2	..	†
Fish	6–12	..	..	‡
Lamb	14	4	3	*
Pork	12	..	1	§
Pork	12	2	1	*
Pork	12	4	..	‖
Poultry	10	4	2	¶
Veal	14	4	3	*

* C. W. DuBois, D. K. Tressler, and Faith Fenton, *Proc. Inst. Food Technologists* **1940,** 167.

† O. C. Young, *Fisheries Research Board Can., Progress Repts. Pacific Coast Stas.*, **42,** 16 (1939).

‡ J. M. Lemon, *Food Freezing* **1,** 48 (1945).

§ O. G. Hankins and R. L. Hiner, *Refrig. Eng.* **41,** 185 (1941).

‖ W. A. Gortner, Faith Fenton, Frances Volz, and Ella Gleim, *Ind. Eng. Chem.* **40,** 1423 (1948).

¶ C. W. DuBois, D. K. Tressler, and Faith Fenton, *Refrig. Eng.* **44,** 93 (1942).

products are largely subjective and, hence, less clear-cut. The two common measures of change in frozen meats and poultry are (1) rancidification of the fat as detected by chemical (peroxides) and sensory (odor, flavor) means, and (2) general palatability as detected by standard taste tests.

In Table 7 are summarized a few of the observations recorded in the literature on the freezing and storage of meats and poultry. Both rancidity and palatability measures were used in assessing "quality." A general trend similar to that observed for frozen vegetables is apparent. At 15° or 10° animal products retain a quality approaching the fresh meat for only a few months. At 0°F., storage of these foodstuffs can be safely prolonged to approximately a year.

The importance of storage temperature is given added emphasis by studies of frozen fish. As pointed out in the previous chapter, there is some evidence that higher quality accompanies faster freezing rates for fish. Yet tasting panel tests on frozen and stored halibut [7] and salmon [8] have clearly demonstrated that the temperature of storage is more important in maintaining quality than is the freezing rate.

Here, then, is an indication of why 0°F. ("zero storage") is recommended for the holding of various types of frozen foods. There is little justification in having such storage extended to more than a year. Frequently, however, the last quart of strawberries or the final porterhouse steak is removed from the freezer just ahead of the incoming foods from the following season's harvest. At temperatures above zero, quality food throughout the year is less readily assured. At zero, food need know no "off-season."

Storage at above zero temperatures. There are occasions when only short-time storage of a frozen-food product is desired. And there are freezer units incapable of efficient operation at 0°. In such cases as these, the desirability of fixing a general recommended maximum storage period for foods above 0°F. becomes evident.

The variability in foods—and in flavor perception of individuals—makes any generalization unsafe. However, a few investigators have attempted to draw up a flexible rule of thumb to guide those who will be storing frozen foods at 10° to 15°.

Winter and Hustrulid [9] have suggested the storage periods noted in Table 8. These workers point out that "most products will remain *edible* for considerably longer periods than shown in this table." The suggested time–temperature storage relationships, chosen as representing safe conditions for retaining high quality

[7] O. C. Young, The quality of fresh, frozen and stored halibut as determined by a tasting panel, *Fisheries Research Board Can., Progress Repts. Pacific Coast Stas.* **37**, 12 (1938).

[8] O. C. Young, Further tasting panel tests on frozen and stored fish, *Fisheries Research Board Can., Progress Repts. Pacific Coast Stas.* **42**, 16 (1939).

[9] J. D. Winter and A. Hustrulid, Freezing foods for home use, *Minn. Agr. Ext. Bull.* **244** (Revised June 1945).

in frozen foods, serve as a useful guide for processor, distributer, and consumer.

Temperature fluctuation in the freezer. The mere establishment of a desirable maximum temperature for frozen-food storage is not in itself sufficient. Having recognized that frozen foods may be safely stored for a number of months at temperatures near 0°F., we must now more rigidly define or restrict the storage temperature because of other considerations.

TABLE 8. APPROXIMATE STORAGE PERIODS FOR FROZEN FOODS AT 0° TO 10°F.

Product	Approximate Storage Period in Months		
	0°F.	5°F.	10°F.
Beef, fruit juices	12–15	10–12	6–8
Fruits, vegetables, veal, venison	10–12	8–10	3–6
Lamb, poultry, rabbits, game birds, eggs	8–10	6–8	3–4
Fresh pork, ham, creamery butter, cheese	6– 8	4– 6	2–3
Ground meat (unsalted), lean fish, cottage cheese	4– 6	3– 4	1–2
Beef liver, fatty fish, slab bacon, cooked foods	2– 4	2– 3	1–2

Source: J. D. Winter and A. Hustrulid, *Minn. Agr. Ext. Bull.* **244** (Revised June 1945).

Fluctuating temperatures within the freezing range may, for purely physical reasons, alter the quality of frozen foods. The most evident effect of temperature cycling is in moisture loss.

When a freshly slaughtered animal is brought immediately into the 32°F. chill room, a fog is formed from the rapid condensation of moisture vapor leaving the warm carcass for the cool air. This phenomenon is largely the result of vapor-pressure differences. Vapor pressures are measures of the tendency for a liquid or solid to exist as a gas or vapor. Just as heat is dissipated from high temperatures to lower temperatures, so is moisture vapor moved from regions of high vapor pressure to those of lower pressure. The rate of flow in these cases is proportional to the difference in temperature or vapor pressure. This is but one more example of the dictum that nature tends to seek an equilibrium.

The warm air immediately next to the animal carcass can and does hold a large amount of water vapor formed through evaporation of surface moisture. The colder air of the chill room has a lower vapor pressure and when "saturated" can hold only one eighth as much moisture as can the air near the still warm meat. When this cold air is warmed in passing over the carcass, its capacity to hold water vapor is increased by this considerable factor. The net result is that moisture is rapidly drawn from the surface tissue and carried away as vapor. When the moisture-laden air leaving the meat is again cooled, its ability to hold water vapor is greatly diminished, and the excess moisture condenses as fine droplets in a fog.

This phenomenon of moisture leaving the warm product that is placed in cooler air is also operative when the temperatures are in the subfreezing range. Whenever the food is at a temperature higher than the refrigerated air, water is drawn from the tissues to be carried away as vapor. Whenever temperatures are fluctuating in the freezer, the air temperature can change more rapidly than the product temperature. Accordingly, the latter will lag behind on the cooling phase of the cycle, sometimes as much as a 6-hour lag being not uncommon even in a relatively small freezer. The more often this situation is encountered, the more opportunity there is for desiccation. The greater the temperature differences and the higher the average temperature, the greater is the amount of water vapor which the air can carry away from the product, and the more rapid is the process. It thus becomes evident that the frequency and magnitude of temperature fluctuation, as well as the range at which the temperatures are varying, are factors in the rate of drying of frozen foods.

Temperature variation in the subzero range. Reasoning from this knowledge of the moisture-carrying capacity of air, one would immediately predict that temperature fluctuation in the subzero range would have a minimal effect on the foods in storage. At these low temperatures, the air has only a very low capacity for holding water vapor—perhaps one tenth that of air in the household refrigerator—and accordingly the drying process would be very slow. Thus, it has been observed[10] that, where the tempera-

[10] A. Hustrulid and J. D. Winter, Effect of fluctuating storage temperatures on frozen fruits and vegetables, *Agr. Eng.* 24, 416 (1943).

ture fluctuation was infrequent and in the range of 0° to −20°F., no significant change in the extent of desiccation, appearance, or palatability of fruits or vegetables was evidenced during the course of 6 months' storage.

Temperature variation in the range above zero. In the freezing range above zero, however, greater opportunity is presented for undesirable desiccation and accompanying deteriorative changes in frozen foods. Many investigators cite the danger of fluctuating temperatures in this range, but satisfactory evidence has not been available in the scientific literature.

A study,[11] in which the product temperature was varied considerably (0° to 20°F.) and frequently (a complete temperature cycle every 6 days) illustrates some of the effects of fluctuating temperatures. At temperatures above 0°, regardless of whether or not the temperature was constant, desiccation tended to be appreciably greater than in control products at a uniform 0°F. The loss in weight of the package and contents was not a true indication of the extent of desiccation, however. The frozen vegetables were also subjected to a drying out within the package as evidenced by the marked accumulation of frost in the package. This "cavity ice" formation was particularly evident where temperature fluctuation occurred during storage. In addition to the physical effects of changing temperatures, chemical changes associated with the greater reactivity at higher temperatures occurred. However, the changes in palatability, appearance, nutritive value, and fat stability over a 12-month storage period apparently were *not* a function of the fluctuation but rather could be ascribed to the magnitude of the temperature and the duration of exposure.

DuBois and Colvin[12] state that temperatures fluctuating between +5° and −5°F. will result in a greater loss of ascorbic acid in frozen peaches than will be observed in peaches stored at a uniform 0°F. Their analytical data do not indicate that any significant loss in the vitamin can be ascribed to this cycling of the temperature.

There seems to be no question of the fact that fluctuating temperatures are to be avoided in frozen-food storage. It is recognized that some variation or cycling is difficult to avoid. The fre-

[11] W. A. Gortner, Faith Fenton, Frances Volz, and Ella Gleim, *Ind. Eng. Chem.* **40**, 1423 (1948).

[12] C. W. DuBois and D. L. Colvin, Loss of added vitamin C in the storage of frozen peaches, *Fruit Products J.* **25**, 101 (1945).

quency of such cycling may depend on the periodic operation of the compressor. This in turn is a function of such variables as room (ambient) temperature, the load, the setting of the control switch, and the frequency and duration of opening of the freezer. Accordingly it is not feasible to fix a maximum number of temperature cycles for any set period of time. The magnitude of temperature fluctuation can, however, be limited.

The establishment of a recommended tolerance or temperature range can be based on experiments on frozen foods together with tables showing the moisture-carrying capacity of air at different temperatures. The available data suggest that, if the temperature of the packaged food does not go above 3° to 5°F.[10, 11] during storage and is at 0°F. or less during most of the storage period, the quality of the food material will not undergo noticeable change ascribable to temperature fluctuation.

REFREEZING OF THAWED FOODS

Many of the more well-known brands of commercially frozen foods bear an admonition that varies in wording but not in meaning: "Do not attempt to refreeze this food after thawing." There are many good reasons to support the wisdom of this advice.

It has previously been pointed out that even frozen foods handled with good sanitary practice will contain some surviving microorganisms. Because of the "tenderizing" effect of scalding and freezing on the texture of foods, bacterial growth is readily supported after thawing—more so than is the case for fresh market produce. It is true that the microorganisms most frequently found in frozen foods are[13] "the common soil types which have always been considered to be without health significance." However, these same microbes "will cause spoilage of the food provided it is not used promptly after defrosting."

For some frozen foods two hours of thawing effects a significant increase in the bacterial content. Commercially packed vegetables will spoil much faster than fruits,[13, 14] and are particularly to be watched. If the defrosted food is allowed to remain at room

[13] Helen F. Smart, Microbiological studies on commercial packs of frozen fruits and vegetables, *Food Research* **4**, 293 (1939).

[14] C. R. Fellers, Public health aspects of frozen foods, *Am. J. Pub. Health* **22**, 601 (1932).

temperature, food poisoning strains of staphylococci[15] and toxin-producing botulinus organisms[16] may develop. However, decay usually precedes or accompanies such growth, and frozen foods that are palatable are probably as safe as are the fresh products themselves.

Fellers[14] points out that the thawed foods provide an ideal medium for the growth of bacteria. Some of his data are shown in Table 9. They dramatically emphasize the point that bacteria

TABLE 9. BACTERIAL COUNTS ON VARIOUS FROZEN FOODS AFTER A YEAR'S STORAGE IN THE FROZEN STATE, AND AFTER THAWING 24 HOURS AT 70°F.

Product	Bacteria per Gram	
	Frozen	After 24 Hours at 70°F.
Raspberries, with sugar 3:1	3,000	8,000
Strawberries, with sugar 2:1	200	2,000
Peaches, with sugar 3:1	60	700
Sour cherries, with sugar 3:1	0	20
Peas, scalded	Less than 1,000	24,000,000
Green beans, scalded	Less than 1,000	40,000,000
Sweet corn, scalded	1,500	60,000,000
Carrots, scalded	3,000	5,800,000
Oysters	22,000	320,000,000
Haddock	38,000	770,000
Beef steak	390	1,400,000
Whole chicken (breast)	0	30
Pork chops	1,300	8,700,000
Eggs (in tin)	190,000	70,000,000

Source: C. R. Fellers, *Am. J. Pub. Health* **22**, 601 (1932).

not only exist after many months in the subfreezing range, but also are capable of very rapid multiplication once the ice has left the food tissues.

[15] A. H. Jones and A. G. Lochhead, A study of micrococci surviving in frozen-pack vegetables and their enterotoxic properties, *Food Research* **4**, 203 (1939).

[16] Fred W. Tanner, R. Beamer Parker, and Charles J. Rickher, Further studies on development of *Clostridium botulinum* in refrigerated foods, *Food Research* **5**, 323 (1940).

Thus, one of the major dangers of refreezing after the produce has thawed is that the microbial population may have greatly increased. Frozen foods having high bacterial counts will then be particularly susceptible to spoilage during the next period of thawing. It has been claimed[17] that frozen eggs of high quality can withstand two complete thawings and refreezings without acquiring an abnormal appearance, odor, or bacterial count. Eggs of poor initial quality, however, usually have a considerable microbial contamination. Here progressive decomposition of the product will result from a period of thawing temperatures.

All are acquainted with reports of successful refreezing of foods when home freezers have been off for a long period because of power failure or mechanical breakdown of the equipment. In such cases it is necessary either to refreeze or to suffer an enormous and often irreplaceable loss in food. Fortunately, two points stand in favor of the success of the refreezing of the defrosted food in such instances. For one thing, the foods are in unbroken packages, which condition largely prevents an external contamination of the thawed food. And only in rare instances does the temperature of the frozen food rise much above freezing. Until all of the considerable quantity of stored food is thawed, the temperature will remain near 32°F., a reasonably safe range for even as much as several days if high quality, well-packaged food is involved.

Defrosted foods are subject to a more rapid increase in bacterial count and a more rapid decrease in nutritional and eating qualities. Even the texture of twice-frozen foods cannot be the equal of fresh-frozen quality produce. As such the recommendations against refreezing are sound. Retail packages of frozen foods are small enough to assure consumption of the contents in one or two meals. Under these conditions, refreezing should not be necessary. In the increasingly rare instances where refreezing may be condoned as necessary, the consumer should not expect the high quality which, more than any other attribute, has been the keystone of the freezing preservation of food.

[17] R. Schneiter, M. T. Bartram, and H. A. Lepper, Bacteriological and physical changes occurring in frozen eggs. Influence of defrosting and prolonged storage on bacterial count and on odor, *J. Assoc. Official Agr. Chem.* **26**, 172 (1943).

Chapter 8

COOKING FROZEN FOODS

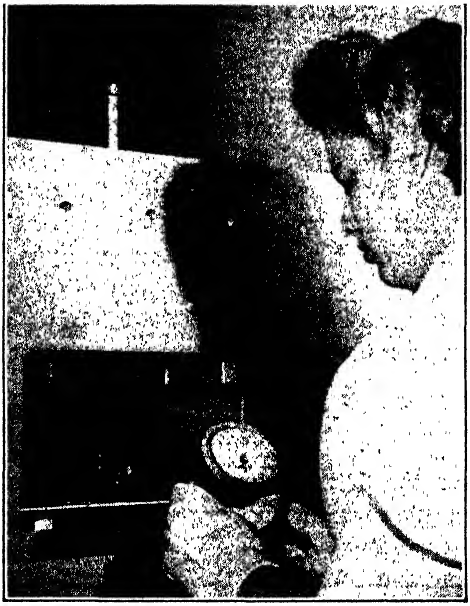
Previous chapters have emphasized the need for care in selecting the right food at the right time; for prompt and proper handling; processing, packaging, and freezing; and for storage at 0°F. or below until the frozen produce reaches the kitchen of the consumer. The need for care in the preparation of this food for the table is no less important. The recommendations for the thawing and cooking of various frozen foods may differ with the kind of food, with the place of the food in the menu, with the size of the package, and with the type of processing prior to freezing of the produce.

THAWING

Procedures for thawing of frozen foods have received much less attention than have such questions as desirable freezing rates or storage temperatures. Perhaps the reason is that many frozen-food packers have considered their job done when they adopted procedures that would assure a high-quality product in the warehouses. There is, however, an increasing awareness in the industry that the best of frozen foods may lose its quality and appeal if improperly handled in the retail store and in the home.

Thawing rates. Some foods are significantly affected by thawing—indeed, for some it is recommended that no thawing period precede actual cooking. Other frozen foods may not be altered regardless of the thawing procedure used. The rate of thawing may play a role as significant in final quality as does the rate of freezing. However, our knowledge—and particularly, our controlled scientific experimentation—is even more meager and inconclusive than the question of quality versus rate of freezing for various foodstuffs. For certain products, nevertheless, there is a fair agreement as to the desirability or undesirability of a given thawing procedure.

A review of much of the available information indicates that for various products, such as meat, the speed of thawing has but minor importance; for other frozen foods, such as fish, slow thawing may be indicated; and for still other foods, including frozen whole milk, a fairly rapid defrosting may be best for the retention of



Courtesy The Great Atlantic and Pacific Tea Co.

Figure 16. Experimental use of high-frequency heat in thawing frozen foods. The frozen cherries are being defrosted between two electrodes and are falling down into the dish. Commercial units using different electrode arrangements from that shown are being developed.

maximum quality. However, the data on which these generalizations are based merely emphasize the need for a more accurate re-examination of this subject as it applies to a diversity of items from the freezer. It is not improbable that many of the divergent statements regarding various techniques in food freezing actually arise because the thawing step was not controlled or properly considered.

Where there is an appreciable tendency for leakage of fluid from the food, thawing at a slow rate may help to minimize this "drip." For the smaller cuts of meat, and for fish, a gradual defrosting permits the tissue solids to reabsorb the major part of the fluid which had separated as ice crystals. With very rapid thawing, the juices may leak away before they can be taken up again by the swelling of the proteins of the flesh.

For slow thawing the product is left in cool air. A faster rate of thawing is secured by raising the air temperature and by increasing the circulation of air about the foodstuff. The usual means of obtaining rapid thawing is to use water as the surrounding medium. Water has a relatively high thermal conductivity compared to air and will greatly hasten transfer of heat to the frozen food.

Recently dielectric ("electronic") heating has been successfully applied to the "quick thawing" of many frozen-food products (Fig. 16). This technique holds promise of improving institutional use of frozen foods. Cathcart[1] cites some of the advantages of this very rapid thawing in the use of frozen eggs in bakeries. Considerable time savings are effected, and the possibility of bacterial growth during defrosting is eliminated (Table 10). The

TABLE 10. THAWING OF FROZEN EGGS

Method	Time Required, hours	Per Cent Increase in Bacterial Count during Thawing
In air at 80°F.	..	1000
In air at 45°F.	63	225
In air at 70°F.	36	750
In running water at 60°F.	15	225
In water at 50–55°F.	15	500
Agitated in water at 60°F.	9	40
Dielectric heat	¼	Negligible

Source: Data of Cathcart, *Western Frozen Foods* **6**, no. 12, 8 (1945).

use of such equipment is still in the experimental stage, and many problems are posed. In particular, the presence of even small bits of metal, and the use of unhomogenous food materials offer difficulties when dielectric heat is used in thawing frozen foods.

[1] W. H. Cathcart, High speed defrosting of frozen eggs by applying broadcast heat, *Western Frozen Foods* **6**, 8 (1945).

Quality as affected by thawing. Studies of the effect of thawing conditions on the nutritive value of frozen foods have dealt largely with vegetables, and with vitamin C as the index of possible change. When peas in their original sealed cartons were allowed to thaw for 24 hours at room temperature,[2] there was no appreciable destruction of the ascorbic acid. No additional destruction of the nutrient during cooking[3] was attributable to the prolonged thaw. However, where the thawed peas were removed from the package and left at room temperature,[4] as much as 27 per cent of the vitamin was lost within an hour. Even in the refrigerator, 24 hours' standing resulted in the disappearance of one fourth of the vitamin present in the frozen peas.

It is reported[5] that over a 24-hour thawing period currants lose only a small fraction of their ascorbic acid, whereas strawberries may lose as much as one half of this vitamin. Where cherries and strawberries are packed without sugar, the loss of nutrient during thawing is greater than when added sugar is present.

Frozen fruits allowed to stand after thawing are not so palatable as when served while still slightly frosted. They tend to collapse with resultant poor texture. Unless treated to prevent change, they discolor. Even when treated the portion of the fruit not covered by sugar or sirup discolors. Leftover fruits, like leftover frozen vegetables, are to be avoided. The selection of the container to fit the use of the fruit pays dividends in quality.

In the previous chapter, it was pointed out that the bacterial count is very significantly altered following the period of thawing (see also Table 9). Fruits were protected somewhat by the presence of added sugar but in any event were less susceptible to extensive bacterial contamination than the frozen thawed vegetables. Thawed animal products were also very excellent media for bacterial growth.

Thus the nutrients, the desirable juices, the sanitary quality, and the firm texture of fresh frozen foodstuffs may disappear with

[2] R. R. Jenkins, D. K. Tressler, and G. A. Fitzgerald, Vitamin C content of vegetables. VIII. Frozen peas, *Food Research* 3, 133 (1938).

[3] Faith Fenton and D. K. Tressler, Losses of vitamin C during commercial freezing, defrosting, and cooking of frosted peas, *Food Research* 3, 409 (1938).

[4] E. N. Todhunter and B. L. Sparling, Vitamin values of garden-type peas preserved by frozen-pack method. I. Ascorbic acid (vitamin C), *Food Research* 3, 489 (1938).

[5] G. L. Dernovskaya-Zelentsova and V. G. Dylevskaya, Stability of vitamin C in stored berries and mandarin oranges, *Proc. Sci. Inst. Vitamin Research USSR* 3, 284 (1941), through *Chem. Abs.* 36, 2943 (1942).

varying rapidity once the produce is left in the thawed condition. Prompt and proper cooking of the food will bring these qualities to the table rather than leaving them in the kitchen.

Thawing of vegetables. Among the frozen foods that are generally cooked directly without prior thawing are the majority of the frozen vegetables in unit packages. Even when not frozen as loose-pack items, these products readily break apart for rapid and uniform thawing at the start of the cooking process.

A few vegetables, notably the greens such as spinach, and stalk vegetables, such as broccoli and asparagus, are better when partially thawed prior to cooking. This facilitates the separation of the green leaves or stalks to insure heat penetration. If these products are not handled thus, the outer portions of the block of frozen food may be cooked to completion while the center still remains cold. One vegetable which is more satisfactory when allowed to thaw completely before cooking is corn on the cob. The slow penetration of heat into the cob, coupled with the danger of overcooking to the detriment of the texture of the kernels, suggests the advisability of the preliminary defrosting. This also would seem to favor a medium or slow rate of thawing, to ensure the melting of the ice within the cob itself.

Thawing of fruits. Frozen fruits without sugar intended for baking or preserving are put directly into hot sirup to prevent discoloration. Fruits to be used in pies or cobblers, usually frozen with sugar, must be thawed enough to spread. Partial defrosting for fruits to be used with ice cream and just short of complete defrosting for shortcakes result in a most satisfactory product. In every instance fruit should be thawed in the unopened original container in order to protect it from oxidation. Fruits that discolor rapidly, such as peaches or apricots, are benefited by rapid thawing.

Thawing and cooking of meats. Freezing, though it has a tenderizing effect, cannot take the place of the natural tenderness nor change the original quality of meat. The chosen cooking method will depend as it does in fresh meats on the grade and quality of the cut. In general, frozen meats may be cooked by any of the variety of methods used for fresh meat of the same quality. Tender cuts may be oven-cooked; the less tender require cooking with water as braising or stewing. To thaw or not to thaw is principally a matter of convenience. The quality of the result does not differ appreciably, other conditions being equal. A longer cooking time must be allowed for unthawed cuts since the meat must thaw in the oven before the desired temperature and doneness are reached.

A meat thermometer, so useful for accurate cooking of fresh meat, is all the more important to register the correct temperature and doneness of frozen meat. Certainly the same cooking principles obtain in frozen-meat cookery as produce high-quality results with fresh; if anything, they should be more strictly adhered to. For uniform cooking, for example, low temperature is a must. The minutes-per-pound guide for cooking to a desired doneness can only be approximate since other factors enter into the length of cooking time, such as the shape and size of the cut, the amount of fat, and the length of the aging time.

Poultry. Poultry, like meat, may be cooked in the frozen state or thawed before cooking. If whole birds are stuffed before freezing they may be placed immediately in the oven for roasting without thawing. Otherwise, it is necessary to thaw roasters sufficiently to stuff them. Cut poultry thaws rapidly. Both cut and whole poultry cooked without thawing require a longer cooking time than fresh. Wrapping the bird in heavy waxed paper before roasting holds in the juices and prevents the evaporation of the slight drip from the frozen product. Low-temperature roasting is necessary in any case.

Eggs. Thawed eggs are used like fresh eggs, and the same cooking principles apply. Thawing in the original container is recommended. The process may be hastened by thawing at room temperature rather than in the refrigerator. Thawing may be further hastened by placing the container before an electric fan or in a pan of *cool* water if the container is watertight. Eggs have been frozen commercially for use by food processors for a long time. Only very recently have they been frozen for household use. A special divided container in which the eggs are frozen makes it possible for the homemaker to remove one or more eggs as she requires.

Bread dough. With the great interest in the freezing of doughs comes a need for increased knowledge in how to handle new products. Experiments conducted by a food co-operative have indicated that bread dough required special handling. The more rapid the thawing, the better the quality of the loaf. The entire process from the beginning of the thawing to the finished loaf required about 2 hours.

Precooked foods. The entire field of the defrosting and reheating of precooked frozen foods is still essentially unexplored. It is highly important that these two problems be thoroughly investigated, not only from the standpoint of a successful product, but also from the standpoint of safety as a food. Precooked foods form an excellent medium for bacterial growth once the bacteria are present. The short cooking time prior to freezing and the fact that the food is only reheated before serving do not make the product sterile. Many opportunities for contamination may have occurred somewhere in the processing line or during distribution.

COOKING FROZEN VEGETABLES

Quality of vegetables as affected by cooking. The quality of any frozen vegetable in the end may depend on how much water the cook puts into the saucepan and how long it is left on the fire before serving. All the diligence in the growing and selection of the vegetable, the care in processing and storage go into the pan with the food. The result is in the hands of the cook. It should not be taken for granted that the homemaker knows how to prepare frozen food successfully nor even that old rules apply. The packer of frozen foods has not only a responsibility of assuring a good product through specific cooking directions on the package, but also an opportunity to improve human nutrition and prevent waste of valuable food nutrients.

The losses of nutrients are mainly by solution in the cooking water. The vitamin loss from frozen broccoli increases as the amount of cooking water is increased (Table 11). Other vegetables show similar results. Since ascorbic acid, other vitamins, and minerals are present in the frost on the vegetables, the frost should become part of the cooking water. Retention of steam by covering the pan reduces the amount of water necessary to prevent burning. When the product is done, the cooking water remaining should be no more than can be served with it. As is the case with ascorbic acid, the loss of thiamine is chiefly in the cooking water, varying from a negligible amount up to half the vitamin originally in the food and increasing with the amount of water used in cooking. Losses of minerals occur because of their solution in cooking water. There may be a greater tendency toward loss of minerals in cooking frozen vegetables than in cooking fresh ones, owing to the disruption of tissues during freezing. The first rule in cooking frozen vegetables is a simple one—*use as little water as is possible.*

The loss of ascorbic acid during the cooking of frozen vegetables also varies with the kind of vegetable and the length of the cooking time. The loss during cooking may account for one third of this vitamin. Careful timing is necessary if frozen vegetables are to be

TABLE 11. RETENTION OF ASCORBIC ACID IN COOKING A 12-OUNCE PACKAGE OF BROCCOLI IN VARYING AMOUNTS OF WATER

Amount of Cooking Water	Ascorbic Acid in Vegetable, per cent	Ascorbic Acid in Solution, per cent
½ cup	82	10
2 cups	57	32
4 cups	53	37

Source: Faith Fenton, *Cornell Univ. Ext. Bull.* **628** (1943).

at their best. Overcooking means not only reduced vitamin content, but also reduced palatability. Scalding for freezing has partially, if not completely, cooked the product. Freezing has further altered the texture. Less time is required to tenderize. *Do not overcook* is therefore the second rule for success. The cooking time for the fresh vegetable should be reduced by one half to one third for the same vegetable when frozen.

Use as little water as possible, do not overcook, and, third, *serve immediately when done.* The third rule implies selection of the size package to fit the family in order to eliminate leftovers. The cooked vegetable loses ascorbic acid on being held hot; cooling and reheating destroys flavor, color, texture, and nutritive value.

Choice of cooking method. In general the same cooking methods used for fresh vegetables may be used for frozen ones. Each method has its particular advantages and disadvantages. Every homemaker has her favorite methods and equipment. A common method for fresh vegetables is that of simple *boiling,* the length of time of the boiling and the presence or absence of seasonings being a sectional affair. Sectional habits have little place in cooking frozen vegetables. Boiling is a satisfactory method for frozen vegetables provided the rules are complied with: a small amount of water, a short cooking time.

To insure uniform cooking in boiled vegetables the frozen mass must be broken apart when it is placed in the rapidly boiling water, else the outer portions will be cooked before the inner mass has completely thawed. Some vegetables such as peas or lima beans break apart readily if covered for a few seconds, but others such as spinach and the more compact ones take a much longer time to separate. For these vegetables, at least partial thawing is suggested. Boiling is more suited to the strong-juiced frozen vegetables just as it is in the case of the strong-juiced fresh ones. *Steaming* may be a preferred method because there is less loss of the ascorbic acid in steaming than in the water cooking. However, color is less attractive in steamed vegetables. The *pressure saucepan,* for many homemakers the most beloved cooking utensil, must be used with caution for frozen products. It is a real timesaver in the preparation of fresh foods, but it may destroy completely the texture of the frozen vegetable unless extreme care is taken not to overcook. More of the ascorbic acid is retained by this method than by any other,[6] but unless the result is attractive and palatable the saving may be in vain. *Oven cookery* appeals to many homemakers for its convenience. Frozen vegetables may be oven-cooked. In fact, it is ideal for such items as frozen corn on the cob, to which the further addition of water is sometimes disastrous. Sweet corn and squash, cooked in the oven or in their own juices in a *double boiler* are definitely superior to sweet corn and squash cooked any other way. Oven cooking requires a longer time than do the other methods and may result in greater losses of food value for that reason, but increased palatability is worth the price in some instances. For uniformity of cooking and to prevent overcooking, partial or even complete thawing of vegetables that are to be cooked in the pressure saucepan or oven is advisable.

[6] Faith Fenton, The cooking of frozen foods: their nutritive value, *Cornell Univ. Ext. Bull.* 628 (1943).

II

THE CONSUMER AND HIS NEEDS

Chapter 9

HOME FREEZING

Frozen food requires low-temperature refrigeration from the initial processing until it reaches the final step of preparation for the table. Just as the retail frozen-food cabinet has been one of the bottlenecks in the distribution of frozen food so has lack of home storage discouraged its use. Women report that they would use more frozen foods had they a place to store them.[1] Some families need storage only. Others, producing food, are interested in preserving it by freezing.

Preserving food by freezing was at first thought to be a commercial process entirely unadaptable to home use. If any thought was given to it by the "experts" it was to say "it couldn't be done." One of the first farm freezers was built by a milk-cooler manufacturer at the insistence of a man of vision to whom the impossible is always a challenge. This freezer, still working today on the farm where it had its start, provides frozen meats, fruits, and vegetables for three tenant families. Free use of the box to store any of the farm products they help to produce greatly increases the real income and the satisfaction of farm tenants.

Why are families interested in home freezing? A high percentage of the food supply of the rural family has always been grown and preserved at home. Canning, drying, pickling, and smoking have kept the farm wife busy during the seasons of production. Only staples have been "store-bought" on many farms. In spite of the untiring efforts of the family, a great deal of food has gone to waste every year. Waste has occurred before processing and afterward. The percentage of loss in home-canned products has always been of concern. Fear of botulism has long been the threat of home-canned foods. The quality of home canning has not always been what it should be. The farmer who said,

[1] Nancy K. Masterman, Survey discloses what women want in cabinets, *Quick Frozen Foods* 7, no. 11, 83 (June 1945).

"Home-canned meat is all right if you have nothing else," was not commenting so much on its quality as he was rebelling against the monotony of flavor and texture of home-canned meat that soon palls. Where farm-killed meat has been kept for eating fresh, the race to get it used before it spoiled frequently resulted in the bacteria winning. It has been claimed that 30 to 40 per cent of the pork slaughtered on farms in the South has spoiled.[2]

Advantages of freezing. Freezing is the most satisfactory method of food preservation yet developed for certain fruits and vegetables. The fresh quality of meat is more nearly preserved by freezing than by any other process. The color, texture, flavor, and nutritive values of frozen foods compare favorably with those of fresh foods. Indeed, the nutritive values may be superior to the so-called market-fresh out-of-season fruits and vegetables. It has been claimed that the availability of the iron of frozen foods for use by the body is greater than that of the unfrozen foods.[3]

With the advent of locker plants the chore of slaughtering, with its dependence on the weather, and the entire task of preserving meat could be removed from the home. Not only loss from spoilage but also the waste from unskilled handling of the animal carcass is eliminated. It is no longer necessary for the farmer to sell meat animals and buy fresh meat over the retail counter. All the cuts of meat, the more desirable as well as the less desirable, are made available for the home table in fresh form. Many a farm family never knew what it was to have a choice steak until their home-grown meat was processed by freezing for their own use.

Freezing versus canning. The simplicity of the task of freezing is a more tangible gain to the homemaker than are food values. Home packers report that freezing requires from one third to one half the time required for canning, with about the same decrease in labor and with much less fatigue. With freezing it is not necessary to get out seldom-used equipment, or to scrub, test, and sterilize jars or jar rubbers. The time spent in watching the canning kettle or the pressure cooker and handling hot jars is eliminated. Homemakers appreciate that freezing is done with less heat, less

[2] H. Carlton, The freezer locker plant is going commercial, *Food Industries* 18, 1542 (1946).

[3] F. R. Theriault and C. R. Fellers, Effect of freezing and of canning in glass and in tin on available iron content of foods, *Food Research* 7, 503 (1942).

steam, and less confusion in the kitchen than is canning. It may be done in small amounts as garden surplus permits when daily meals are being prepared; or the entire family may form a production line and process large quantities of food with dispatch and fun.

Freezing will never replace all home canning. Low-temperature storage space for the entire family food supply is not a possibility for the majority of families even if all foods were equally adapted to freezing. Because certain home-canned foods are especially enjoyed, their preservation by canning will be continued. Home-canned peaches, green beans, chicken, and other foods will probably always be in favor. Variety in the diet—one of the greatest needs of farm families—will best be achieved by using all the forms of food preservation. Wise choice in the method for each particular product will result in improved nutrition and greater eating pleasure.

THE PORTABLE HOME FREEZER

Home-freezer ownership. The early freezer owners were enthusiastic about their equipment. "Our freezer has made it possible for us to live better than ever before" is a statement to which the majority agree. Not only was freezing fun and a fascinating topic of conversation, but also it resulted in improved-quality food from home gardens and farms. "We never used to have decent vegetables and fruits late in the year. We were always using up something to keep it from spoiling. With freezing, our three months' farm produce becomes a twelve months' source of food." "The use of our home-grown meat represents the greatest saving in box ownership." In these words are expressed the attitude of many pioneers in home freezing. The confidence in home-unit freezing and the pride in home-frozen foods have been borne out by recent research which has shown that it is possible to have products from home freezers of a quality equal to those from the freezers of industry.

The manufacture of home units was stopped in 1942 when production lines were converted to war requirements. The industry was at a standstill until late in 1945. Research, however, was extensive. The war years were a propitious time for study of specifications for home equipment, design, and processing methods. The margin of the unknown was pushed back to the extent that the postwar owners of home equipment can go ahead with considerable information for their guidance—a lack keenly felt by the early users.

The freezing of food at home is still awaiting its big development. It takes several years for a family to get the maximum use of low-temperature storage space. Freezing wisdom and skill comes with experience. Some freezer users have learned lessons the hard way. They can give good advice to the novice or prospective freezer owner.

The freezer most commonly in use in 1942 in New York State was the top-opening chest type. The larger freezers usually had a fan to provide circulation of air in the freezing compartment. Portable freezers ranged in size from 10 to 40 cubic feet, the most common size in use in New York State being around 18 cubic feet. Freezers were generally considered too small. The greatest interest of users contacted in the New York survey seemed to be in freezers larger than 30 or 40 cubic feet.

Cost of prewar freezers. The average cost of these prewar freezers was between $400 and $500. In no instance was there a feeling that the freezers had not justified their cost. All users were in income groups that do not count costs so much as they count satisfactions. Many families expressed the opinion that, though no money savings had been made, the nutrition of the family was greatly improved, and the convenience of having good food on hand was worth a great deal. Many expressed the hope that freezers in the future might be low enough in price so that their benefits could be extended to a large number of homes.

Operation costs. The cost of freezer operation depends on the construction of the freezer. The power required to operate a freezer and storage unit is related not only to the insulation efficiency but also to the efficiency of the cooling unit and the size of the box. Based on a rate of 2½ cents per kilowatt-hour, the cost of operation of cabinets in 70° ambient air may vary from $0.84 per month for a 6-cubic-foot cabinet to $1.76 for an 18-cubic-foot box.[4] Actual meter readings of freezers in use in homes show a daily consumption of less than 1 kilowatt for freezers of 5 to 6 cubic feet capacity and between 3 and 4 kilowatt-hours daily for freezers 9 to 30 cubic feet. There is evidence of lower power con-

[4] C. E. Lund, Technical phases of home freezer development, *Refrig. Eng.* **51,** 520 (1946).

sumption per unit volume with increasing capacity of the unit.[5] This is owing to the decrease in the relative importance of the losses in the motor and compressor of the larger units as well as to the decrease in the ratio of wall area to the volume of the box.

The cost of operation also depends on the amount of freezing done in the unit and on the other uses of electricity affecting the rate. Freezers located on poultry farms, for instance, with a high use of current and a correspondingly low unit rate, cost less to operate than do freezers of the same size on other-type farms or in village homes. The cost of operation for a well-constructed freezer, no matter where located, is part of the total cost of freezer ownership and may be relatively small.

Freezer size. The question of freezer size for varying needs is the great enigma. After long deliberation manufacturers have arrived at a decision as to the size or sizes of the first postwar freezers. With time and experience modification is to be expected. The size of the freezer will determine not only its use in the home but also its location. Excessive bulk and weight have made the handling of factory-built freezers very difficult. They have usually been located in the place that would accommodate them, rather than where they would be most convenient or best suited to efficient operation. Because of their bulk it has been impossible to get freezers into some houses. Outside locations, such as an open porch, a garage, dairy house, or barn have been used. The ultimate choice of a freezer may still be governed by its size. Certainly if a freezer is to go into a house it must go through a door. It must not be too long to make possible turns in hallways nor too bulky nor tall to go down stairs. The ideal location for a freezer would be a dry room off the kitchen, preferably unheated in winter, cool in summer, with cross ventilation. The temperature differential between the surrounding air and that within the cabinet should be kept as low as possible for efficient operation of the unit.

Freezer shape. The relative merits of the chest type and the upright freezer have long been a matter of debate. Unflattering terms such as "dive-in" and "Fibber McGee's closet" have been applied to both and not without just cause. Each type has its advantages and its disadvantages. Neither type has solved all the

[5] J. R. Donnalley, Jr., Performance characteristics of commercial home freezers, *Cornell Univ. Eng. Expt. Sta. Bull.* 34 (1944).

problems. The prospective freezer buyer must decide which model best fits his particular needs.

The available location may be the deciding factor in the choice of the freezer. The upright requires less floor space because its capacity can be incorporated in heights in excess of the top-opening cabinet. The length is the only really variable dimension in the

Courtesy Conn. Agr. Eng. Freezer Bull. 373

Figure 17. Solution for easy food removal is not in the door location alone. Removing packages from the upper compartment of an upright freezer is easy, removal from the lower compartment is more difficult. A deep chest-type freezer is inconvenient for a short person.

chest cabinet. The width and height of the chest freezer are fixed dimensions. The width cannot exceed 29 inches if the freezer is to go through the average door. The over-all height is fixed by the necessity of the ease of accessibility of the food to persons of normal and less than normal heights. The floor space required for a chest of large capacity is not available in many homes.

The handling of packages of frozen food may be less in upright freezers having shelves as freezer plates than from the freezing compartment to the storage compartments of the chest. The upright may be difficult of organization of packages for ready accessibility. Merely opening the freezer on the side does not solve this problem. The depth of the shelves and the size of the door must be considered from this angle. It may be difficult to utilize the full space between the shelves. Packages of frozen food are slippery, and there is a tendency for the packages to shift forward when the door is closed. They are ready to spill out when the door is again opened. Removal of food from the lower section of an upright cabinet may involve squatting instead of bending (Fig. 17).

More frequent defrosting is necessary for the upright than is required for the chest freezer. Because cold air is heavy, it tends to spill out when the door is opened. Warm moist air is drawn into the freezer. Although this may not affect the heat load appreciably, it does add to the frost on the plates (Fig. 18). Less moist air enters the chest when the lids are lifted. A well-insulated tightly sealed nonsagging door is an essential in the side-opening unit. The homemaker may consider its appearance more attractive than that of the chest, and the upright will be more easily sold to her for that reason.

Courtesy Conn. Agr. Eng. Freezer Bull. 373

Figure 18. Frost on freezer shelf of side-opening freezer. Moist air drawn into side-opening freezer when the door is opened forms frost on the freezing plates.

The disadvantages of the chest freezer are known to more persons since this design has a longer history than has the upright model. These disadvantages have been well aired. The accounts of users falling into the freezer, though few, are dramatic and have had wide publicity. The major complaint of the users has been that of the inaccessibility of foods and the necessity of handling many packages before the desired one is located (Fig. 19). Early freezers were designed with small openings and were of such a depth and width as to be inconvenient to use. The one-compartment unit is especially difficult to organize, the problem being one of size as well as shape. The larger the freezer the more convenient it becomes, since it may be divided into compartments. The allotment of a certain space to one kind of food is possible where large quantities of the same food are stored.

Problems in freezer use; user specifications for solution. In the words of a user: "The chief limitation of freezing is the constant sorting and organization of foods in the freezer, and even

Figure 19. Difficulty in locating foods. The user must handle and sort packages to find the one she wants.

then things get lost in the box. No matter how methodical the person, or how carefully the packages are put away, packages get scrambled so things cannot be found." This difficulty, though irritating, may not be a serious one when compared with other problems in freezer use. Homemade contrivances lessen the problem of food organization—partitions of plywood or wire screen (wire mesh permits free circulation of air), baskets, racks, use of colored tapes, string or wrapping papers, and freezer maps were some of the results of early efforts to make freezers more convenient. An attempt has been made by some manufacturers to design freezers for convenient use. Some freezers have baskets and movable partitions for flexible arrangement (Fig. 20). Freezers in the future will be less deep, less wide, and have larger openings. Less deep will answer the question, especially for short women: "Am I going to get something out or am I going in myself?" Less wide will mean that the freezer will go through the door of the house and that packages in the freezer are within reach. Larger openings, replacing the small opening inherited from the ice-cream cabinet, will expose more packages for choice (Fig. 20). Drawers that pull out as in a filing cabinet will prevent the spilling out of packages when the door in the upright cabinet is opened. It is to be hoped that the problem of the drawers freezing tight between the times of opening will be solved for this design. Baskets may have a place on the shelves of the upright as well as in the chest freezer.

One criticism users made of the first freezers was the lack of any way of knowing the temperature in the unit. If thermometers were placed inside, they had a way of slipping down between packages and becoming lost and frequently broken. There was no warning of power interruption or unit failure to tell the user of dangerously high temperatures in time to do anything about it. The food stored in the freezer, though comparatively small in volume, may represent a considerable investment. Because freezers are infrequently opened, a loss of refrigerant, a blown fuse or gasket, a broken belt, or other breakdown may go undiscovered until too late. Some new designs include an alarm device—a bell or a light connected with a different circuit from that of the freezer or operated by batteries. It will be necessary to keep the alarm device checked to be sure it is in operating order. Some units include a visible thermometer. Hermetically sealed condensing units may reduce the problem of servicing. Trained men for servicing low-temperature equipment have been few and not readily available. Though service men may be available in the future, the problem of early discovery of need for replacement will still exist.

The hermetically sealed condensing unit will reduce some of the other user difficulties, such as oiling. It provides more quiet operation. Noisy compressors irritate, not only because of the disturbance, but also because the owner is constantly made aware of the long-operating cycle of the motor and its power consumption.

Courtesy Sears, Roebuck & Co. and Deepfreeze Div., Motor Products Corp.

Figure 20. Relation of size of lid to convenience. Large openings make food more accessible and reduce the time the freezer is open. Movable partitions, baskets, and trays are a convenience in food arrangement.

Other user specifications for home freezers have been tightly sealed, well-insulated lids, hinged rather than the lift-off type, counterbalanced, with easily grasped handles. Freezers should be made of durable rustproof materials of permanent finish that are easy to clean. They should be free from odors of paint or finish and of sturdy construction. They should include a locking device.[6]

Good insulation, mechanical dependability, and convenience in use are the first requisites of any home unit according to the pioneer users. The first cost and probable savings will be of greater concern to the many new prospective buyers than it was to the pioneers in home freezing.

Buying a freezer. Buying a freezer will represent a major investment for many families. Buying a freezer will compete with buying other farm or household necessities or luxuries—water systems, new plumbing, radios, tractors, new cars, washing machines, dishwashers—a world of new equipment at hand to make life more comfortable and satisfying. The family considering seriously the choice of a freezer should answer certain questions before signing on the dotted line.

What are the family needs? To determine the family's needs for freezing equipment the following points should be considered: (1) What foods are produced—garden products, poultry, meats? (2) How are they to be preserved—by canning, by freezing, or both? (3) Where are they to be preserved—home or locker plant? (4) Where will frozen food be stored—at home, at locker plant, or both? (5) How much will be stored at one time—a supply for one week, two weeks, one month, one year?

What size freezer will satisfy the family needs? The size of freezer needed will depend on whether food is to be frozen and stored at home without benefit of locker-plant services, whether a combination of home equipment and locker services are to be used, or whether the unit is to be used for short-time frozen-food storage. If the processing facilities of the locker plant are used, the home unit may be a storage type, without a freezing compartment. The advantages of combining a home-storage unit with locker-plant services would be the transfer of the entire work of processing to the plant, a smaller investment in the home unit, and lowered operating costs, because more current is required for

[6] Nancy K. Masterman, Using the home freezer, *Cornell Univ. Ext. Bull.* **658** (1944).

freezing than for storage. The amount of low-temperature space at home depends on the frequency of the trips to the plant. Adequate short-time storage may be found in a frozen-food compartment of 1 to 2 cubic feet capacity built into the domestic refrigerator, or in a small storage unit to hold a supply of frozen food for several weeks. The inconvenience of distance to the community plant is minimized by home storage of food for current needs with the major supply of the food held at the plant. A unit at home makes additional uses of low-temperature space possible. A very attractive and useful feature of home storage is the freezing of baked goods and precooked foods which would be impractical at a locker plant. A small cabinet with a freezing compartment may be preferred if fruits and vegetables are to be frozen at home in small quantities as they come from the garden.

The size of equipment needed for both freezing and storing in the farm home will depend on the size of the farming operations, the type of produce, the number of persons to be supplied with food from the freezer, and the family way of living. For storage of meat in large quantities, it may be well to consider walk-in storage to provide space for chilling and aging as well as for freezing and storing. With a small farm operation or garden, a portable unit with a freezing compartment and compartments for storage may be adequate. In general, 5 or 6 cubic feet of low-temperature storage space per person is enough to hold vegetables and fruits from season to season and a variety of meats throughout the year. By planning a constant turnover of the food in the cabinet, its storage capacity is increased by as much as three or four times.

What about the cabinet construction? In the final selection of a piece of equipment, the construction details for operating efficiency and convenience in use should be carefully considered. Unfortunately, performance cannot be judged by appearance. A de luxe exterior may be misleading.

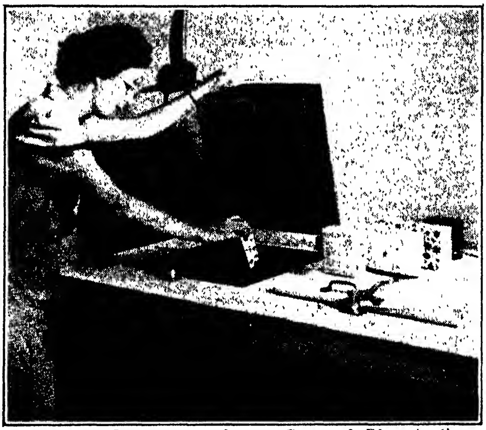
Convenience features are more easily judged by appearance. It is an essential that the food be easily accessible. The box should be neither too deep nor too wide for the food at the bottom to be reached with ease. If the box opens on the side, shelves should be spaced for efficient use and be of a convenient depth. Openings large enough to expose considerable space for the organization of packages are an asset. If organization devices (partitions, racks, baskets, or boxes) are supplied, they will be more convenient if flexible rather than fixed.

The lids of the chest freezer should not be too heavy to be lifted easily (Fig. 21). Counterbalanced lids are convenient, provided the hinge or device for counterbalance does not interfere with the food-storage space. Hinged lids are preferred to lids that must

Figure 21. The top-opening freezer with lift-off lid. For a person with short arms this lid is difficult to lift.

be lifted off (Fig. 22). Side-opening doors should not be cumbersome and must be equipped with hardware to permit ease in opening and closing the door. A thermometer or some means of knowing the temperature in the box is desirable. An alarm device is essential. Since considerable difficulty and expense are incurred when locks are installed after a box is in the hands of the user, provision for locking should be incorporated in cabinet design. Locks are a safety device not only for the safekeeping of the stored food, but also a protection against injury of small children.

When buying a cabinet one should know how much food may be frozen at one time and one should know the actual storage capacity of the cabinet. The usable space may differ widely in cabinets of the same dimensions because of plate spacing and location. A temperature of 0° should be maintained at the normal setting of the thermostat. It is advisable to know how much variation there is in the temperature between the top and the bottom of the box, how long the temperature may be expected to hold when the power is off, what the estimated daily power consumption to hold a zero temperature is, and if the compressor operates quietly.



Courtesy Rochester Gas and Electric Corp.

Figure 22. Top-opening freezer with hinged lid.

Construction specifications and details should be supplied by the manufacturer. The material of which the cabinet is made, the kind and thickness of the insulation, the sealing of the unit, and the refrigeration equipment should be specified. Attention should be paid to the guarantees and provisions for servicing offered by the manufacturer. Instructions for the care and use of the unit should be supplied by the manufacturer. A reputable manufacturer back of the product is of inestimable value.

Up to the present time, many persons have considered freezer ownership a luxury. Prospective buyers will have to weigh the costs of ownership against possible savings and the convenience advantages of having a freezer. In the postwar period home freezing will undoubtedly become a reality to many farm families.[7]

[7] Nancy K. Masterman, When you buy that freezer, *Successful Farming* **43**, no. 6, 42 (1945).

The refrigerator and frozen-food storage. The nonproducer of food does not need equipment adaptable to freezing and storing large quantities of food. Undoubtedly the home refrigerator will be called on to store frozen food in greater quantity than it has in the past. Ice-cube trays were largely relegated to the cupboard during the war and the evaporator of the refrigerator not only became a storage place for frozen food, but also was used for freezing.

Freezing meat in the refrigerator was quite generally the practice during rationing because it could be kept longer—meat was bought when and where it could be found and stored for use as far ahead as capacity would allow. Whether or not freezing of food *should* be done in the refrigerator is of little concern to many homemakers. They will continue to freeze small amounts of food in the refrigerator. Refrigerator manufacturers should take account of this. With an increase in consumer acceptance of frozen food, its general availability, and less frequent shopping, more space for storage in the refrigerator is necessary. With home delivery of frozen food, added space for a quantity of food is needed to make delivery less expensive. One or two cubic feet of low-temperature space within the refrigerator is the possible answer for many homes.[1]

Refrigerators with frozen-food storage can be an excellent supplement to lockers in a community plant. Families without a refrigerator and access to a locker plant would probably prefer to make the investment in one piece of equipment rather than in two. A separate storage unit for frozen food would bring other homes, already having good refrigerators but not of replacement age, up-to-date in food storage.

WALK-IN FARM FREEZERS

Farm refrigeration needs. Refrigeration requirements for an individual farm are determined by the type of the farming operation, the location of the farm with respect to a marketing or shopping center, its proximity to a freezer locker plant, the size and composition of the family, the kinds of products to be stored and the length of the desired storage period. Adequate refrigeration for the everyday food needs of the family are of prime importance and should receive the first consideration. The higher the nutritional level of the diet, the greater is the need for refrigeration. Meats, fruits, vegetables, eggs, butter, milk all need the safeguard of cold. A temperature of 40° will protect the immediate daily food supply of fresh foods. If food is to be preserved for future use by freezing and stored over a period of time, new problems in farm refrigeration present themselves.

Through freezing, the full use of farm products becomes possible, adding immeasurably to the standard of family living. The farm business profits through the sale of better-quality products, although the opportunity of increasing the farm income through better refrigeration will vary with the type of farm. Home-built or assembled-on-the-spot refrigeration plants may make possible efficient marketing in season and the preservation of foods for off-season use. Ideal farm development would provide adequate storage at temperatures both in the neighborhood of 35° and 0°.

User specifications for walk-in units. Although the engineering specifications form the basis for the design of walk-in units, the voice of the homemaker should be heard before construction begins.

Location. If the unit is to combine low temperature with the normal temperature of the household refrigerator, as it may well do, it must be so designed and so located that food for daily use is conveniently at hand. The opening of the normal refrigerator should not entail extra steps. A refrigerator is opened on the average of 25 times a day. The zero section may be opened only once a day or less often. Thus, where the unit contains the kitchen refrigerator, the back porch is usually preferable to the basement or other location.[8] The kitchen refrigerator may then be built into one side and open directly into the kitchen.

Size of refrigerator and cold room. A common complaint among refrigerator owners is that the refrigerator is too small.[1] These complaints range from the statement that 6 cubic feet is none too large for one person to the assertion that 6 cubic feet would barely serve three persons. According to Dana and Miller the minimum size for the home-built refrigerator is 12 cubic feet, but 18 or 20 cubic feet would be preferable. A large refrigerator in combination with zero storage may supply the needs of the

[8] H. J. Dana and R. N. Miller, Home built farm refrigeration, Wash., *Eng. Ext. Bull.* 68 (1944).

village or suburban home with all the refrigeration needed. An extra cold room, 32° to 40°F., is an essential on a farm with its multitude of products to be stored while awaiting market in addition to those for home use. Such space is a necessary adjunct to the zero storage for the chilling and aging of meat on the farm. From the experience with home-built equipment on farms in the State of Washington, Dana and Miller recommend as a minimum size for a cold room 8 ft. x 8 ft. x 6 ft. 6 in. In addition to this a 50-cubic-foot zero box is recommended.[8]

Other specifications. If the walk-in is to give satisfaction to the housewife, its doors must open and close with ease. Heavy cumbersome doors with difficult-to-operate hardware make man's work of removing food from the freezer. It may be an ax man's job to open the door where gaskets do not provide a tight seal to prevent icing shut.

The problem of defrosting the zero section should be minimized. Women find defrosting a problem both in the kitchen refrigerator and in the freezer cabinet.[6] The choice of refrigerating coils is important to the homemaker who must defrost the unit. Finned tube coils with fans, suitable for the cold room, are not suitable for the zero box because they accumulate frost rapidly. Used in the cold room they defrost on the off-cycle. Some means of catching the drip should be provided, however, and the coils should be so located that this is conveniently accomplished. The removal of frost from refrigerated plates with their flat surfaces is less difficult than is the defrosting of pipe coils. To defrost bare pipe coils it is necessary to brush or scrape the frost off with a blunt tool or stiff brush, or in extreme cases to remove all the food from the box, shut off the current, and wipe the ice from the coils when it becomes soft. Refrigerated plates may be freed of frost by scraping with a wooden wedge or tool such as a hive tool or putty knife with a rounded edge.[9] Sharp corners or edges likely to injure the plates should be removed from such a tool. That many users of refrigeration equipment are oblivious to the need for defrosting is readily recognized on surveying refrigerators and home freezers in use and reading such articles as one in which the author gloried in her ice cave where the coils were coated

[9] Nancy K. Masterman and F. A. Lee, The home freezing of farm products, *Cornell Univ. Ext. Bull.* 611 (1943, revised 1946).

thickly with frost and the icicles and frozen snow hang from the ceiling and from the pipes.[10]

Inside lighting of walk-in units must be provided. Safety features cannot be ignored. The home plant is a locker plant in miniature, and the features of convenience and safety that apply to the large plant may well be considered in the design of the small one.

[10] Katherine A. Taylor, Now that we have the freezing outfit, *Reader's Digest* (Nov. 1943).

Chapter 10

THE PATRON AND THE COMMUNITY LOCKER PLANT

Early beginnings of services. The locker industry, with its beginnings as a sideline of other enterprises, has assumed proportions far beyond the dreams of its pioneers. The history of the growth of the community frozen-food locker plant is the history of the development of services to meet the demands and needs of the persons served. According to Harry Carlton [1] it is likely that all the "first" freezer locker operations began without knowledge of similar freezing operations in other communities, the result of a spontaneous demand.

In the beginning, farmers were permitted as a special favor and gesture of good will to store food in one corner of the refrigerated room of commercial cold-storage plants.[2] Each farmer furnished his own box or basket; often no charge was made for the space it occupied. It is interesting that food loss by pilferage, still one of the problems in locker plants,[3] created the demand for one of its first services. Wooden lockers or lockers made of chicken wire and wood were installed about 1913.[4] Management instituted a small charge, not as a means of increasing income, but to discourage farmers from using storage space in this manner.

In these early operations management assumed little or no responsibility for the safekeeping of the food. The farmer often furnished his own lock and key. Management was not interested in either the incoming or the outgoing food. It was not at all concerned with its quality. No attempt was made to regulate tem-

[1] H. Carlton, The frozen food industry, *Tenn. Agr. Expt. Sta. Bull.* **173** (1941).

[2] S. T. Warrington and P. C. Wilkins, Frozen food locker plants, *U. S. Dept. Agr. Misc. Rept.* **81** (1945).

[3] Nancy K. Masterman, Are locker patrons satisfied, *Locker Operator* **6**, no. 6, 12 (Jan. 1945).

[4] I. R. Bierly, Cold storage lockers in New York State, 1938, *Cornell Mimeo. A. E.* **264** (Apr. 1939).

peratures other than that required by the commercial cold storage. Temperatures in the storage rooms fluctuated with the season and the amounts of food stored. Meat was stored anywhere from 1 month to 3 years. Vegetables were stored as long as 3 years. As a result the early growth of the industry was slow. In 1936 there were only 250 locker plants in the entire country.[2]

TABLE 12. LOCKER PLANTS IN THE UNITED STATES

As of January 1	Total Plants *	States with Plants	Increase over Previous Year
1936	250	19	....
1937	450	20	200
1938	800	22	350
1939	1400	27	600
1940	2100	34	700
1941	2900	36	800
1942	3800	39	900
1943	4738	47	938
1944	5093	49 †	355
1945	6329	50 ‡	1236
1946	8000	50 ‡	1671

Compiled largely from S. T. Warrington and P. C. Wilkins, *U. S. Dept. Agr. Misc. Rept.* **81** (1945). The data from January 1943 on are quoted from: W. Carver, *Locker Operator* **7,** no. 7 (Jan. 1946), and the *1945 Guide Book,* Locker Publications Co., Des Moines, 1945.

* Including branches.

† Including Hawaii.

‡ Including Alaska and Hawaii.

Meat processing. In 1930 a few newly built plants in the West Central states offered meat-freezing service in a special room at temperatures below zero. Others, in addition, had a room in which meats might be aged at 36°F. Meat-cutting equipment to be used by the patron was provided. The inevitable happened. Patrons were careless in their use of equipment and in handling their own products. The chill room and freezer were often overloaded and at other times not in use. As a result of these conditions, most of these plants later hired the personnel to process meat for patrons. Warrington and Wilkins [2] mark this step as the foundation on which the system was to grow rapidly from 1935. Other factors helping to accelerate the growth were increasing research work in the fields of processing and freezing; dissemination of knowledge so obtained; addition of supplementary processing services, such as pork curing and smoking, lard rendering, often growing out of demands of patrons; improvement in refrigeration and its adaption to small-scale units; efforts and educational work of equipment and insulation organizations; increased demand and desire on the part of rural and small-town families for better diets. The addition of services as a result of patron demand benefited not only the patron but also the operator.

A community service. Thus the locker-plant industry grew into a community service of large proportions. The U. S. Department of Agriculture estimated that by the end of 1943 locker plants were serving more than 1,500,000 families with about 7,500,000 persons, and with a turnover of some 865,000,000 pounds of foodstuffs annually. Of this food about 84 per cent was reported as beef, pork, poultry, and game.

The growth in numbers and distribution of plants is shown in Table 12 and by the maps prepared by the Farm Credit Administration of the U. S. Department of Agriculture (Fig. 43, p. 234).

PROBLEMS IN LOCKER USE AND USER SPECIFICATIONS FOR LOCKER PLANTS

The growth of the locker-plant industry inevitably has been influenced by many specific problems facing operator and patron alike (Fig. 23).

Inconvenience of lockers. The most common problem facing the patrons of a locker plant is the lack of convenience in their personal use of the plant equipment.[5] Narrow deep lockers are difficult to organize for ready accessibility of stored foods. The continual sorting of packages in the cold room is so disagreeable that it is usually postponed until the products are in a hopeless jumble. It is practically impossible to use foods in the order of their processing since the newly processed are piled on top of the old. As a result, the packages on the top are used, regardless of

[5] Nancy K. Masterman, The patron and the locker plant, *Quick Frozen Foods* 7, no. 5. I–VIII (Dec. 1944).

the length of storage time or preplanned menu. The deterioration of the quality of certain foods is the inevitable consequence when stored overlong.

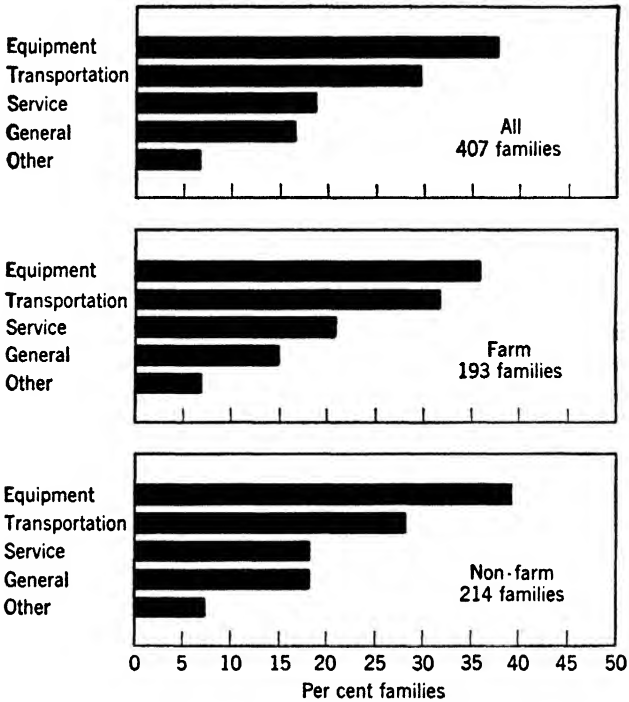


Figure 23. Problems in the use of locker plants, according to a survey of 407 families among patrons of 31 locker plants in New York State in 1943. Patrons' problems in the use of plants group themselves around the plant equipment; the distance of the plant from the home, or transportation problems; the plant services; general problems, such as the lack of storage space in the home refrigerator and inconvenience of not having food on hand; and other problems, such as poor quality of frozen food, poor housekeeping.

The upper door-type locker is particularly inconvenient. The necessity for ladder climbing, the inaccessibility of the packages in the back of the locker, and the spilling out of packages when the door is opened combine to make food removal a disagreeable task.[6] Well-constructed secure ladders designed for locker use,

[6] Nancy K. Masterman, Are locker patrons satisfied?, *Locker Operator* **6**, no. 6, 12 (Jan. 1945).

with a basket or shelf for holding food packages, are now available and in use in many plants. Any equipment to add to the ease of organization of a locker for the quick location of a desired food is profitable to patron and operator alike.

The shape of the drawer-type locker has a relation to its convenience. With an increase in breadth and decrease in depth from front to back and from top to bottom, more packages are exposed to view when the drawer is opened. The space layout makes possible a systematic arrangement of foods; locker design shows a trend toward this type. Where tried, this new wide locker has won ready acceptance by plant employees whose job it is to parcel out the newly frozen food, and patrons are enthusiastic in their appraisal of this design. The wider locker takes slightly more floor space to install than does the conventional type, and fewer lockers can be set up within a given area. More convenience to patrons with less total locker rental income, or more rental income with less convenience to patrons, is the choice of the management. However, management will do well to remember that convenience encourages locker use and inconvenience may lose patrons.

Devices for convenience. Since much of the patron's time in the locker room is spent in sorting food packages, provision should be made to speed the process. In many plants there is nothing other than the floor on which to place packages while sorting or removing them from the locker. This is recognized by patrons as both inconvenient and insanitary. A cart, hanging basket or other device to hold packages should be provided. Meat identification is simplified by the use of colored tapes for sealing, or papers of different colors for wrapping. Poor labeling of packages adds to the task of food removal.[5] Poor lighting further complicates it.

Devices for safety. Poor lighting also adds to the uneasiness of some patrons in entering the locker room. Fear of being shut in adds to the discomfort of the cold. Claustrophobia may be lessened by the installation of a window in the side wall of the locker room or in the door connecting with the lobby. Special multipane windows are available for this use. Some illumination should be provided at all times in the locker room,[7] the additional illumination being controlled by a switch placed conveniently for the pa-

[7] Anonymous, Recommendations for frozen food lockers, *Locker Operator* 6, no. 7, 12 (Feb. 1944).

tron. That an infallible safety device should be installed in cold rooms has been borne out by the tragic deaths of several operators trapped in their own plants. A telephone installed in the locker room would mean day and night protection. Plants using ammonia or methyl chloride should have additional safety features.

Courtesy Armstrong Cork Company

Figure 24. A locker tier. A patron of this Polar Chest locker plant has raised a tier of lockers from the refrigerated area to a convenient height so that she can remove frozen foods from her locker.

Automatic lockers. Regard for the comfort of patrons and recognition of their dislike of entering the cold room has influenced engineers to design locker plants that permit the withdrawal of food from a locker without entering the refrigerated room. There is appeal in the slogan, "Freeze the product, not the customer." In one of these types, the top of the refrigerated compartment is made of insulated covers which may be opened so that any locker can be raised on demand (Figs. 24 and 25). In another a wheel brings the locker into place at a door when the proper button is pushed (Fig. 26). In still another the lockers are on a conveyor belt limited to 120 lockers in one band. A push of the button brings them into place at a door within 35 to 70 seconds, according to the position of the locker on the conveyor.

A mechanized design bringing freedom from the cold may entail waiting in line for one's turn; however, some patrons find waiting in line less disagreeable than the cold room. Provision of additional hoists that make it possible for several patrons to use their lockers at the same time would minimize the problem of waiting for one's turn.

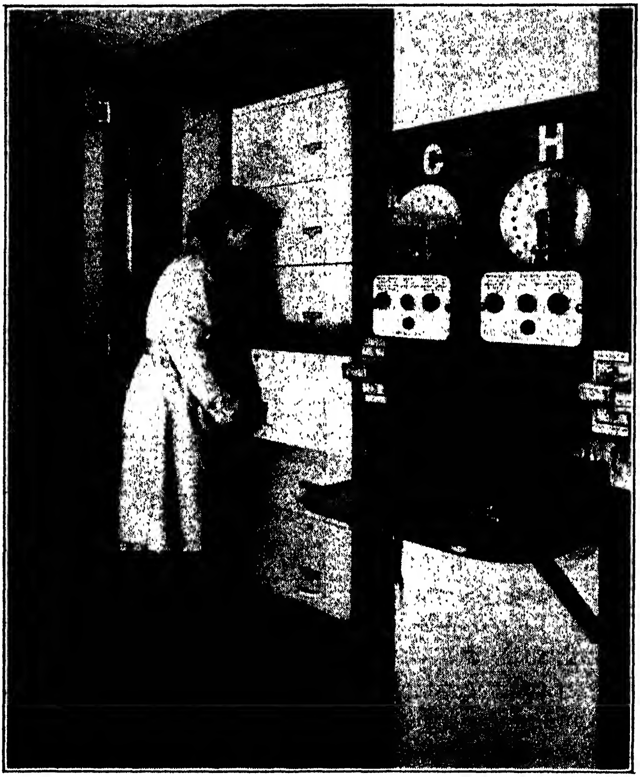
Courtesy N. J. Agr. Exp. Sta.

Figure 25. A freezing tier. The freezing tier is used by plant employees for quick-freezing foods. The tier is lowered into the refrigerated area. When the foods are frozen they are placed in the patron's locker.

Defrosting may present more of a problem to the management in the mechanized design than in the conventional locker plant. The plants are more expensive to install. There is increased likelihood of breakdown and necessary repairs due to the more highly mechanized plan. The character of the community and the amount of money to be invested should influence the choice of any particular type plant for a community. Patron satisfaction might make the additional investment in the automatic type profitable.

Plant sanitation. An outward sign of efficiency and good housekeeping is a patron's specification for a good plant. A clean sanitary plant is the due of every locker patron. Thorough cleaning of food processing, mixing, and handling equipment is essential to keep sanitary standards high and to make quality control more certain. A daily routine to keep a plant in a scrupulously sanitary condition saves time and man power, prolongs life of equipment, and facilitates quality control. Yet it is at this point that many locker plants fail.[6]

Patrons object to cluttered aisles; to food piled on the top of lockers (not only an unsightly practice but one that may interfere with air circulation incidental to refrigeration of locker rooms).



Courtesy Salem Engineering Company

Figure 26. The service room of the Salem automatic locker. A selector dial is located at the side of the service-room door. Customers place the dial hand at the number corresponding to the number of the tier in which their lockers are located. When the operating button is pushed, the proper tier comes and stops in front of the refrigeration-room door. A tier of 5 to 7 lockers is at hand. Each locker has its individual key.

Slippery or icy spots on the floor are a hazard to safety. The presence of flies in the plant, untidy-appearing employees, and unsanitary handling of food in the processing rooms are objectionable to patrons. Postponement of or neglect in cleaning of lockers where leakage has occurred leads to trouble. Poor housekeeping and faulty sanitation lead to disagreeable plant odors, not only objectionable in themselves but also detrimental to stored food. Packaging materials may take on odors or permit their passage to the food.

Business methods. Businesslike methods and good record and account keeping develop patron good will. Locker patrons are a suspicious lot. Records help to allay their fears or suspicions that food is going astray. A strict accounting for all food handled increases patron good will. Accurate records, invaluable from the standpoint of keeping the management and the banker informed about the plant business, are necessary in this as in any business for sound operation and for income-tax returns.[8]

A perpetual inventory system instituted by the management is a protection for itself. It keeps the patron informed as to locker contents so that use of the stored food can be more intelligent. Good records also lead the renter to feel that the plant is taking precautions in his behalf and is assuming responsibility in accepting food for processing and storage.[5]

Convenient plant hours. Patrons often find they cannot deliver products to freeze nor remove food for use at the time most opportune. Also lack of home refrigeration has restricted the use of food from the lockers. It may prove to the interest of the locker industry to promote the increase in home storage for frozen food. Home storage should remove the barrier of distance, the inconvenience of plant hours, by supplementing the locker at the plant, thus making frozen food more readily available at home, and encouraging more frequent use of frozen food. Increased processing should follow the increased demand.

With the increased use of home freezers in Tompkins County, N. Y., there has been an increased demand for all the services of the community locker plant. The sale of frozen-food containers for the 1946 season was more than twice that of the 1945 season. In the first ten months of operation of the locker plant in 1945, 11 per cent of the total meat processing was for nonlocker patrons. In the same months of 1946, processing of meat for nonlocker patrons was 35 per cent of the processing. Meat processing increased 50 per cent in the winter of 1946–47. Had it been pos-

[8] Arlene L. Nuttall, An accounting system for a frozen-food locker plant, *Cornell Univ. Ext. Bull.* **649** (1944).

sible for the plant to handle all requests, the increase would have been greater.

High-quality food. All grievances of locker patrons are minor when compared with that of poor-quality foods. It may mean the cancellation of the locker by the patron. More often than not it means a condemnation of the entire process of locker-plant freezing. A contributory factor to poor-quality food has been the poor packaging materials and careless packaging techniques in use in many plants.[6] Often processing charges have not been high enough to permit the plant's use of the better packaging materials. The less expensive materials have not had high protective value for long storage[9] (see Chapter 5). They have not been tough enough to stand the necessary handling. Some paper is readily punctured by bones. It cannot be drawn tight to the meat without tearing, so that loose wrapping is encouraged. It is often torn by the wire freezing baskets and by handling in the locker storage. Meat dehydrates rapidly and develops off-flavors when stored in this type of paper.

Unsatisfactory products result from conditions other than poor packaging. Homemakers who have worked rapidly with excellent products, holding each package in the coldest part of the refrigerator until taken to the plant, have found their efforts wasted.[6] Products may stand for hours, even days, at room temperature before being frozen. Inadequate freezer facilities, freezers too small to care for peak loads, or inefficient management may undo all previous efforts to produce quality. Poor meat results from crowded aging rooms and hanging too long before freezing. Locker-room temperatures are too high and too fluctuating in some instances to provide good conditions for long-time storage.

Often the problems of the locker operator are not at all appreciated by the patron. To accomplish a high-quality processing job at a cost that will afford the plant a profit and yet at a price the patron can pay is the task of the locker operator. With increasing labor costs and fixed rates locker plants have been through difficult times in maintaining quality without operating at a loss. Some plants have attempted to solve the problem by offering dif-

[9] Nancy K. Masterman and K. Winsor, Moisture losses in stored frozen meat vary with packaging material and wrapping method, *Food Freezing* 1, 140 (1946).

ferent grades of service. In plants where this has been tried, 90 to 99 per cent of the patrons selected the higher grade of service.[10]

Full locker use made possible. The distance between home and the locker constitutes a disadvantage to many locker-plant patrons in the use of the community facilities and a real problem to other patrons. The full use of the locker services also is limited by distance.[6] Many fruits and vegetables are canned by farm families who rent locker space because of the practical problem of getting the products to the plant for processing in small amounts as they come from the garden, or at the time when the maturity is just right, or when the family has the time to prepare them. The delay between the home scalding and packing and the freezing at the plant is detrimental to the quality of locker-frozen vegetables. The first trial of vegetables thus frozen is likely to be disappointing in that they may be no better or even less palatable than the canned product. The poor quality of such products is a score against the process in the minds of the novice patron.

Direct patron education is the responsibility of the plant operator. Patrons need sound information on processing; how to select and process foods for freezing and the principles of packaging. They need instruction in the care of frozen food after it leaves the plant and in its preparation for serving. The friendly helpful attitude of the operator, his willingness to listen to problems, his businesslike operation of a clean sanitary plant, and high standards of processing create patron satisfaction and good will, the basis for the successful operation of any business.

COMMUNITY FOOD SERVICES IN THE LOCKER PLANT

Basic services. The proportion of plants with limited service has steadily declined. The kinds and the extent of service still vary considerably from one plant to another, depending on local conditions and the age of the plant. They differ with the section of the country. Certain services, however, might be classed as basic (Fig. 27). Complete meat-processing facilities from the slaughtering of the animal through scientific aging, skilled cutting, packaging, freezing, and storage is such a service.

10 Anonymous, More price questions, *Locker Operator* 7, no. 3, 66 (Oct. 1945).

Whether a plant renders lard or provides pork curing is of prime importance in some regions, relatively unimportant in others. Complete poultry processing occupies a similar position. However, just as local production has created the demand for services, so may the availability of services profoundly affect the agricultural production of a region. Many farm families formerly con-

Figure 27. Meat processing, a basic service in locker plants. The community locker plant makes possible the chilling and aging of carcasses under proper conditions.

tent to eat the culled dairy cow become intensely interested and actively engaged in the production of the beef-type animal when they have been introduced by the locker plant into the realm of freezing. It is the old story of the evolution of higher standards of living, through luxuries becoming necessities, that has been operating in this infant industry.

Recent information on the services performed by locker plants is not available. The survey of the Farm Credit Administration in 1942 lists the services performed by locker plants in operation at that time as shown in Table 13.[11]

[11] W. Carver, Taking inventory of the locker industry, *Locker Operator* 7, no. 7, 24 (Jan. 1946).

TABLE 13. SERVICES PERFORMED BY LOCKER PLANTS IN 1942

Service	Per cent Plants Performing Service
Cutting, wrapping, and freezing	88.3
Grinding	78.8
Slaughtering at the plant	27.8
Slaughtering at the farm	30.9
Curing	40.6
Smoking	36.9
Dressing poultry	32.2
Rendering lard	28.1

Patron evaluation of services. A study of the patrons of 31 of the 38 locker plants operating in New York State in 1943 was directed toward collecting information concerning the services offered by locker plants and the satisfactions and dissatisfactions of patrons using them. About one half of these plants were operated as a part of a general cold-storage business; one sixth were in connection with food markets. The remainder were not connected with any other business.

The services offered by the plants included in the survey varied greatly from plant to plant. A few plants offered no service other than a locker in a cold room in which to place products, where they froze in time and remained until removed. Most of the plants offered some processing. Meat processing was fairly complete, in some instances including slaughtering, but more usually chilling, aging, cutting, wrapping and freezing prior to storage. A few had curing, smoking, and lard-rendering service. Only one plant offered service in the processing of fruits and vegetables.[5]

The majority of farm patrons devoted three fourths of the locker space to storing meat and poultry. Three fourths of them froze only home-grown meat. Eighty-seven per cent of them grew their own poultry. The meat-processing service was used by 75 per cent of all patrons. Meat was prepared at home and brought to the plant for freezing by 19 per cent. It was the consensus of opinion that the meat-processing service was invaluable to farm patrons—the point at which real savings were made by locker use.

Suggestions by patrons for improved processing included both the improvement of services already in operation and the addition of services lacking in some plants. Patrons of plants with complete or fairly complete meat-processing facilities expressed a desire for meat cutting more in accordance with their specifications, better-trained meat cutters, a plant personnel trained to advise on meat cutting, better aging procedures, better meat-wrapping materials and techniques, and maintenance of low and constant temperatures in the storage rooms. Patrons were interested in additional services such as slaughtering, lard rendering, pork curing and smoking, poultry processing.

A swap service as a means of increasing the variety of foods in the locker was considered desirable. Such a service, in some areas, would increase the value of the locker to the individual by making a variety of products available through disposal of surplus. An increase in plant processing income would result.

A contact service, whereby patrons might be put in touch with a source of good products to buy for freezing, was requested. A service between the consumer and producer of quality products, that is, fruits and vegetables of a known variety suitable for freezing and meat of freezing grades, would undoubtedly improve the quality of the frozen product. Patrons who had made their own contacts were not always sure of the products they bought. Lack of success in freezing some products was attributed to the choice of wrong varieties of fruits and vegetables, and meat of poor grades.[5]

Brokerage service. In the past many locker plants have supplied patrons with meat for freezing, charging a small brokerage fee for the service. Whole carcasses, halves, quarters, and even live animals have been made available to the non-meat-producing patrons by their plant. Farmers have had the opportunity of thus selling good meat animals. Choice meat from packers supplied the locker holder with meat. This service, curtailed by meat rationing, will be welcomed again by some patrons. The convenience of having meat at hand will have to offset the added cost of the service.

Fruit and vegetable processing. The locker operator of the one plant in New York State offering fruit and vegetable processing in a plant kitchen reported that 65 per cent of the patrons used the service. It was his belief that the demand for the service would increase continually.[5] The National Frozen Food Locker Operators' Association developed plans for processing kitchens in plants in answer to the many demands of locker operators for such information. Its plans were drawn under the supervision of a member of the association who had successfully operated such a kitchen for the previous four years in his own plant.[12] It was the experience of a few locker men who have operated vegetable kitchens that from 75 to 95 per cent of their patrons made use of them. Where a kitchen has been installed for reasons other than patron demand, its use will be limited without patrons' education. An unpromoted complete kitchen, an experimental feature of a plant in Ithaca, N. Y., was used by only a small per cent of the patrons. The few who did use it were most enthusiastic about the conveniences it afforded: the opportunity to work without interruption and the speed between the processing steps made possible by the use of laborsaving devices provided in the kitchen. The fact that the food could go directly into the freezer after packaging eliminated the problem of getting it to the plant in haste. Locker operators who add services must be certain that their patrons are educated to use the services and receive the information necessary to bring about a change in practice.

Wholesale frozen-food service. Though considerable produce was bought for freezing, patrons of the New York survey expressed an interest in buying frozen foods in case lots. About half of all patrons expressed a desire for this opportunity. Of the vegetables wanted the greatest interest was in peas, followed in order by lima beans, sweet corn, asparagus. Of fruits, strawberries led in preference, followed by cherries, peaches, red raspberries. Frozen fish would undoubtedly prove a popular item, according to the interest of inland patrons. Plants that have added frozen-food merchandising have been greatly pleased with its reception. In some plants the sale of commercially frozen foods now overshadows the processing business. Merchandising is a logical development and one which will undoubtedly increase as locker plants reconvert to compete with postwar business within the community.

[12] Anonymous, The locker plant kitchen, *Locker Operator* **5**, no. 8, 10 (Mar. 1944).

Delivery service. The return of delivery of frozen foods and house-to-house sales of food from refrigerated trucks, dating back to 1938 and 1939, and discontinued during the war, is awaited by many frozen-food consumers. Locker-plant patrons, especially of the urban and suburban areas, are interested in a delivery service. It is reasonable to expect that an increase in distribution costs would be reflected in consumer costs. It is doubtful that such a service for locker patrons, though convenient, could be justified from an economic standpoint.

Short-time storage. There are times during the year when the locker patron has more food to store than can be placed in his rented space. At other times he has more space than he really needs. To take care of the fluctuation in space needs, short-time storage is desirable. Extra space may be rented by the month for the period needed. The need of this arrangement is keenly felt by patrons in those plants without facilities for extra storage or temporary storage.

The home-freezer supplement. As indicated in the New York survey, 1943, there was a tendency for farm families to rent more than one locker in the plant. The farm patron needed lockers to fit his production. The nonfarm patron, who buys most of his products, can better fit his products to the locker than the farm patron who cannot slaughter half a beef. Home units were owned by about 8 per cent of the farm patrons. Fifty-four per cent of them said they would like to use a home unit. Their second preference was for a locker with a home unit to supplement the locker. Only 17 per cent of the patrons said they preferred to use the locker plant solely. One locker is not sufficiently large to hold a variety or a quantity of meat. With only one locker, often part of an animal must be canned or sold. One farm locker patron who was also a pre-Pearl Harbor freezer owner compared his locker at the community plant to the useful cedar chest in his attic, a place to store surplus. Certainly the unit at home can serve to make frozen food available when it is needed, to eliminate the disadvantages of distance and inconvenient plant hours. It will store many miscellaneous products for which plant storage is not convenient such as home-baked goods and precooked foods. A small storage unit may supplement the rented space at the plant at less investment than is necessary to purchase and maintain a large unit at home for which the farmer would process his own food and assume all depreciation and risks of power failure or breakdown.

The position of the locker plant in the postwar world is a matter of much speculation and debate. Certainly the function of a locker plant has never been clearly defined or set. Its pattern for the future is still unformed.

The official magazine of the Frozen Food Locker Operators' Association, *Locker Operator,* of January 1946 lists as the services that have made money for locker men in the past and that have created still greater demand for locker facilities:

1. The slaughtering of meat animals.
2. The killing and dressing of poultry.
3. The rendering of inedible offal, the sale of resulting grease and tankage.
4. The culling of poultry flocks.
5. The operation of a hatchery department.
6. The killing, dressing, and sale of broilers and fryers to restaurants, hotels, and caterers.
7. The sale of poultry and livestock feeds.
8. The making and selling of sausage, head cheese, and other meat specialties. This department is especially profitable to plants conducting abattoirs, because such plants have opportunities for purchasing much edible offal from patrons at low prices.
9. The cutting, wrapping, and freezing of meat, poultry, game, etc.
10. The purchase and sale of hides and skins.
11. The purchase and reselling of frozen foods. Many plants are making plans to engage in the frozen-food business as distributors for a territory of several counties; others are planning to install frozen-food stores in connection with locker plants.
12. The production and sale of frozen-meat cuts.
13. The freezing, storage, and resale of locally grown vegetables and fruit crops. A number of plants have built up a considerable commercial freezing operation with their market confined to nearby communities.
14. The production and sale of precooked foods. Many locker plants are now producing and selling such items as beef stew, vegetable soup, chop suey, chicken à la king, and bakery specialties.
15. The making and selling of ice cream. With equipment becoming available we predict hundreds of locker plants will enter the ice-cream business—reversing the procedure of a decade ago when many ice-cream companies went into the locker business.

The position of the locker plant in any community will depend upon how it serves that community, how vital it makes itself to its patrons. Its usefulness will be measured in terms of patron satisfaction, be they individuals or institutions, be they locker renters or shoppers for frozen food.

III

THE ENGINEERING OF FOOD FREEZING

Chapter 11

THE ROLE OF FOOD IN ENGINEERING DESIGN

The home freezer may be the engineer's darling or the working man's toy, but it *must* be the homemaker's slave. The average housewife is less interested in the means to the end than in the end itself, namely, frozen food of best quality and properly preserved.

The locker operator and the commercial packer of frozen foods are no less interested in maintenance of high quality in the processed foods. The appeal, the flavor, the nutritive goodness which characterize frozen foods that have been properly prepared and handled must be assured in all of the many steps that such products must travel in reaching the mouth of the consumer. During processing, during freezing, during storage in the refrigerated warehouse or the freezer locker, and during transportation within and between plants, care must be taken to preserve those characteristics of the fresh foodstuff which frozen foods, more than any other form of preserved foods, possess.

To assure that the equipment will be such as to perform safely and surely the various tasks incidental to freezing preservation, certain requirements or limitations are imposed by the food itself. This is true whether the equipment is to be placed in the home, the community locker plant, or in the factory of the large-scale commercial frozen-food processor.

Some of the points discussed in previous chapters are here summarized from the viewpoint of their relationship to the proper design and construction of facilities and equipment for preparing frozen foods.

Processing equipment. The best possible freezing equipment cannot insure a satisfactory product if the equipment used in preparing and processing the food has been ill chosen, ill placed, or ill used.

Fruits and vegetables entering the plant are often—and preferably—processed for freezing without an appreciable storage after harvest. If some delay is necessary, proper refrigeration must be assured to minimize loss of quality. Meats, on the other hand, are held for periods varying from a very few days for pork to many days, or even several weeks, for beef. Here, proper refrigeration is even more important. In selecting the conditions for refrigerated storage, temperature and humidity must be considered insofar as they affect the stored foods.

Temperatures in the cooler are generally in the range just above freezing. Occasionally somewhat higher temperatures are used for special reasons, such as when ultraviolet-ray lamps are used in the cooler. These lamps generally are more efficient at 40°F. or higher than at the 32–36° range of the average meat-holding room.

To avoid desiccation, or shrinkage, during refrigerated storage relative humidities approaching the 100 per cent of moisture-saturated air are desirable. Only in this way can one effectively check moisture losses induced by differences in vapor pressure between the storage air and the film of air surrounding the refrigerated foods. On the other hand, such high humidities at above-freezing temperatures offer the best environmental conditions for the growth of the microorganisms associated with food spoilage. Accordingly, somewhat lower humidities are found to be necessary. In designing for a given temperature and humidity range, consideration must be given to the possible influence of incoming warm produce. Improper precautions may result in the condensation of moisture on cold food materials when "steaming" carcasses or foods are brought into the cooler. Such conditions will favor the growth of bacteria, yeasts, and molds on the damp foodstuffs.

The sorting and cleaning equipment must be such as to prevent the bruising of plant products. Aside from the immediate localized softening, undesirable enzyme-catalyzed reactions are induced by the bruising of the tissue.

Scalding equipment must be such as to assure rapid and uniform heating and closely controlled temperatures. All particles of the vegetable to be scalded must be processed so that the enzymes inducing deteriorative changes are inactivated, and yet so that no particle is "overcooked" or mushy. The water in the scalding tanks for poultry to be picked mechanically must be kept above 125°F. if efficient removal of the feathers is to be obtained and yet below 130° if the proper "bloom" is desired. The cooling equipment for heat-treated foodstuffs must be efficient and adequate.

The composition of the varied equipment coming in contact with the foods must be carefully considered. The materials must not contaminate the food with toxic elements and must not induce changes in color, odor, flavor, texture, or nutritive value. The materials must be resistant to the action of air, water, food constituents, and chemical or abrasive cleansing materials. Some metals are adversely affected by prolonged contact with brines such as are used in curing meats. Some, notably copper and iron, may either directly or indirectly affect the color of fruits or vegetables. Some materials, such as lead, are toxic and should never be present in equipment with which foods are in contact during preparation or processing.

In the design or layout of equipment for the food-freezing plant, many specific problems may be posed by the product. For example, once the protective skin is removed from peaches, oxidative enzymes may very rapidly cause a browning of the surface tissues. Only by excluding air by chemical (antioxidants) or physical means can this undesirable pigmentation of the fresh peach tissue be checked. Here, rapid handling and prompt, complete, and continued immersion of the sliced peaches obviates the difficulties.

Improper use of flumes for cooling and transporting food between stages in processing may contribute to a lowering of quality. Excessive fluming of cut or scalded products will result in the leaching of soluble materials and a loss of flavor.[1] Evaporative cooling and other means of in-plant transportation of foods for freezing will avoid much of this lowering of quality.

Freezing capacity. Several factors enter into the problem of providing adequate freezing facilities.

Prompt cooling. The first consideration is that the unit must be able to cool the foods with sufficient promptness to assure protection from spoilage prior to freezing. Naturally, heat transfer from the packaged foods to the circulating refrigerant can be hastened by proper choice of package size and placement in the freezer which will insure the maximum of exposed surface. How-

[1] W. V. Cruess, Studies of frozen food samples bought in open market, *Food Freezing* 1, 243, 306 (1946).

ever, equipment capable of handling peak loads with reasonable rapidity must also be provided.

Scalding of vegetables greatly reduces the enzyme activity, but does not completely destroy all enzymes capable of catalyzing undesirable changes in the food. Similarly, the bacterial population is very considerably reduced if proper precautions are taken in scalding, but the microorganisms that survive scalding will multiply very rapidly if the temperature is not lowered promptly. At room temperature, a delay of only a few hours between the scalding and freezing of vegetables results in an increase in bacterial count that is significant from the viewpoint of quality. Such an observation serves to emphasize the importance of providing equipment that will promptly bring the temperature of the produce to the near-freezing range.

Prompt freezing. A second consideration in assessing freezing capacity is that of "turnover." In commercial freezing processes, very rapid freezing is essential so that production volume is maintained at a high level. Here, however, the problem is economic and not one imposed by food quality alone. For some products, notably fish, rapid freezing rates are desirable from a quality standpoint. For many other foodstuffs high quality is possible with relatively slow freezing conditions. Nevertheless, it seems reasonable to insist that the freezing capacity be such that at peak loads the produce be frozen within 12 to 14 hours, if only to insure that produce in the freezer overnight can be removed to make room for fresh produce to be processed the following day.

Protection of stored products. To protect the quality of frozen food, it is essential that the refrigeration be such as to maintain subfreezing conditions in *all* stored produce while freezing new foodstuffs. The question of whether a separate freezing compartment is necessary, or whether both freezing and zero storage can be satisfactorily accomplished in a single chamber will depend on the size and type of the refrigerated space and refrigeration equipment. Precautions must be taken, however, to eliminate the possibility of frozen food in storage even partially thawing because of the placement of a peak load of warm foodstuffs in the freezer.

Storage requirements. Storage temperatures above 0°F. generally lead to accelerated deterioration in the quality of frozen food. At 10°F., meats may start to develop off-flavors (incipient rancidity), and vegetables may lose their desirable flavors and high vitamin content in a matter of weeks, whereas at lower storage temperatures these changes occur only over a period of months.

The recommended maximum temperature for the safe storage of frozen foods over an extended period of time is 0°F. Certain products may remain unchanged at a somewhat higher temperature, and some frozen products are improved by storing at even lower temperatures. The general rule, however, is that much will be gained by lowering the temperature down to 0°, but little will be gained by a further lowering of the storage temperature.

Degree of tolerance in storage temperature. If a 5° tolerance in air temperature is to be allowed under load conditions, it becomes apparent that the manufacturer of home-freezer cabinets, the locker operator, and the frozen-food warehouseman are faced with a problem of temperature equalization. This specification implies that the uppermost package, whether in a small freezer box or a large refrigerated room, be exposed to a temperature no higher than 5°F. Thus temperatures in the space from top to bottom, under small load and under maximum load, and during the on-and-off cycling of the compressor must all be considered and made to conform with the conditions imposed by the food itself.

Temperature fluctuation during storage of frozen foods has proved to lead to an accelerated loss of moisture from the product (see Chapter 7) as well as to the formation of "cavity ice," leading to desiccation within the package. However, all considerations point to a maximum of 3°F. (food temperature) as being a range of temperature cycling readily attainable and probably acceptable for most products. If the product temperature fluctuates frequently over a range much greater than 3°, desiccation and other undesirable deteriorative changes are likely to be encountered.

Humidity. A secondary consideration in defining proper freezer storage conditions is the humidity. The desirable ideal will be the use of packages highly impermeable to moisture vapor, so that foods will not be subjected to desiccation under low relative humidity conditions that may be encountered in the air surrounding the packages. The usual package for frozen foods, while resistant to the passage of moisture vapor, is sufficiently permeable to make humidity a definite concern. Since desiccation in its several stages, or as it evidences itself in various frozen products, may make the food unmarketable, unattractive, or unstable, its importance is evident to the pocketbook and palate alike. The obvious goal is to insure a high humidity and hence a low tendency toward drying out of the food during prolonged storage. One suggested means of effecting this is by maintaining a very small differential between the temperatures of the stored food and the circulating refrigerant in the coils or plates.

Sanitation features. The art of reproduction is well developed among the various microorganisms. To the sauerkraut manufacturer, this has proved useful. To the frozen-food processor, this is invariably a disadvantage. The tendency of bacteria, molds, and yeasts to multiply rapidly over a wide temperature range, and especially when supplied with the favorable diet found in food plants and in the kitchen, emphasizes the necessity for a clean well-lighted sanitary plant.

Proper facilities. Water plus light are important ingredients that go into cleanliness or sanitation. Adequate materials for a frequent cleansing and sufficient light to make cleanliness—or its lack—apparent are "must" items. However, good intentions also need to be supplemented with good engineering. The design of all equipment and facilities used in the handling, processing, or storage of perishable foods—and all frozen foods are perishable—must be chosen with sanitary requirements in mind.

To cite an obvious example, the tracks from which animal carcasses are hung must be of a height sufficient to insure that no part of the animal touches the floor during transportation and storage in the plant. Simple, obvious—and yet not infrequently overlooked! A less obvious example is selection of packaging materials. Studies[2] have indicated that wrapping papers and cartons may vary greatly in the number and type of contaminating microorganisms. For food materials some of these packaging materials might prove undesirable from considerations of sanitation.

The room and the equipment must be capable of an easy and *sure* cleaning so that food particles are not left or trapped where they can harbor the multiplying microorganisms of spoilage and disease. Because of its porosity, wood is hard to keep in a sanitary condition. Particles of food plus moisture can make wooden tanks, tables, and trays breeding places for undesirable microorganisms.

[2] J. R. Sanborn, Suitable paper wrappers and containers for foods, *Am. J. Pub. Health* **28,** 571 (1938).

Thus particular care must be taken in the design and use of such equipment to minimize the possibility of contaminated food products. Temperature and time are perhaps the most important factors influencing microbial growth; they can and should be controlled through the design and layout of the food-processing establishment.

Proper handling. The perishable foods destined for freezing offer the nutrients and moisture so favorable to microbial growth. The best preventive measures that can be prescribed are rapid handling and cool temperatures. The receiving, storage, preparation, and processing facilities for fresh foodstuffs in the food-freezing establishment must be planned with this in mind. Warm food entering the plant must be cooled promptly. Warm vegetables leaving the scalding medium must be cooled even more promptly. A minimum of delay should be encountered in the orderly progress of preparation, processing, packaging, and freezing of the food to be preserved.

Prompt handling is the byword of food quality and sanitation. A well-designed plant and a well-conceived process will insure that this objective is achieved.

Chapter 12

CONSTRUCTION OF LOW-TEMPERATURE SPACE

In all branches of the frozen-food field space must be provided in which to freeze and store the foods. This space is commonly maintained at or near the temperature of 0°F., whether it be in the smallest home-storage unit or a large commercial plant. When such space is to be built, special consideration must be given to the location, design, and materials of construction to serve its purpose both economically and satisfactorily over a reasonable life period.

Locating the storage space. Frozen-food storage space need not be housed in a new structure intended for the purpose, but may be placed in an old building. Many satisfactory zero storages have been placed in ice plants, ice-cream plants, stores, and other similar buildings, as well as in numerous homes, chiefly in cellars or basements of either house or barn. And many new plants, such as locker plants, have been built especially to serve the frozen-food trade, both for freezing and storage.

The type of structure in which the zero or refrigerated space is to be placed will be governed by local conditions and needs. However, certain limitations on size are imposed by the nature of the construction. A low-ceilinged room, such as a basement, may not serve the purpose because the thickness of insulation used reduces the headroom to the point where it might be impossible to install the necessary equipment. Also the insulation used in the walls reduces the floor space. These factors should be considered in choosing the site of a cold-storage room.

Holding low temperatures. It should be borne in mind that the temperatures in refrigerated spaces intended for frozen foods range from 0° to −30° or even −40°F. On the other hand, the outside temperatures may be as high as 90° to 100°F., or even higher in some sections of the country. It is also to be remembered that heat flows from warm bodies or space to colder bodies or space in direct proportion to the temperature difference between the two. The material through which the heat flows governs the rate of flow. Some materials, notably metals, permit very rapid flow, whereas others, commonly known as insulating materials, retard the flow.

In general masonry building-materials are not good insulators. Lumber or lumber with air spaces divided up into small cells retards heat transmission fairly well. Where large temperature differences exist, as with refrigerated spaces, and where the temperature difference must be maintained by artificial means requiring the use of power, it is necessary to use insulating materials of a quality to retard the heat flow effectively. Even with good insulation there still is heat leakage.

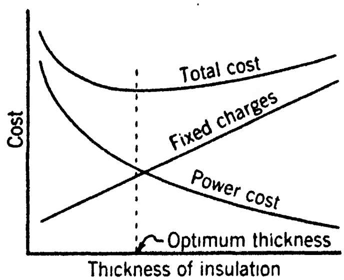


Figure 28. Typical cost curves. These illustrate how, as insulation thickness is increased in a given installation, the fixed charges increase while the cost of power for refrigeration decreases. The total cost of operation, however, reaches a minimum value at the optimum thickness of insulation.

Although the heat leakage is inversely proportional to the thickness of insulation applied, it is not economically sound to use more than a certain maximum thickness for any given set of conditions. The increase in fixed charges resulting from the use of insulation beyond a certain thickness would no longer be compensated for by the relatively small saving in power consumption. Figure 28 shows in a general way how the fixed charges increase with insulation thickness while the cost of power diminishes. However, the total operating cost reaches a low point for some particular optimum thickness of insulation.

Because heat leakage is generally proportional to the temperature difference for a given installation, there will be more such leakage through walls exposed to sunshine than through shaded walls and more in warm weather than in cold. Consideration of the exposure of refrigerated rooms may, therefore, lead to savings in power consumption. For example, outside walls that are to be insulated should never be placed, if avoidable, in exposures that receive much direct sunshine. If such an exposure is necessary, a ventilated air space should be planned for between the outside walls and the insulated walls, or the exposure might be used for nonrefrigerated rooms.

Insulation. The many insulating materials can be classified in three general groups: (*a*) Loose-fill or bulk insulation, (*b*) batt type insulation, and (*c*) block-, board-, or slab-type insulation. In some cases all three forms may be made of the same material. Each type requires special handling. The loose-fill type requires a double-wall construction providing a space into which to pour or pack the insulation. The batt type requires a supporting wall to which the batts can be attached, and a substantial inside protective covering, as wood sheathing. The solid types may or may not require a substantial wall for support, depending on the degree of rigidity of the blocks. Some are strong enough to be used both for the structure of partition walls and, at the same time, as the insulation. Others require some support. Block types require a protective covering on both sides, such as coats of plaster.

There are listed in Table 14 several of the more commonly used types of insulation together with their coefficients of heat conduction, called conductivity, k. The coefficient k is expressed in British thermal units [1] of heat that will pass in one hour through a layer one inch thick and one square foot in area when there is a temperature difference of one degree Fahrenheit between the two sides. The heat that would pass through one square foot of any such material with a greater temperature difference than one degree Fahrenheit can be found by multiplying the conductivity factor k, by the temperature difference in degrees Fahrenheit. If the thickness is greater or less than one inch, the factor should be divided by that thickness in inches, as the heat transmission is inversely proportional to the thickness. The heat transmission through a wall of corkboard 4 inches thick and having a temperature of 90°F. on the outside and 0°F. on the inside would be

$$Q = \frac{k}{\text{thickness}} \times \text{temperature difference}$$

$$= \frac{0.27}{4} \times (90 - 0) = 6.07 \text{ B.t.u. per hour per square foot}$$

[1] The British thermal unit, hereafter abbreviated as B.t.u., is the unit of heat that, when added to or removed from one pound of water, raises or lowers its temperature one degree Fahrenheit.

The heat leakage into a room having such insulation on all sides for the period of one day would be the product of Q times the total area of walls, floor, and ceiling, times 24.

TABLE 14. DENSITY AND CONDUCTIVITY OF INSULATING MATERIALS COMMONLY USED

Material	Density, lb. per cu. ft.	Conductivity, k B.t.u., in./sq.ft., hr., °F.	Authority *
Air cell, 1-in. asbestos paper with air spaces	8.80	0.50	..
Asbestos, packed	44.0	1.62	2
loose	29.0	1.07	2
thin sheets	31.0	0.49	1
board	60.0	0.84	1
Cement wood (Portland cement and sawdust)	45.0	0.97	3
Cork, granulated	8.1	0.31	1
Corkboard	8.3	0.27	4
Cotton wool, loosely packed	.....	0.29	..
Diatomaceous earth	5.06	0.39	5
Eel grass	30.0	0.56	5
Foamglas	10 to 11	0.40	8
Glass wool	1.76 to 5.37	0.265 to 0.224	4
Hair felt, not compressed	13.0	0.26	1
Insulation boards, fiber, various	15 to 21	0.32 to 0.38	4
Kapok, loosely packed	0.87	0.24	1
Masonite	15.0	0.33	..
Mineral wool	10.5	0.31	..
Planer shavings, various	8.7	0.40	1
Rock wool	10 to 14	0.275	1
Rubber, expanded	4.85	0.21	4
Sawdust, various	12.0	0.41	1
Shredded redwood bark	5.0	0.26	..

Compiled largely from *Refrigerating Data Book*, New York, American Society of Refrigerating Engineers, 1942.

* Authorities: 1 Bureau of Standards; 2 Groeber; 3 Nusselt; 4 Hechler and Queer; 5 Griffiths; 8 Pittsburgh Corning Corporation.

Where various materials are used in the construction of a wall, such as masonry or other building materials together with insulating material, it becomes necessary to calculate an over-all coefficient of heat transfer U expressed in British thermal units per hour per square foot per degree Fahrenheit temperature difference. Table 15 lists various common building materials together with their

TABLE 15. DENSITY AND CONDUCTIVITY OF BUILDING MATERIALS COMMONLY USED

Material	Density, lb. per cu. ft.	Conductivity, k B.t.u., in./sq. ft., hr., °F.	Authority *
Brick		5.0 to 9.2	
Cement mortar		12.0	
Cement plaster		12.0	
Concrete		12.0	
Fiber gypsum concrete, 87.5% gypsum, 12.5% wood chips	51.2	1.66	6
Sand and gravel	142	12.6	6
Limestone	132	10.8	6
Stucco		12.0	
Tile or terrazzo		12.0	
Gypsum between layers of heavy paper	62.8	1.41	7
Gypsum plaster		3.30	
Wood, across grain, typical			
Balsa	8.8	0.38	1
Redwood, California, 16% moisture	22	0.74	6
Fir, Douglas, 16% moisture	26	0.76	6
Maple, hard, 16% moisture	40	1.15	6
Pine, white, 16% moisture	32	0.78	6
Pine, yellow, 16% moisture	36	1.04	6

Compiled largely from *Refrigerating Data Book*, New York, American Society of Refrigerating Engineers, 1942.

* Authorities: 1 Bureau of Standards; 6 Rowley; 7 Peebles.

conductivities k. And from the individual conductivities of the different materials used in a wall, floor, or ceiling, the over-all coefficient U can be found by use of the following relation:

$$U = \frac{1}{\dfrac{1}{f_o} + \dfrac{t_1}{k_1} + \dfrac{t_2}{k_2} + \dfrac{t_3}{k_3} + \dfrac{t_4}{k_4} + \dfrac{1}{f_i}}$$

where the letter t represents the thickness in inches of the various materials used, whose conductivities are k with the corresponding subscripts. Heat transfer between air and wall surfaces is taken care of by coefficients f_i for still air, as inside, and f_o for moving air at 15 miles per hour, as outside, having values of 1.65 and 6, respectively. For example, an insulated outside wall might be constructed of ½-inch stucco on the outside of 8-inch brick, having 12 inches of shredded redwood bark held in place by a ½-inch sheathing of white pine. The over-all coefficient for such a wall would then be

$$U = \frac{1}{\frac{1}{6} + \frac{0.5}{12} + \frac{8}{12} + \frac{12}{0.255} + \frac{0.5}{0.78} + \frac{1}{1.65}}$$

$$= 0.0204 \text{ B.t.u. per hour per square foot per degree Fahrenheit}$$

From such a factor the entire heat loss of a wall may be determined. And similar coefficients may be calculated for each part of the structure.

Thickness of insulation. The thickness of insulation to be used on different parts of a refrigerated space can only be determined after consideration of the economics involved. The more insulation used, the less will be the heat leakage, and, consequently, the less the cost of power to maintain the desired temperature. However, at the same time the cost of the insulation is increased in proportion to the thickness. This is offset to some extent by the smaller-sized refrigerating machinery required for the work. The results of a good deal of study on the part of insulation manufacturers and others have led to the recommendation that sufficient insulation be used on zero space to provide, together with the other building materials used, an over-all coefficient of about 0.03 to 0.05 B.t.u. per hour per square foot per degree temperature difference. For ready reference Table 16 shows the thicknesses of insulation commonly recommended for different parts of different rooms insulated for frozen-food processing and storage.

Whenever block-type insulating material is used, it is advisable to apply it in two layers with all joints broken or staggered. The thicknesses given in Table 16 are for the total insulation. Therefore, the material should be purchased in thicknesses of half as great. The purpose of this is to provide additional protection against vapor infiltration by having every joint in the first layer covered by an asphalt-dipped block in the second layer. All joints should be bonded with great care.

TABLE 16. RECOMMENDED INSULATION THICKNESSES

Type of Space	Inside Temperature	Part of Insulation	Thickness,* inches
Chill or aging room	30° to 40°F.	*Walls* exposed to outside temperature.	4–5
		Walls exposed to 0°F.	3–4
		Ceiling not in direct contact with roof exposed to sun.	4–6
		Floor over basement at outside temperature.	4–5
		Floor directly on ground.	3–4
Frozen food storage space	0°F.	*Walls* exposed to outside temperature.	6–8
		Walls exposed to chill or aging room conditions.	3–4
		Ceilings not in direct contact with roof exposed to sun.	6–8
		Floor over basement at outside temperature.	6–8
		Floor directly on ground.	6–7
Freezing space	−10° to −20°F.	*All parts.*	Add 1–2 inches to thicknesses recommended for 0° storage

* The values in this table are based on the use of corkboard having a coefficient of 0.27 B.t.u. per hour per inch per square foot per degree temperature difference. If any other material is used, the thickness should be that given multiplied by the ratio of the coefficient of the material to that of corkboard.

Cheap forms of insulation such as sawdust and wood shavings can be used. Where their use is recommended, thicknesses up to 18 inches are sometimes suggested. Such materials should be clean, dry, and odorless. The greatest of care must be taken to protect against water vapor and its effects.

Walls insulated with loose-fill materials make attractive nesting places for rodents. Much damage has been caused when precautions were not taken to prevent rodents from getting through the outer wall. Rodents will also, on occasion, break through block-type insulating materials to get at foodstuffs stored within. Cellular glass-block insulation appears to be a protective material in this respect. Breaking into the insulation also destroys the vaporproofing, with consequent injurious results.

Vaporproofing of insulation.[2] Moisture in the atmosphere can be a very serious menace to insulation if proper precautions are not taken in the original installation. Practically all insulating as well as building materials are porous to some extent, that is, they will permit the passage of water in vapor form even if not in liquid form. Walls of cold-storage spaces are subjected to very different temperatures on the two sides. A difference in atmospheric water-vapor pressure usually accompanies this temperature difference. The vapor pressure is greater on the warm side than on the cold side in proportion to the temperature difference. Hence, there is a marked tendency for water vapor to move from the warm or high-vapor-pressure side toward the cold or low-vapor-pressure side. And at the same time the wall material itself varies from warm to cold. Therefore, if vapor penetrates, as it would be bound to do where there is no protection against it, it would soon reach a region within the wall where it would condense. From there it would flow as water by capillary action, gradually permeating all the wall. This moisture would affect the insulating properties of the wall seriously, because water conducts heat about 16 times as readily as does cork. It is necessary, therefore, to provide what is known as a vapor barrier on the warm side of the insulation. Nearly all types of insulation require this kind of protection. An exception to this is a cellular glass insulation known as Foamglas. The surface of Foamglas, no matter where cut, forms a vapor barrier of itself.

Walls should be vaporproofed according to the type of wall construction and the type of insulation to be applied. Details of different methods may be seen in the various illustrations in this chapter.

[2] Details of vaporproofing, insulating, and finishing materials and their application can be had from several of the manufacturers of insulating materials in pamphlet form.

Insulated floors. When insulated floors are to be placed directly on the ground, as in many locker-plant installations or in cellars of homes or barns, great care must be taken to avoid the possibility of freezing the ground under the cold-storage space. Again the characteristics of heat transfer enter the picture.

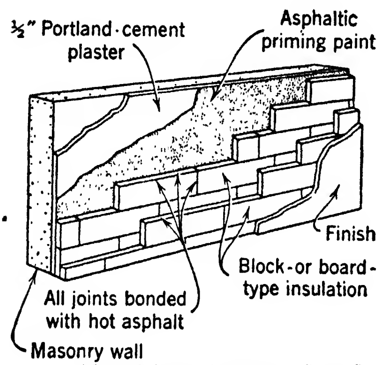
Foundations. Even though the floor be adequately insulated, the heat in the ground under the floor will flow, in time, into the cold space above. The temperature of the ground then drops to lower and lower values. When the outdoor temperature is low, or when the ground is of such a character that heat does not flow through it readily to replace that lost upward, the temperature of the ground may reach or go below the freezing temperature of water. If, then, the ground is moist, it will freeze. And if the soil is of a clayey nature, it will heave on freezing. This may, in turn, lift the floor of the refrigerated space in such a manner as to cause it to be seriously damaged by cracking. The vaporproofing is then destroyed and the floor thrown out of level, causing great inconvenience if not injury to the equipment on it.

To avoid such trouble the soil on which the floor is to be laid should be studied in advance. If it is found to be clay or material subject to moisture, it is imperative that some means be found to eliminate the source of trouble. This may be done by excavating the clay to a depth of 1½ to 2 feet and filling the space with well-packed crushed rock, river pebbles, cinders, or very coarse gravel. Provision should be made to drain this space in order to prevent its ever becoming filled with water. The floor can be laid over the fill. If the ground is sandy or gravelly in nature, it is only necessary to make sure that there is ample provision for good drainage.

Floor construction. The floor of the refrigerated space should be designed as in any ordinary case, but with special emphasis on its being dry, as previously noted. Where it is to be laid directly on the ground, the best construction is obtained by the use of reinforced concrete, laid over the well-tamped fill. The concrete floor should be reasonably smooth and level. Over this a heavy coat of hot asphalt should be flooded or mopped to form the vapor seal. Floors above ground level should be prepared for insulating by vaporproofing in the manner used for walls of the same construction.

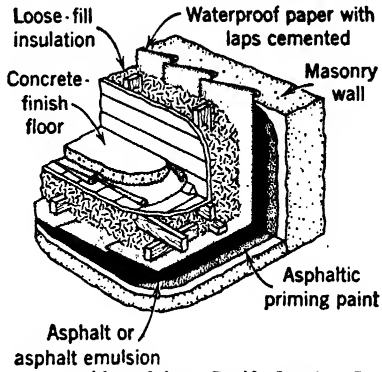
After the bearing floor is prepared properly, the desired insulation may be applied. If it is of a block type capable of bearing load, a wearing floor of wood or concrete may then be laid directly on it. Before concrete is poured, the top surface of the insulation must be carefully waterproofed. When the insulation is of the loose-fill type which can support no load, suitable furring and sleepers must be installed to support the wearing floor.

Insulation of walls. Masonry walls that are to be insulated should be clean, dry, and smooth. If the walls are rough they



Adapted from Armstrong Cork Co.

Figure 29. The usual method of applying block- or board-type insulation to a masonry wall.



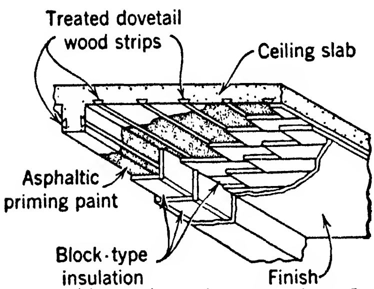
Adapted from Pacific Lumber Co.

Figure 30. Loose-fill insulation applied to a concrete floor and masonry wall. The inner wall supporting the insulation is of wood, while a concrete wearing floor may be used.

should be smoothed by being filled out with a coat of Portland-cement plaster as is illustrated in Fig. 29. When this is thoroughly dry, it should be primed with one or more coats of an asphaltic priming paint. The block type of insulation can then be dipped in hot asphalt and applied directly to the wall. A second layer of insulation is then applied to the first with all joints broken and with hot asphalt as the bonding medium. Loose-fill insulation requires the construction of an inner wall to support the material (Fig. 30). The insulation is packed into place, starting at the bottom, in such a manner that it has the recommended density and will not settle at a later time, leaving uninsulated voids.

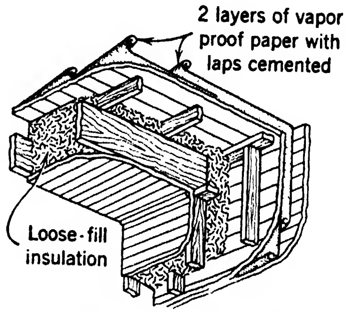
Wood walls should be covered with one or more layers of asphalt-impregnated vaporproofing paper before either type of insulation is applied. Block-type insulation is then applied with hot asphalt and galvanized nails driven through the first layer into the wood. Loose-fill insulation is used as described with an inner retaining wall.

Insulation of ceilings. Ceilings are somewhat more difficult to insulate than are walls and floors. The procedure is essentially the same. First the ceiling must be vaporproofed by the application of asphalt-impregnated roofing paper to the under side of



Adapted from Armstrong Cork Co.

Figure 31. Block- or board-type insulation applied to a concrete ceiling. The dovetail wood strips are imbedded in the concrete in new ceilings. On old ceilings plain strips must be attached with suitable anchors. The blocks are bonded to the ceiling and to each other with hot asphalt. In addition, the first course is nailed to the strips. Wooden skewers are used to help hold the second course to the first.



Adapted from Pacific Lumber Co.

Figure 32. Loose-fill insulation as applied to a wooden wall and ceiling. Special care is necessary to insure complete sealing of the vaporproof sheathing and in packing the insulation so that no voids remain.

wood ceilings, or one or more coats of asphaltic priming paint to concrete. The method of attaching the insulating material to the ceiling will depend on the ceiling and the insulation. Figures 31 and 32 illustrate methods that can be used with concrete or wood ceilings and the different types of insulation.

Interior finishes for insulated space. Floors, as previously noted, may be finished with concrete or wood as desired. Concrete is advisable when much wear is anticipated, or where there is possibility of water dripping or spilling on the floor. In zero space any water falling on the floor would freeze and would have to be scraped off. Such scraping would soon injure wood floors.

A concrete wearing floor should be applied only after the surface of the insulation or the subfloor over the insulation has been completely waterproofed to prevent moisture from the concrete penetrating into the insulation. The floor should be laid with a slope of 1 inch in 10 feet if there is to be any drainage or washing of the floor, as in aging rooms.

Walls of block-type insulation should be protected by a coating of an asphalt emulsion or a plaster or some other type of wall covering. Water emulsions of asphalt with sand and asbestos fibers can be troweled on to such insulating materials as corkboard or Foamglas. This material can be painted with special asphalt base paints, but not with ordinary oil paint, because the asphalt is dissolved by the oil and stains the paint. A Portland-cement plaster may be applied in two ¼-inch layers to all but Foamglas to which it will not adhere satisfactorily. A gypsum plaster may be used on Foamglas. Plaster finishes may be painted if desired.

Decorative finishes, such as ceramic tile or tileboard, may be appiled to block-type insulation, preferably after a plaster coat has been applied. Washable tiles are particularly desirable in such rooms as chill and aging rooms in locker plants where the walls should be washed down from time to time.

Ceilings are most easily finished with asphalt emulsions. However, plaster can be used. It is advisable to strengthen a plaster finish by applying it over galvanized metal lath or wire netting, firmly attached to the insulation by galvanized staples.

Where loose-fill insulation is used, the flooring can be handled as described. The rest of the construction requires an interior sheathing to retain the insulation. This may serve admirably as the interior finish as well. It should be carefully chosen without loose knots and other defects. It should also be durable, not subject to absorbing or giving off odors, and it should hold paint under the conditions to be met in such storage spaces. California redwood, Douglas fir and spruce are suitable for this purpose. The use of plywood sheets can reduce the labor costs by a considerable amount.

Chapter 13

REFRIGERATION FOR LOW TEMPERATURES

Ice and salt mixtures. In order to maintain the temperatures required for freezing foodstuffs and for the preservation of frozen foods it is necessary to use some artificial means of removing heat. This is known as refrigeration. Early efforts at freezing and storing frozen foods, accomplished with the aid of a mixture of salt and ice, were costly and awkward. Mechanical means of refrigeration, when developed, quickly superseded the salt and ice method.

Mechanical refrigeration. In mechanical refrigeration some fluid, known as the refrigerant, is used in a closed system to carry heat from the place being cooled to some place where that heat can be rejected. To the layman the concept of removing heat from a space whose temperature is around 0°F. may seem strange. Yet it is the leakage of heat into such a space that causes the temperature to rise. Hence, it is the removal of the heat that leaks through the walls of the cold space that keeps its temperature low. This is the function of refrigeration. In the use of ice for refrigeration it is the melting of the ice that absorbs or uses up the heat that leaks into the refrigerated space. In that case heat is absorbed at 32°F., or at the melting point of ice. Or, if a mixture of ice and some salt is used, its temperature may be well below 32°F. In mechanical refrigeration it is the boiling or evaporation of the refrigerant that takes up the heat which is to be removed.

Boiling points. Different liquids boil at different temperatures when they are exposed to atmospheric pressure, as water at 212°F., or liquid ammonia at −28°F. Other refrigerants behave similarly, as shown in Table 17. It is also true that every liquid will boil at a different temperature for each pressure to which it is subjected. For example, water in a boiler under pressure will not boil till the temperature is at the boiling point, or saturation temperature, *corresponding to that pressure.* At a gage pressure of 100 pounds per square inch, water will not boil till the temperature reaches 338°F. Ammonia boils at 0°F. when the gage pressure is 15.7 pounds per square inch.

TABLE 17. PRESSURE–TEMPERATURE RELATIONS OF VARIOUS COMMON REFRIGERANTS

Saturation Temperature or Boiling Point, °F.	Ammonia		Freon, F 12		Methyl Chloride		Sulfur Dioxide	
	Pressure *	Latent Heat †	Pressure *	Latent Heat †	Pressure *	Latent Heat †	Pressure *	Latent Heat †
−40	8.7	597.6	11.0	73.50	15.8	190.66	23.5	178.61
−30	1.6	590.7	5.5	72.67	11.4	188.52	21.2	176.97
−28	0.0	589.3						
−21			0.0	71.89				
−20	3.6	583.6	0.5	71.80	6.1	186.34	17.9	175.09
−11					0.0	184.34		
−10	9.0	576.4	4.5	70.91	0.2	184.12	13.9	172.97
0	15.7	568.9	9.2	69.96	3.8	181.84	8.9	170.63
10	23.8	561.1	14.7	68.97	8.7	179.54	2.6	168.07
13.6							0.0	167.75
20	33.5	553.1	21.1	67.94	13.6	177.11	2.5	165.32
30	45.0	544.8	28.5	66.85	20.6	174.59	7.0	162.38
40	58.6	536.2	37.0	65.71	28.1	172.00	12.4	159.25
50	74.5	527.3	46.7	64.51	36.3	169.35	18.8	155.95
60	92.9	518.1	57.7	63.25	48.1	166.62	26.2	152.49
70	114.1	508.6	70.1	61.92	57.8	163.82	34.9	148.88
80	138.3	498.7	84.1	60.52	72.3	160.91	45.0	145.12
90	165.9	488.5	99.6	59.04	87.3	157.92	56.6	141.22
100	197.2	477.8	116.9	57.46	102.3	154.85	69.8	137.20
110	232.3	466.7	136.0	55.78	118.3	151.65	85.0	133.05
120	271.7	455.0	157.1	53.99	139.3	148.46	106.2	128.78

* Above line: Vacuum in inches of mercury. Below line: Pressures in pounds per square inch gage. (Standard atmospheric pressure assumed.)
† Latent heat of vaporization in B.t.u. per pound.

Evaporation at constant pressure. If liquid ammonia could be introduced into a vessel where the pressure is maintained the same as that of the atmosphere, the liquid ammonia would boil at the low temperature of −28°F. However, it requires heat to vaporize the liquid. With the vessel surrounded by an ideal insulating material through which no heat could flow, the liquid ammonia would not boil at all, because there would be no flow of heat to it

TABLE 18. PROPERTIES OF REFRIGERANTS

Refrigerant	Chemical Formula	Volume per lb. at 68°F. and 1 Atm.	Boiling Point at Standard Atm., °F.	Weight Circulated per Standard Ton, lbs./min.	Underwriters' Laboratory Toxicity Group No.	Kills or Seriously Injures			Explosive Range Concentration in Atmospheric Air	
						With Exposure of	Concentration in Air			
							Per Cent by Volume	Pounds per 1000 Cu. Ft.	Per Cent by Volume	Pounds per 1000 Cu. Ft.
Ammonia	NH_3	22.6	−28.0	.422	2	½ hr.	0.5–0.6	0.221–0.256	16–25	7.1–11.05
Carbon dioxide	CO_2	8.75	−109.3	3.528	5	½–1 hr.	29.0–30.0	33.2–34.3	Noninflammable	
Dichlorodifluoromethane (Freon 12)	CCl_2F_2	3.18	−21.6	3.916	6	2 hr.	28.5–30.4	89.6–95.7	Noninflammable	
Dichlorethylene	$C_2H_2Cl_2$	3.97	118.0	.....	4	2 hr.	2–2.5	5.04–6.3	5.6–11.4	14.1–28.7
Dichloromonofluoromethane (Freon 21)	$CHCl_2F$	3.76	48.0	2.237	4b	½ hr.	10.2	27.1	Noninflammable	
Ethyl chloride	C_2H_5Cl	5.96	54.5	.....	4a	1 hr.	4.0	6.72	3.7–12.0	6.21–20.1
Methyl chloride	CH_3Cl	7.62	−10.6	1.345	4	2 hr.	2–2.5	2.62–3.28	8.1–17.2	10.6–22.6
Methyl formate	$C_2H_4O_2$	6.41	89.2	1.056	3	1 hr.	2–2.5	3.12–3.9	4.5–20.	7.02–31.2
Methylene chloride	CH_2Cl_2	4.53	103.6	1.492	4a	½ hr.	5.1–5.3	11.25–11.70	Noninflammable	
Sulfur dioxide	SO_2	6.01	13.8	1.414	1	5 min.	0.7	1.165	Noninflammable	
Trichloromonofluoromethane (Freon 11)	CCl_3F	2.8	74.7	2.961	5	2 hr.	10.	35.7	Noninflammable	
Trichlorotrifluoroethane (Freon 113)	$C_2Cl_3F_3$	2.1	117.6	3.672	4b	......	....	.....	Noninflammable	

Compiled largely from material in *Refrigerating Data Book*, New York, American Society of Refrigerating Engineers, 1942. (The information on toxicity and explosive range was obtained from *Underwriters' Lab. Repts.* **MH-2256, MH-2375**, and **MH-2630**, and the *U. S. Bur. Mines Repts.* **R.I., 3013** and **R.I. 3185**.)

even with the temperature of −28°F. in the vessel. Were the vessel surrounded by a real insulating material, through which heat does flow, the ammonia would vaporize in proportion to the amount of heat that leaked through the insulation.

Table 17 shows the amount of heat required at any pressure to change one pound of a refrigerant completely from liquid to vapor at the saturation temperature or boiling point corresponding to that pressure. This is known as the latent heat of vaporization. In the case of ammonia at atmospheric pressure this latent heat of vaporization is 589 B.t.u. per pound. Hence, if 589 B.t.u. leaked through the insulating cover of the vessel in one hour, one pound of ammonia would be vaporized in that time, while the temperature remained constantly at −28°F. Similarly, at other pressures ammonia would boil or vaporize at other temperatures, using other amounts of heat. Other refrigerants would behave in a like manner, as shown by the figures of Tables 17 and 18. In the case of sulfur dioxide the pressure required to permit vaporization at 0°F. is below atmospheric pressure, or a vacuum of 8.9 inches of mercury.

Refrigerants. There are a considerable number of substances that can be used as refrigerants. Their properties differ widely, as may be seen from Table 18. Some are suited to very low-temperature work, whereas others are more desirable for higher temperatures. Some are dangerously toxic, while others have no harmful effect on humans except when encountered in great concentrations, when suffocation may result. Some readily form explosive mixtures with air, so presenting additional hazards if leakage occurs.

The most *commonly used refrigerants* are ammonia, various Freons, especially 12 and 22,[1] methyl chloride, sulfur dioxide, and carbon dioxide. Ammonia and Freon 12 are the two that are used most widely for cold storage of foods as they seem to be the most desirable for that type of service. Methyl chloride is both toxic and explosive in a greater degree than is ammonia and, therefore, is not so desirable. It was substituted for Freon 12 during the war years when the latter was unavailable. Sulfur dioxide is not easy to handle, because any water in the refrigeration system combines to produce an acid which is very corrosive to most of the

[1] Dichlorodifluoromethane, known commonly as Freon 12; Monochlorodifluoromethane, known as Freon 22.

metal parts. The chief disadvantage of carbon dioxide is the high pressure required. High pressure means the use of special pipe and fittings, and considerable trouble from leakage can be expected. Ammonia also requires rather high pressure. But the advantages in its properties outweigh this disadvantage. The very large latent heat of this refrigerant means that a relatively small amount is required to do the refrigerating work, compared with other refrigerants of which 3 to 11 times as much by weight must be circulated.

Leakage of refrigerants is one of the major sources of trouble with refrigeration plants. Refrigerants that are without odor can leak away in serious amounts without being detected unless some odorous material is added to make leaks noticeable. Such an addition, however, is not generally recommended. Refrigerants like ammonia, having strong odors of their own, are very good in this respect because they make themselves known as soon as there is the slightest amount of leakage. However, the odor merely indicates leakage without necessarily showing the location. To detect leaks of nonodorous refrigerants and to locate all types of leaks there are certain devices available.

For ammonia the burning of sulfur candles or the presence of concentrated hydrochloric acid reveals the source of leakage, because the fumes from either combine with the ammonia to form a white cloud which is most marked at the point of leakage. Leakage of sulfur dioxide can be detected by the use of a strong solution of ammonia in water. Again a white cloud is formed when the sulfur dioxide and ammonia combine. Freon vapors can be detected by means of a halide torch or lamp. A normally blue flame turns bright green when one of these vapors is drawn into it. Inert gases, such as carbon dioxide, and inflammable gases cannot be detected in these ways. The surest method of detecting leaks is to apply a soap solution to all places where leaks might exist. Bubbles will indicate leakage. Some refrigerants carry oil from the compressor all through the system, and where leakage occurs there will be evidence of oil.

The handling of gases under pressure has in it elements of danger. It is, therefore, recommended that persons having to do with mechanical refrigerating plants of any size familiarize themselves with precautions that should be observed. Information can be obtained from such a publication as *Safe Handling of Compressed Gases*.[2]

The mechanical refrigeration cycle. In mechanical refrigeration the refrigerant is introduced, as a liquid, into a vessel which serves as a boiler or evaporator. The evaporator is placed in the space to be cooled. There the refrigerant absorbs heat from its surroundings, while the pressure in the vessel is kept constantly at such a value that the boiling point is several degrees below the temperature of the cooled space. Thus, for every pound of refrigerant evaporated an amount of heat is absorbed equal to the latent heat of vaporization of the particular refrigerant at the particular pressure used.

Heat removal by vaporization. This process converts the refrigerant from a liquid to a vapor carrying a great deal more heat energy than when it was a liquid. But the vapor is still at the boiling-point temperature. In order to remove the heat from it at this temperature, there would have to be some cool body at a still lower temperature to which the heat would flow. However, if there were such a cool body there would be no need for the elaborate refrigerating machinery. The heat is, therefore, removed from the refrigerant in a different way. The refrigerant is drawn off from the evaporator as fast as it is vaporized. For that purpose, a motor-driven compressor is used. This both maintains the desired pressure in the evaporator and compresses the vapor to a much higher pressure. The process of compressing the vapor, because of the work done on it, also raises its temperature to a value considerably above that of the surroundings.

Heat rejection in condensation. It is possible then to cool the refrigerant by means of air or cooling water. The hot vapor is allowed to flow into a condenser, consisting of a finned pipe coil exposed to a stream of air or surrounded by water. There the same heat that was absorbed at the low temperature, plus some that was added by the work of compression, is rejected to the cooling air or water. This cooling of the vapor causes it to condense and return to the liquid state, while still at the high pressure imparted to it by the compressor. In the case of ammonia being condensed by the use of water at about 70°F. the pressure imparted by the

[2] Issued by Compressed Gas Manufacturers Association, 11 West 42d Street, New York.

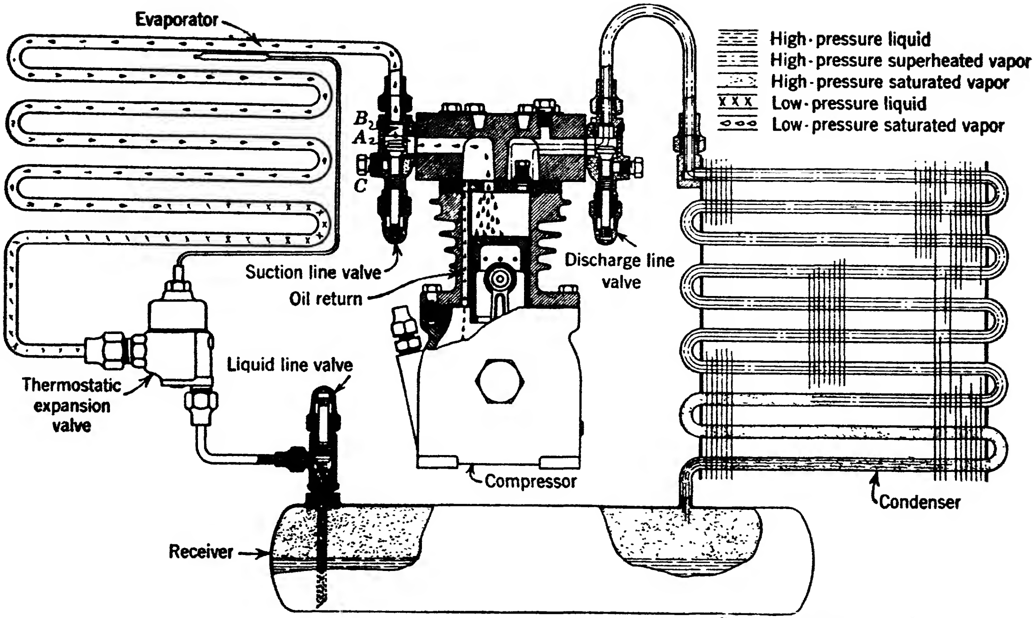
compressor must be about 114 pounds per square inch gage (Table 17).

Cold through expansion. There remains only one step to complete the refrigeration cycle, the reduction of pressure of the liquid refrigerant from that at which it is condensed to that at which it is evaporated. This is accomplished by permitting the liquid to flow through an opening only large enough to admit as much refrigerant as is being evaporated in the process of refrigeration. The small opening through which the liquid flows is generally known as the expansion valve, because it permits the expansion of the fluid from the high pressure to the low. At the same time the size of the opening can be regulated like a valve, either automatically or by hand, to control the amount of flow.

The process of expansion results in a cooling of the refrigerant, because no liquid can exist at any given pressure with a temperature higher than the corresponding boiling point. High-pressure liquid refrigerant which is at or near room temperature, therefore, undergoes a marked drop in temperature when its pressure is reduced. The excess heat in the high-pressure high-temperature liquid goes to vaporize some of that liquid in the process of expansion, with the result that only some 80 per cent, more or less, of the refrigerant enters the evaporator as low-temperature liquid. It is this portion of the refrigerant that accomplishes the desired cooling or removal of heat.

The refrigerating machinery. The diagram in Fig. 33 illustrates the application of the refrigeration cycle. At the bottom of the diagram is shown a reservoir containing the high-pressure liquid refrigerant. This is commonly called a receiver. The space over the liquid in the receiver is filled with refrigerant vapor at the pressure corresponding to the temperature of the receiver and its contents. This pressure tends to force the liquid to flow out through the pipe or tube leading to the expansion valve. The valve shown is called a thermostatic expansion valve because the temperature of the refrigerant vapor leaving the evaporator controls the opening of the expansion valve automatically.

In passing through the expansion valve the pressure of the refrigerant is dropped from that of the receiver to the low pressure of the evaporator, that is, the pressure corresponding to a temperature several degrees below that of the space being refrigerated. In the evaporator the process of absorbing heat goes on, and the



Courtesy Brunner Manufacturing Co.

Figure 33. A diagram illustrating the refrigeration cycle. Liquid refrigerant at high pressure flows from the receiver through the expansion valve to the evaporator where it picks up heat while refrigerating the surroundings. The heat causes it to evaporate, and it is then drawn into the compressor and discharged at high pressure once more to the condenser. There the refrigerant is returned to the liquid state and delivered back to the receiver as the cycle is completed.

liquid refrigerant is converted into vapor which is drawn off by the compressor. It enters the compressor by the suction line, is compressed, and leaves by the discharge line. It then enters the condenser where it is cooled by means of air circulating between the fins on the tubes. As the heat is removed, the refrigerant returns to the liquid state, still at the pressure imparted by the compressor. The liquid refrigerant then flows by gravity into the receiver where it remains till it is used again to repeat the cycle.

The only part of the refrigeration system that is placed in the space to be cooled is the evaporator. The supply line from the expansion valve and the return or suction line to the compressor are the only connections, and they must pass through the insulated wall.

Condensing units. In small installations such as are used in household refrigerators, home freezers, milk coolers, and the like, the combination of parts that condition the refrigerant for the cooling process, namely, the compressor with its driving motor, the condenser, and the receiver, are commonly known as a "condensing unit." Condensing units are usually assembled by the compressor manufacturer. They are sold ready to connect to an evaporator, with suitable controls, and put immediately into operation. In larger installations, such as locker plants and other large refrigeration applications, the compressor and condenser are chosen and purchased separately, though often from the same manufacturer.

Compressors. In small and moderate sizes compressors are usually rated according to the power of the driving motor, rather than by the amount of refrigeration they can accomplish. Larger sizes are rated, on the other hand, in terms of tons of refrigeration. A ton of refrigeration is defined as the amount of cooling that can be achieved by the melting of one ton of ice in 24 hours. This is equivalent to removing heat at the rate of 12,000 B.t.u. per hour. Table 19 lists capacities of different-sized condensing units as averaged from the ratings given by a number of different manufacturers.[3]

These values are only approximate, as there are wide variations between the ratings by different manufacturers. Therefore, the foregoing values should only be used as a guide and not for any

[3] The manufacturers from whose published data Table 19 was compiled are: Baker Ice Machine Co., Inc., Omaha, Neb.; Brunner Manufacturing Co., Utica, N. Y.; Carrier Corp., Syracuse, N. Y.; Copeland Refrigeration Corp., Sidney, Ohio; Vilter Manufacturing Co., Milwaukee, Wis.; Worthington Pump & Machinery Corp., Harrison, N. J.; and York Corp., York, Penn.

final design calculations. The actual capacity of the machine to be purchased, as rated by its manufacturer, should be used.

Factors affecting capacity. Table 19 shows two interesting facts. The evaporator temperature, and consequently the pressure at which evaporation takes place, has a marked effect on the capacity of the condensing unit. This is illustrated by the difference in

TABLE 19. CAPACITIES OF CONDENSING UNITS USING FREON, F 12, EXPRESSED IN B.T.U. REMOVED PER HOUR

Horse-power	Evaporator Temperature, 0°F. Room Temperature, 90°F.		Evaporator Temperature, −20°F. Room Temperature, 90°F.	
	Air-Cooled	Water-Cooled	Air-Cooled	Water-Cooled
1/6	775	......	430	......
1/5	1,060	......	530	......
1/4	1,471	......	775	......
1/3	2,010	2,380	1,175	1,465
1/2	3,135	3,500	1,775	2,210
3/4	5,080	6,160	2,960	4,325
1	6,630	7,980	3,825	5,650
1 1/2	9,300	11,275	5,815	7,525
2	12,230	15,200	7,750	10,400
3	15,000	20,420	10,700	13,250
5	......	31,820	......	21,630
7 1/2	......	51,550	......	38,500

capacity as listed for the same machine running with 0°F. in the evaporator in one case and with −20°F. in the other. Another difference lies in the increased capacity that comes with water cooling of the same-sized machine. The reason for this is simply that the transfer of heat to water is considerably better than it is to air.

It would seem then that all condensing units should be used with water cooling in order to get the most cooling effect for the power put in. But the use of water for cooling usually entails additional cost, whereas the use of air does not. In small installations the difference in power cost resulting from using the air-cooled unit of a size large enough to do the job and using a smaller water-cooled unit is usually less than the cost of the cooling water. With large units, however, it is impossible to depend on air cooling, as the quantities of heat to be removed reach such proportions that only water cooling can accomplish the result satisfactorily.

Location of the condensing unit. In locating the condensing unit in any installation it is well to remember that much heat is given off by the unit. All the heat that is removed from the space being cooled must be carried away from the condensing unit. In addition, all the electric energy put into the motor is eventually converted into heat and must be dissipated. If, for example, the condensing unit of a home freezer were placed in a closed room together with the freezer cabinet, the temperature of that room would steadily rise until the heat leakage out of the room became equal to the energy input to the compressor motor. Where this occurs, the cost of power will go up in proportion to the rise in temperature of the room. The electric power will be serving to heat the room as well as cool the freezer. The obvious remedy for this tendency to heat the room is to provide ample ventilation. An alternative is to place the condensing unit, when possible, in a separate well-ventilated room.

Locating the home freezer. From the point of view of power consumption a cool dry basement is an ideal place to locate the home freezer. If, however, the location chosen is damp, moisture will probably condense and collect on the lids or drip on the floor. This may result in frozen doors, corrosion of the cabinet, or puddles on the floor.

For the convenience of the user a location on the first floor near the kitchen is most desirable. A room not heated in winter and not exposed to much sunshine and high temperatures in summer would be ideal.

Power consumption. The power consumption of different-sized compressors is of interest in predicting the cost of operation of small plants. Table 20 lists such values obtained by averaging the published data of two manufacturers.[4] Again these values cannot be used indiscriminately. They should serve only as a rough guide. The power consumption of any compressor varies a great deal with the conditions of operation. Also, the daily power consumption will not necessarily be the product of the quantity from the table

[4] Carrier Corp., Syracuse, N. Y., and Vilter Manufacturing Co., Milwaukee, Wis.

times 24 hours, because the compressor rarely runs more than a total of 16 to 18 hours per day. Under heavy-freezing load conditions it might run continuously for a day, but under all other normal conditions it should run only a fraction of the time, showing that it has a reserve of capacity for specially heavy demands.

TABLE 20. POWER CONSUMPTION OF VARIOUS SMALL CONDENSING UNITS

Horsepower	Power Consumption in Kilowatt-Hours per Hour of Operation			
	Evaporator Temperature, 0°F. Room Temperature, 90°F.		Evaporator Temperature, −20°F. Room Temperature, 90°F.	
	Air-Cooled	Water-Cooled	Air-Cooled	Water-Cooled
¼	0.34	....	0.280	.....
⅓	0.49	0.46	0.40	0.390
½	0.69	0.59	0.57	0.495
¾	1.03	0.88	0.84	0.740
1	1.35	1.16	1.11	1.02
1½	1.87	1.70	1.58	1.35
2	2.50	2.30	2.12	1.92
3	....	3.05	....	2.41
5	....	5.10	....	4.07

Many manufacturers build compressors for refrigeration work. Most of them are very similar to each other, both in construction and operation. Although the condensing-unit combinations are classed as air- and water-cooled, the compressors themselves, in many cases up to sizes as large as 25 horsepower, are air-cooled. For this purpose their cylinders are cast with fins which help to radiate to the surrounding air the heat generated in compression. Frequently the compressor flywheel is made with spokes in the form of fan blades, so that a stream of air is forced over the compressor while it is running. There are many compressors built, however, with water jackets for water cooling.

Details of construction. Figure 33 shows a cutaway view of a typical small-sized compressor. Most compressors, like this one, have two or more cylinders. This helps to eliminate vibration due to moving parts. The refrigerant is drawn into the compressor from the suction line through suitable valves. After being compressed, it is discharged through valves in the head to the discharge line.

Provision is always made for self-lubrication of all bearings and the pistons in the cylinders from the store of oil in the crankcase. A special seal is provided around the shaft where it projects through the crankcase in order to prevent loss of refrigerant along the shaft. The V-belt type of drive is used very widely between motor and compressor in single or multiple form, depending on the power transmitted. It is both efficient and silent and requires little space.

Condensers. The condensers used with small compressors are of either the air-cooled or water-cooled type. *Air-cooled condensers* are made of a nest or coil of small tubes about which are fitted fins of thin metal (Fig. 33). The high-pressure high-temperature refrigerant from the compressor enters the top of such a condenser and gives up its heat through the fins to an air stream. The air is blown over the condenser usually by means of a fan attached to the driving motor. This process cools the refrigerant and condenses it to the liquid state. It then runs by gravity to the receiver.

Water-cooled condensers usually consist of a steel shell or tank, inside of which is placed a coil or nest of tubing. Water is made to flow through the tubing, while the refrigerant flows into the shell at the top. This serves also as a receiver or reservoir for storage of the liquid refrigerant. Larger-sized water-cooled condensers are made with removable heads so that the water tubes can be uncovered for inspection and cleaning.

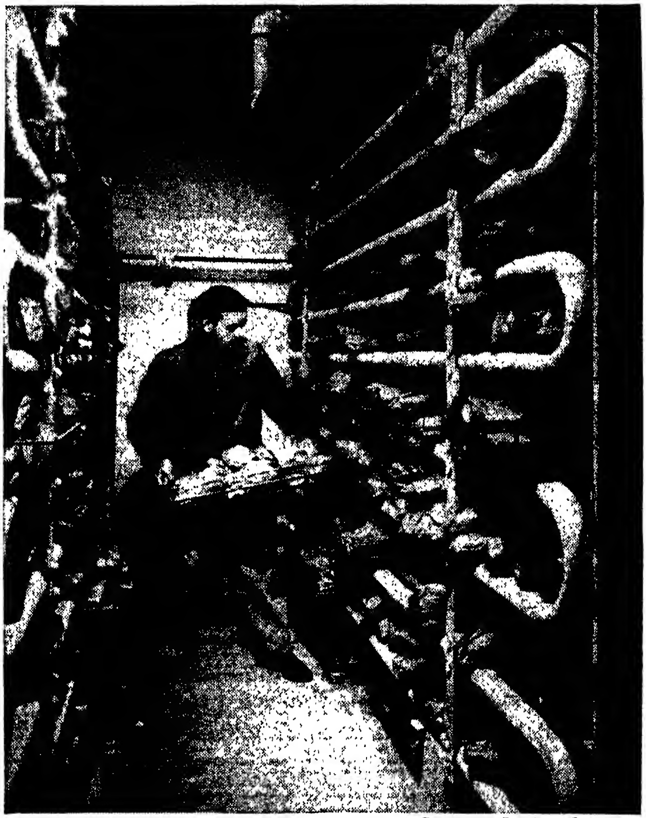
Evaporative condensers are often used where the quantity of refrigerant is too great to be condensed in an air-cooled condenser and where there is not an abundant supply of cooling water. The condenser proper consists of a bank of finned tubes similar to that of the air-cooled condenser, housed in a cabinet in such a manner that water can be sprayed downward over the finned tubes. The spray water is caught in a tank at the bottom of the cabinet and resprayed by means of a small pump. At the same time large volumes of air are drawn upward through the coil. This air is usually discharged to the outside, as it carries a good deal of water vapor. The operation of this type of condenser depends on the evaporation of a small part of the water that is sprayed over the coil. This evaporation process absorbs a great deal of heat in cooling and condensing the refrigerant inside the coil. Enough water must be added from an outside supply to make up for the evaporation. Such condensers require only 1.5 to 10 per cent of the amount of water demanded by water-cooled condensers. If the supply of air used for cooling is also drawn from the outside, there will probably be no need to use the spray in wintertime in cold climates. The cold air alone will suffice to do the cooling and condensing.

Evaporators. Many types of evaporators are available and can be made for the cooling of different kinds of refrigerated space. The most common are simple bare pipe coils. These are made of iron pipe or copper tubing, depending on the size of installation. Enough surface must be provided to care for the transfer of all the heat that must be removed from the space to the refrigerant. Most manufacturers recommend heat-transfer coefficients of 1.6 to 2.3 B.t.u. per square foot per hour per degree Fahrenheit for bare pipe coils with natural air circulation.[5] When the amount of heat to be removed, both from leakage and from freezing and cooling foodstuffs is known, the number of square feet of pipe-coil surface can be calculated. The coil or evaporator can then be made up accordingly.

Bare pipe-coil evaporators are most commonly made in one of two forms. For freezing space they are made (Fig. 34) of several pipes each, laid side by side and connected so as to permit the flow of refrigerant through them from an expansion valve. Arranged in this manner the evaporator pipes may serve also as shelves. Several such shelves or groups of pipe may be connected to one expansion valve. The evaporator serves to chill the space in which it is placed. At the same time foodstuffs placed on trays on the shelves are frozen more rapidly because of the contact than if they were placed in still air. For the refrigeration of large spaces, such as locker rooms, long banks of bare pipe, as in Fig. 44, are suspended from the ceiling over the aisles. These are connected to one or more expansion valves separate from the freezing space. Natural air circulation is depended on for conducting heat to the coils.

[5] *Refrigerating Data Book,* New York, American Society of Refrigerating Engineers, 1942.

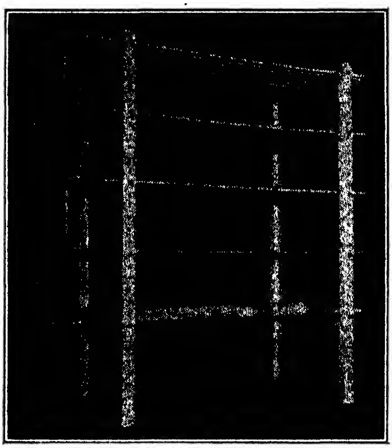
The plate type is another form of evaporator that is in wide use. This type consists essentially of a tube coil into which the low-pressure refrigerant flows from the expansion valve. However,



Courtesy Locker Operator

Figure 34. A locker-plant freezer equipped with pipe-coil evaporators constructed in the form of shelves. The packaged foods may be placed directly or in trays on the pipe-coil shelves for freezing.

the coil is wound flat to fit within a rectangle and is sealed between two sheet-metal plates welded or soldered at the edges, or the coil is formed in the sheet metal by stamping one of the plates (Fig. 35). Plate evaporators can be used not only to do the refrigerating but also as shelves in front-opening cabinets or as walls or spacers in top-opening cabinets. They are usually rated on the basis of 2 B.t.u. per square foot per hour per degree Fahrenheit. Both sides are considered to be useful when they are exposed to the cold space. In such plates the useful surface area is much greater than that of the tubing enclosed within. Use of the plate area instead of the tube surface is justified in making calculations because heat transfer from the sheet metal to the tubes is much better than that from air to the sheet metal.



Courtesy Kold-Hold Manufacturing Co.

Figure 35. Plate-type evaporators connected together and mounted in a stand form the shelves of a cabinet or walk-in freezer. These evaporators are made by stamping a sinuous groove in one plate which is then welded to a flat plate to form a continuous passage for the refrigerant.

Eutectic plates. Some plate evaporators contain a eutectic solution in the space between the cover plates surrounding the tubes and store up refrigeration in the form of ice which melts at a low temperature. For home-freezer cabinets the melting point of the solution would be designed, by the use of a suitable concentration of some salt in water, to be slightly lower than the normal space temperature. Such plates are used to safeguard against failure of the condensing unit or power failure. They only afford a limited amount of protection, proportional to the weight of eutectic solution. Such plate evaporators are also used to refrigerate trucks. The freezing of the eutectic solution and the chilling of the truck bodies are accomplished during the night at the main plant, where the plates are connected by means of flexible couplings to the main refrigerating system. Then, during the day, the refrigeration of the trucks is carried on by the eutectic ice in the evaporators.

Finned-tube coils. Other evaporator coils are made with finned tubes. These are copper, brass, or steel tubes on which have been pressed or wound a series of thin sheet-metal plates or fins. The fins are either soldered to the tube or pressed on in such a manner as to provide good heat conduction. Thus the fins serve to en-large or extend the heat-transfer surface. The finned tubes are arranged in banks and when used with a fan or blower are usually known as unit coolers. The added area of the fins is justified when forced circulation of air is used. With natural air circulation there is not much gain from the use of fins. The heat-transfer rate with fins and natural circulation is about the same as that of plain tubes. The chief gain comes in the form of space saving, as the surface area per linear foot of tube is materially increased by the fins.

Frost and defrosting. When moisture-laden air comes in contact with surfaces whose temperature is below the dew point, part of the moisture condenses on the cold surfaces. This is owing to the fact that cold air can support less moisture than can warm air; that is, vapor pressure is proportional to the temperature. If the cold surfaces are at a temperature below 32° F., the moisture that condenses forms frost. Hence, it is evident that all evaporator surfaces in frozen-food freezing and storage space will soon become coated with frost. Likewise, pipes carrying cold refrigerant will become frosted over if they are not insulated and vapor-proofed. In cold-storage space most of the frost formed comes from moist air admitted when doors are opened. Some comes from leakage through walls that are improperly sealed and some through poorly gasketed doors. Some of the moisture, however, may come from the foodstuffs stored or being frozen in the space.

In warm, humid weather there is a very great difference in vapor pressure and moisture content of the air within and without the cold-storage space. Under such conditions there is apt to be a very rapid growth of frost on evaporator coils. Also in all blast-type systems, where air is chilled by being blown over coils before being circulated for either freezing or cooling, a very rapid accumulation of frost is to be expected because of the relatively small surface area of the evaporator. In cold weather, especially in the northern states, the winter atmosphere is usually very dry, and there is then a proportionately smaller deposition of frost on coils. In every case, however, where frost accumulates on cooling coils the rate of heat transfer is reduced in proportion to the thickness of the frost covering, because the frost acts much as a blanket. It is filled with multitudes of air pockets where there can be little if any air circulation and heat conduction is poor.

This makes it difficult for heat to penetrate to the cold refrigerant. It is, therefore, necessary to remove the frost from time to time.

Defrosting by brushing or scraping. The frequency of removal of frost depends on the type of evaporator and its use. Pipe coils and plate shelf freezers are constantly defrosted to some extent in the process of loading and unloading. Nevertheless, this does not clear the surfaces completely, and it is desirable that all the frost be removed two or three times a year with a stiff brush or a blunt scraping tool or by means of hot gas (see below). The same applies to plate-type shelf freezers. Care must be taken not to puncture the relatively thin sheet metal of the plates in the process of scraping.

Pipe coil and plate evaporators used for cooling storage spaces should be defrosted at least often enough to prevent the formation of a layer of frost more than ¾ inch thick.

Defrosting finned coils. Nearly all blast-type coolers, whether used for freezing or for storage refrigeration, are made with finned-tube coils which become choked with frost very quickly. It is necessary to defrost them regularly at short intervals. The intervals may be as short as a day when in service such as the freezing of scalded vegetables in bulk, that is, unpackaged, or several days where there is less moisture present. The defrosting of this type of coil cannot be done by brushing or by scraping. It can be done best by means of water spray or hot gas, though some of the frost may be blown off the coils by the high-velocity air stream.

Water-spray defrosting involves the use of suitable spray nozzles that sprinkle tap water over the coils and their fins. This rapidly melts the frost, even though the tap water may seem cold to the touch. Adequate catch pans and drains must be provided. All water piping within the low-temperature space must be sharply sloped so that it will drain entirely free of water after each defrosting operation.

Hot-gas defrosting involves the circulation in the evaporator of warm refrigerant vapor directly from the compressor. The warm refrigerant thaws the frost near the coil surface. In some evaporators, such as the bare-pipe and plate types, that is sufficient, as the rest of the frost then falls off or can easily be knocked off in large pieces. In other types the defrosting must be continued with the hot gas until all the frost has been melted. With this method of defrosting adequate drip or collecting pans must be provided to catch the frost or water. Electric-heating elements are sometimes used to defrost finned coils.

Evaporator coils of all kinds used for refrigeration of space at temperatures higher than 32°F. usually defrost automatically during the "off" cycle of the compressor. If the "off" cycle is not long enough for complete defrosting, some provision must be made to care for this at regular intervals. The defrosting of household electric refrigerators is an illustration of the latter.

Controls. In the great majority of cases the basic control of automatic refrigeration is cared for by some temperature-sensitive device. The simplest of these is the thermostatic expansion valve.

The thermostatic expansion valve. Liquid refrigerant enters the device and is stopped by a needle or conical valve. This valve is held closed by a spring. It is opened by the pressure of a vapor generated in a bulb fastened to the outside of the suction line at a point where room temperature will have no effect (Fig. 33). The vapor pressure in the bulb varies with the temperature of the refrigerant in the suction line. And this pressure is transmitted through a capillary tube to a bellows in the expansion-valve housing. When the temperature of the refrigerant in the suction line is high, the vapor pressure in the bulb and bellows is also high. This pressure acting in the bellows opens the expansion valve. Refrigerant then flows out of the expansion valve to the evaporator. When the quantity of refrigerant reaching the evaporator equals or exceeds the amount being evaporated, the temperature of the refrigerant returning to the compressor will drop. This affects the temperature and consequently the pressure of the vapor in the bulb and bellows so that the expansion valve partially closes, reducing the flow. When the temperature of the refrigerated space reaches the desired point the temperature of the bulb will cause the expansion valve to be closed entirely.

Automatic expansion valves. Under certain conditions of operation the pressure of the refrigerant in the evaporator may be made to serve directly as the means of controlling the flow of refrigerant. This is accomplished by means of an automatic expansion valve. This type of valve differs from the thermostatic type in that it lacks the temperature-controlled bulb and bellows. Instead, there is an adjustable spring-loaded bellows within the valve housing which is acted on by the pressure of the expanded refrigerant.

If that pressure exceeds the value for which the valve is set, the valve is made to close, stopping the flow of refrigerant until the pressure in the evaporator drops once more. Since the automatic valve maintains a constant pressure in the evaporator, which means also in the suction line, a low-pressure control switch cannot be used to start and stop the compressor motor. A thermostatic control switch must be used. This works on the same principle as the thermostatic expansion valve, the bulb being located in a suitable place in the refrigerated space.

Close temperature control can be obtained with automatic expansion valves. But they are not suited to use in multiple installations, because the pressure produced in the suction line by one of the valves might affect adversely the performance of one or more of the others in the system. Furthermore, it would be impossible to use the thermostatic control switch under such conditions.

Pressure control switch. When the flow of refrigerant to the evaporator is stopped by the action of a thermostatic expansion valve or other control device and the compressor continues to operate, the pressure in the suction line drops rapidly. This acts on a secondary control located at the compressor motor. The secondary control is a pressure-controlled electric switch, which stops the motor when the suction-line pressure falls below a certain value and starts the motor again when that pressure is built up to a higher value. The starting of the motor is accomplished by the joint action of the two controls. When the temperature of the refrigerated space, and consequently of the thermostatic bulb, rises to a certain point, the expansion valve opens and permits the flow of refrigerant to the evaporator once more. This builds up the pressure in the suction line, and the pressure control switch starts the motor. The motor and compressor then continue to function until the temperature goes down to the proper point, when the suction-line pressure once again falls and causes the motor to stop.

High-pressure cutout switch. Many other types of control device are in use. They are nearly all based on the foregoing principles, however. Some compressors are fitted with a high-pressure cutout switch in addition to that already mentioned. This prevents the compressor running if something is wrong in the system and the discharge pressure becomes too high. It is merely a safeguard.

Solenoid valves. In some systems it is necessary to close off one or more parts of the system from time to time while other parts continue to carry on refrigeration. This is frequently done by means of temperature-controlled electromagnetic valves, known as solenoid valves. The needle valve closes by the action of gravity when the electromagnetic circuit is broken. When the electromagnet is energized, the valve opens all the way. Such a valve is sometimes used in conjunction with a thermostatic expansion valve and very often with automatic expansion valves to insure that no liquid refrigerant will flow into the evaporator during the "off" cycle of the compressor. Solenoid valves require the use of thermostats to control their opening and closing.

Multiple temperature control. The diagram in Fig. 36 illustrates the application of several of these controls to an installation, such as a locker plant, having three spaces refrigerated at different temperatures. The aging or holding room is kept at a temperature between 35° and 40°F. The locker room, in which frozen food is stored, is kept at 0°F. And the small room or cabinet in which freezing of foodstuffs is carried on is kept at a temperature somewhat lower, as −10°F.

Liquid refrigerant is supplied through a small line to the three thermostatic expansion valves marked *T*. However, as thermostatic expansion valves do not always close positively, there are placed ahead of them in the liquid lines three solenoid valves *S*. These solenoid valves are opened and closed by means of room thermostats *R* in the respective rooms. When the temperature of one or more of the rooms rises above the limit for which the thermostat is set, the corresponding solenoid valves are opened. These admit liquid refrigerant to the expansion valves, which, under such conditions would also be open. They in turn admit it to the evaporators.

The pressure in the evaporators determines the temperature of the refrigerant. In the two colder spaces this should be somewhat below −10°F. The forced-air blast in the freezer will cause the air to be chilled to very near the temperature of the refrigerant. However, the natural circulation of air in the locker room will produce, in most installations, an air temperature of about 0°F. with a refrigerant temperature 5° to 15°F. lower. Therefore, the evaporators in these two rooms should be held at about the same pressure, namely, that to produce a temperature of −12°F. or so.

Thus they can both be connected directly to the suction of the compressor.

The evaporator in the aging room, however, should be supplied with refrigerant at a much higher temperature, say 20° to 25°F., in order to avoid too great a temperature difference between the air

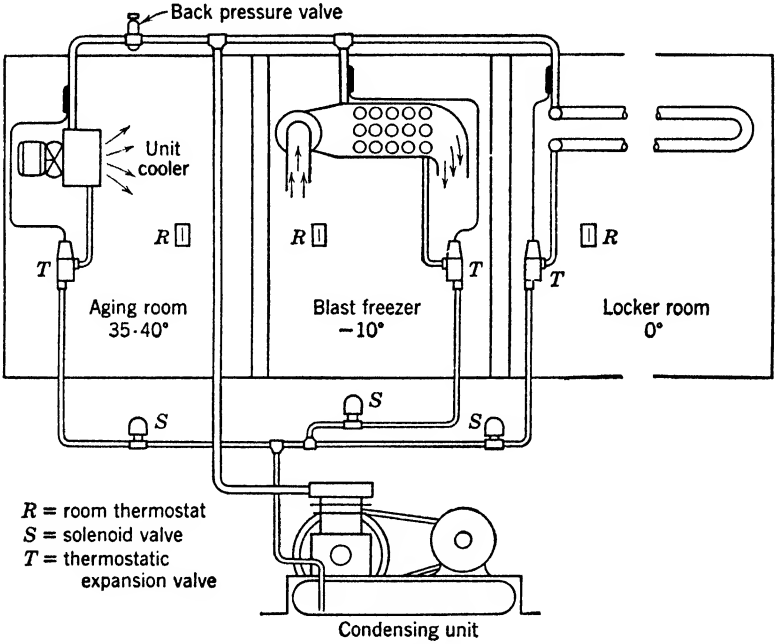


Figure 36. The piping diagram for the control of different temperatures in three rooms refrigerated by the same condensing unit.

and the refrigerant. Since the refrigerant from this evaporator must eventually return to the compressor serving the other rooms, a *back-pressure* or *suction-pressure control valve* must be inserted in the line between the evaporator and the compressor. This is an adjustable pressure-controlled valve which permits flow of refrigerant from the evaporator only when the pressure in the evaporator exceeds a certain value. The valve is adjusted in this case for the proper pressure and consequently the proper temperature to carry on refrigeration in the aging room.

The operation of the system shown in Fig. 36 is as follows. When the temperature in all three spaces is satisfied, the three solenoid valves will be closed by their respective thermostats. The compressor will rapidly pull the pressure in the suction line down to the point where the pressure control switch, mounted on the compressor, will shut off the motor. When heat load in any part of the system causes the temperature in that part to rise above the upper limit of the thermostat setting, the solenoid valve to that part will open. This permits the flow of refrigerant to the space evaporator. There it evaporates and flows on into the suction line, causing the pressure to rise and start the compressor. The system is thus put into operation. While the compressor is running, the remaining parts may also demand refrigeration. Or one or more parts of the system may be satisfied. However, the compressor will continue to run until all parts are satisfied.

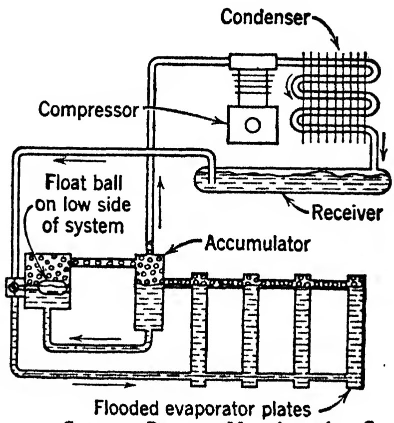
Evaporator operation. Liquid refrigerant drawn into a compressor along with the returning vapor is liable to cause mechanical injury. It is necessary, therefore, to guard against such liquid slugging. One method, the dry expansion system, controls the flow of refrigerant to the evaporator so that it is entirely evaporated and somewhat superheated by the time it reaches the compressor. Another method, the flooded system, permits the refrigerant to flow at such a rate that some liquid may leave the evaporator with the vapor. This liquid must then be separated from the vapor before the compressor is reached.

Dry expansion system. Thermostatic or automatic expansion valves are generally used in this system to control the flow of refrigerant to the evaporators. The valves are adjusted to permit complete evaporation and about 10° of superheating by the time the refrigerant leaves the evaporators. Superheating is the adding of heat to a dry vapor to raise its temperature above the boiling point.

Connections for such a system are best made with the inlet for liquid refrigerant from the expansion valve at the top of the evaporator. The liquid then runs by gravity toward the bottom, absorbing heat and vaporizing as it goes. In a properly functioning system the refrigerant will be entirely evaporated by the time it reaches the bottom of the coil or evaporator. The superheating is usually made to take place in the last portion of the evaporator. From that point the suction line carries the refrigerant back to the compressor.

If compressor lubricating oil is carried along with the refrigerant, as is often the case, this arrangement of connections allows it to drain downward with the refrigerant in the evaporator. Eventually it is carried back to the compressor where it separates from the refrigerant and returns to the crankcase. Where refrigerant is permitted to enter the evaporator at the bottom, there is a possibility of oil being trapped in the evaporator. This impairs heat transfer and at the same time depletes the oil supply in the compressor crankcase and should, therefore, be avoided.

Flooded system. In many large installations a flooded evaporator system is used. This means that the evaporator coils are filled with liquid refrigerant, except for the bubbles produced by vaporization. The action of this type of evaporator is to discharge a mixture of liquid and vapor from the outlet end. It is necessary in such a case to use a surge tank or accumulator into which this mixture can flow. There the vapor separates from the liquid. The vapor is drawn off by the suction of the compressor, while the unevaporated liquid returns to the evaporator. This system uses a liquid float valve in place of an expansion valve of the usual type. Such a valve admits liquid refrigerant, with a reduction of pressure, until the level of the liquid in the accumulator is at the proper height. This valve is known as a low-side float control valve, because the float is in a low-pressure region. When the proper temperature in the refrigerated space is reached, no further evaporation of refrigerant takes place, and the pressure in the suction line drops to the point where the pressure control causes the compressor to stop. Figure 37 shows an elementary system of this type.



Courtesy Brunner Manufacturing Co.

Figure 37. An elementary flooded refrigeration system controlled by a low-side float valve.

Other modifications of the float valve are in use. One is known as the high-side float control valve. This uses a float in the liquid receiver under high pressure which permits the flow of liquid to the evaporator, but closes when the liquid level drops to a point where high-pressure vapor might flow. The evaporator in this system is also flooded and must be provided with a suitable space in which the vapor and liquid can separate before the vapor enters the suction line. This type of system can only have a certain definite amount of refrigerant charged into it. Otherwise there would be a tendency for the compressor to draw liquid into the suction line along with vapor.

Auxiliary equipment. The presence of any moisture in a refrigeration system is liable to cause much trouble. It may collect and freeze in the narrow passages of the expansion valve, partially or completely choking the flow of refrigerant. With certain refrigerants, moisture can form corrosive compounds which destroy the valves of the compressor or other parts. To prevent trouble from moisture, therefore, very great care should always be used in preparing a refrigeration system before the refrigerant is put into it. This consists in pumping out all air and moisture with a vacuum pump. Then, as an added precaution, it is good practice to put a *drier* or *dehydrator* in the system. This is simply a small cylinder with connections at each end that is placed in the liquid line between the receiver and the expansion valve. The cylinder is filled with dry calcium chloride or some other drying agent. All the refrigerant flows through the drier, and any water which may be mixed with the refrigerant will be absorbed by the drying agent and held there.

Fine wire-mesh *strainers* are usually included in the construction of expansion valves on the inlet side. If there is none in the valve, one should be provided to prevent any solid particles from entering and clogging the small passages of the valve.

In many cases it is desirable to warm the refrigerant in the suction line slightly to insure against liquid being carried back to the compressor. At the same time it is advantageous to chill the liquid refrigerant on its way to the expansion valve. These two things can be accomplished easily by the use of a *heat exchanger.* A heat exchanger can be made quite easily by soldering several feet of the liquid supply line to the suction line in small installations, or a commercial unit may be installed.

Oil separators are sometimes installed to trap and return to the crankcase any lubricating oil that may be carried out of the compressor by the refrigerant. In small installations this is usually omitted, but the piping and the arrangement of the evaporator coils are made in such a manner that any oil that leaves the compressor will collect at a low point in the suction line. Then the rapidly moving refrigerant vapor returning to the compressor carries the oil back with it. A connection is provided in the compressor from the suction opening to the crankcase.

Condensing units are always equipped with several *shutoff valves*. On both the suction and discharge sides of the compressor are located *back-seated valves* like the ones shown in Fig. 33. All such valves have screw caps, which, when screwed down tight, prevent leakage of refrigerant and tampering with the valves. Such valves have three openings, *a, b,* and *c,* and the valve stem can be turned to close the passage through either *b* or *c*.

If refrigerant is to be added to or removed from the system, connection is made to the opening *c*. This would be done on the suction-side valve for adding refrigerant. For removing refrigerant, connection *c* on the discharge-side valve would be used. In addition to the two afore-mentioned valves on the compressor, there are usually two similar valves on the receiver, one at the inlet and one at the liquid outlet. It is usually not necessary to have other valves in a simple small refrigeration system. However, in larger and more complicated systems it is advisable to have hand valves of the diaphragm packless or other refrigeration type located at points controlling different parts of the system. It is then possible to close off one part of the system or another for repairs, without interfering with the whole system.

Gages. In large refrigeration systems it is most desirable to have gages connected to both the suction and discharge lines to show at all times the conditions of operation. In small systems, although it would be desirable also to have such gages, it is usually not of sufficient importance to warrant that added expense. A check by a competent refrigeration service man at the time of installation and at any time when operation does not seem to be correct should be ample.

Temperature recorders. All large refrigeration storage systems, especially for frozen foods, should be equipped with some type of temperature-recording device. Such a device has a clockwork, either electric or mechanical, that rotates a chart once in a certain period of time, usually 7 days. The temperature in the storage or other space acts on a fluid in a bulb which is connected to the recording device by means of a capillary tube. The pressure variations in the fluid act, in turn, to move a pen over the chart in proportion to the temperature variations. Thus a continuous record of temperature is made. Such a record serves as a check on the operation of the refrigeration system. And at the same time it can serve as positive evidence of proper operation if any question arises. In some states law requires that such a temperature-recording device be applied to the locker rooms in locker plants.

Chapter 14

THE FREEZING PROCESS

Although there are numerous devices and types of equipment especially designed for the freezing of foodstuffs, there is only one process involved in them all, the continued removal of heat from the foodstuffs until a temperature of about 0°F. has been reached. In the process of chilling the foodstuffs to that temperature a change of state from the unfrozen to the frozen takes place.

The freezing process. The first step in the process is one of cooling the material down to the freezing point, which involves the removal of heat in a quantity roughly approximating one British thermal unit per pound of food per degree drop in temperature. This phase starts out quite rapidly because of the relatively large temperature difference between the warm food and the cold refrigerating medium or refrigerated surface. As the temperature of the food approaches more nearly to that of the refrigerating medium or surface the rate of heat transfer slows down. In time, however, the temperature reaches the freezing point of the foodstuff, and freezing commences.

Throughout the time that freezing is progressing, the temperature of the commodity remains practically the same. During this time an amount of heat, known as the latent heat of fusion, must be removed. This varies from as little as 22 B.t.u. per pound for dried beef to about 144 B.t.u. per pound, or the latent heat of water, for vegetables or fruits with a high water content. When the whole piece or package of foodstuff has frozen, the temperature will continue once more to drop. As long as the foodstuff is left in contact with the freezing medium or surface, its temperature will continue to drop until it reaches that of the refrigerant. Table 21 lists the specific heats of various foods before and after freezing, as well as the latent heats of fusion of the same foods. The specific heat of a substance is the amount of heat that must be added or removed in order to change its temperature one degree Fahrenheit.

TABLE 21. SPECIFIC AND LATENT HEATS OF FOODS

Foodstuff	Specific Heat, B.t.u./lb.		Latent Heat of Fusion, B.t.u./lb.
	Before Freezing	After Freezing	
Asparagus	0.95	0.44	134
Berries	0.89	0.46	125
String beans	0.92	0.47	128
Cabbage	0.97	0.47	130
Carrots	0.87	0.45	122
Green peas	0.80	0.42	108
Fish	0.82	0.41	105
Oysters (shelled)	0.90	0.46	124
Bacon	0.55	0.31	30
Beef, lean	0.77	0.40	100
fat	0.60	0.35	79
dried	0.34	0.26	22
Mutton	0.81	0.39	96
Poultry	0.80	0.41	90
Pork	0.60	0.38	66
Veal	0.71	0.39	91
Eggs	0.76	0.40	98
Milk	0.90	0.46	124
Water	1.00	0.53	144

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Heat removal in freezing. It is possible to calculate how much heat must be removed from a pound of any of the foodstuffs listed in order to freeze it, if the initial temperature, the freezing point, and the storage temperatures are known. A formula expressing this would be

$$Q = W[c_1(t_1 - t_f) + h_f + c_2(t_f - t_s)]$$

where Q is the total amount of heat that must be removed from W pounds of the food, c_1 and c_2 represent the specific heats of the food before and after freezing, respectively (Table 21), t_1, t_f, and t_s represent the temperatures before cooling, at the freezing point, and at the end, respectively, and h_f represents the latent heat of fusion. If, as an example to illustrate this, a 2-pound package of shelled oysters at 55°F. is to be frozen and chilled to 0°F., heat must be removed to the extent of 0.90 B.t.u. per degree per pound from 55°F. down to the freezing point, or about 30°F. This quantity of heat is $(55 - 30) \times 2 \times 0.90 = 45$ B.t.u. Following this, the latent heat of fusion, or 124 B.t.u. per pound, must be removed. And last the frozen oysters must be chilled down to zero from 30°F. by the removal of 0.46 B.t.u. per degree per pound. This latter amount will be $(30 - 0) \times 2 \times 0.46 = 27.6$ B.t.u. The total heat removed during the process is then the sum of the three quantities, or $45 + 248 + 27.6 = 320.6$ B.t.u. for the two pounds, or 160.3 B.t.u. per pound. Per pound this is equivalent to chilling one pound of water from 33.4 to 32°F., freezing it, and further chilling it down to 0°F.

The freezing curve. This process is shown graphically in Fig. 38. In the diagram the temperature variation within a pack-

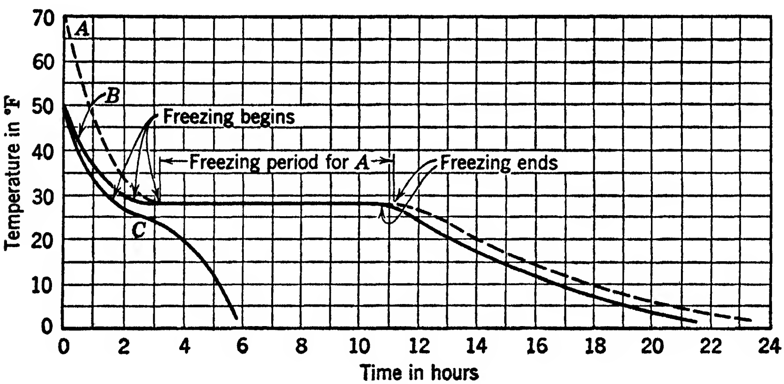


Figure 38. Typical freezing curves. These curves show the rate at which the temperature of the food falls when the food is subjected to different methods of freezing.

age of foodstuff is shown plotted against the time required for the changes to occur. The dotted curve marked *A* shows the history of a package of food at 70°F. that was placed in the freezer. The solid curves marked *B* and *C* show the history of two packages that were already cooled to about 50°F. before being placed in the freezer. In the three cases it can be seen that the temperature starts falling quite rapidly, as shown by the steepness of the curve. The rate of cooling, however, slackens as the temperature drops. This is owing to the fact that heat flows out of the foodstuff at a rate proportional to the temperature difference between it and the cold body which is absorbing the heat.

As the temperature gets to 32°F., moisture on the surface of the food and on the inside of the package begins to freeze. The rate of temperature drop now falls off very rapidly until at the freezing point of the foodstuff the curve becomes approximately a straight horizontal line for slow-freezing rates. This indicates that little change of temperature is taking place while the latent heat of fusion of the food is being removed, that is, while freezing goes on. However, when freezing is carried on at a very high rate, a curve like that marked *C* in Fig. 38 results. Here the temperature tends to drop continuously, though the rate of drop is slowed during the actual freezing. In either case the freezing point of the foodstuff tends to drop during freezing as water is frozen out of solutions, and greater concentrations of salts or sugars result. This shows up more markedly in the fast freezing, curve *C*, which never becomes horizontal, than in the slow freezing, curves *A* and *B*. The flattened portion of the curves is a measure of the actual freezing time for the food under the particular conditions involved.

When the temperature begins to drop sharply once more, it is an indication that the food is frozen to the core. From this time on the temperature will continue to drop, always at a progressively slower rate because of the diminishing temperature difference, until the food temperature is the same as that of the refrigerating body. Because the cooling process after freezing is slow and represents the removal of only a small amount of heat, it is common practice in commercial freezing, though not always desirable, to remove the foodstuffs from the freezing space to the storage space at or shortly after the end of the freezing period. In some systems a tempering chamber is provided for the final chilling down to the storage temperature.

Effects of freezing. There is a certain diversity of opinion as to exactly what happens within a package of foodstuff when freezing first occurs. There is little question but what most of the moisture present as such freezes in the form of ice crystals.

In most packages some air will remain in the form of voids between the wrapping material and the food or between portions of the food. In the freezing process moisture from the warm food will migrate through these voids as vapor, to the inside surface of the wrapping which is chilled first. There it will condense and freeze like frost. Usually a considerable amount of this frosting occurs in the case of produce such as fish, poultry, and vegetables that have been subjected to washing before being packaged. If the chilling is rapid, much of the free moisture will freeze right where it is. When the surface water has frozen, the temperature of the package contents will proceed to drop below 32°F. to the point where the plant or animal matter begins to freeze because solutions of salts or sugars have freezing points lower than that of pure water.

In relatively weak solutions the process of freezing results in the formation of pure ice crystals first. This increases the concentration of the remaining solution and lowers its freezing point progressively to the eutectic point where all the liquid that remains unfrozen freezes solid. In some cases, however, the eutectic point may be below 0°F., with the result that some liquid may remain unfrozen, as, for example, a heavy sirup. Most of the freezing process takes place in the range of 28° to 30°F. This accounts for the fact that the temperature–time lines in Fig. 38 remain nearly horizontal for a considerable period of time. The relatively small quantities of more highly concentrated solution freeze after the final temperature drop begins and after the foodstuff appears to be solid, provided the temperature is carried low enough.

The *ice crystals* formed within the substance of the foodstuff may be either within or between the cells. The crystals will be larger or smaller, according to whether the freezing rate is slow or fast. It is thought by some that the ice crystals puncture the cell walls. Whatever the exact nature of this part of the process may be, it results in a partial breakdown of the structure of the food. This, in turn, manifests itself when the food is thawed. Fruits and vegetables that were firm and crisp before freezing become somewhat flabby. All foods, if cut or sliced, tend to lose more of their juices on thawing than they would during the normal handling of such foods without freezing and thawing.

Microscopic appearance. The illustrations, Figs. 12 to 15 (pp. 90, 91), and in the studies of Hiner, et al.,[1] show clearly that there is a marked difference in microscopic appearance of foodstuffs frozen at different rates. However, it appears that, whereas the frozen product shows marked differences, in most cases the ready-to-eat or ready-to-cook food has returned to a condition that is nearly the same in appearance for all rates of freezing.

Dehydration during freezing. During the freezing process dehydration may occur, with its attendant bad effects on the quality of the foodstuff. Because, in the process of freezing, the temperature of the foodstuff is always higher than that of the freezing medium or body, the water-vapor pressure in the space immediately surrounding the foodstuff is higher than that of the air at near-refrigerant temperature. Whenever there is such a vapor pressure difference, the water vapor tends to migrate to the colder body where the vapor pressure is lower. There it condenses, and, in the case of subfreezing temperatures, freezes in the form of frost. This process will be most marked in the early stages of the freezing process, because the temperature differences are greatest at that time.

Foodstuffs that are frozen without being packaged show a very marked drying out of the surface, commonly called freezer burn. Foods that are wrapped in poor materials through which water vapor can pass readily show effects almost as bad as though there were no wrapping. Foods wrapped or packaged in the best or most moisture-vaporproof materials show some of this effect if there are air pockets or voids between the food and the packaging material. There the packaging material acts as the cold body, and the moisture evaporates from the food and is deposited as frost on the inside of the wrapping. However, if air is excluded and the packaging material is made to fit closely against the food at all points, or if the food is packed with some liquid in a can or carton so that there is no air space immediately adjoining the product itself, there will be little if any of the migration of moisture which causes dehydration or desiccation. The air space within a cleaned chicken that is wrapped whole and frozen has

[1] R. L. Hiner, L. L. Madsen, and O. G. Hankins, Histological characteristics, tenderness, and drip losses of beef in relation to temperature of freezing, *Food Research* **10**, 312 (1945).

no harmful effects from the standpoint of desiccation, but does lead to oxidation and rancidification of fat in the abdominal cavity.

Dehydration during storage. After the freezing process has been completed and the temperature of the foodstuff is the same as that of the storage space, it would seem that there should be no further tendency for moisture migration with consequent dehydration. However, this is not the case, for it is practically never possible to maintain perfectly constant temperatures in the storage space. Temperature fluctuations occur as a result of the fact that the compressor does not run all the time. During the idle periods the temperature of the storage space rises to the point where the thermostatic control demands more refrigeration. The temperature of the stored foods will also follow this rise, though more slowly. Then the compressor starts once more, and the refrigerating surfaces are chilled well below the temperature of the air and foodstuffs. There is then a temperature difference such as existed during the freezing process which results in a further moisture migration process on a small scale. This process is repeated at intervals, sometimes frequently each day. In the course of a long period of storage a considerable amount of moisture, even though it is in the frozen state, will undergo migration from the foodstuff either to the evaporator, if the packaging material is poor, or to the inside surface of the wrapping. This may result in a serious amount of desiccation where the packaging material is poor or where packaging is done carelessly. Radiation also leads to temperature differences, and, hence, moisture migration even where fluctuation of temperature may be eliminated.

Elimination of dehydration during storage. Eliminating the temperature fluctuations and minimizing the temperature difference between air and refrigerant would be the solution, in a large measure, for this particular problem. This can be done by keeping the refrigerating machinery in operation continually and controlling the amount of refrigeration to the point where it is exactly equal to the load at all times. In very large plants this is actually done. Several compressors are installed, and one or more are kept in operation continuously, according to need. However, in plants as small as most locker plants this becomes impractical. It is necessary to install compressors capable of handling the heaviest loads that may occur. The cost of installing a battery of two or more compressors of such sizes that one or more can be kept running at all times is prohibitive for such small plants. It becomes necessary then to install one compressor that is large enough alone or two that can handle the load together. The disadvantage of relying on two for maximum load conditions is that a breakdown of one would then leave the plant with insufficient refrigeration at a time when it was most needed. Even with two machines to carry the load, it is probable that under normal operating conditions they would not be called on to run continuously. There would then occur the temperature fluctuations previously mentioned.

In the case of home freezers it is, of course, altogether impractical to use more than one compressor. The inevitable result is temperature fluctuations accompanying the cycling—alternate periods of working or standing idle. These fluctuations may be kept within a small range by adjustment of the thermostatic control. When the range is made very small the compressor is forced to start and stop many times a day (short cycling). This adds appreciably to the power consumption and increases the wear on both motor and compressor. A happy mean must be struck, therefore, with a moderate temperature range for the controls and, consequently, a moderate number of cycles per day. Large heat-transfer surfaces or evaporators will result in small temperature differences between refrigerant and air, which, in turn, reduce the vapor-pressure differences and tendency towards desiccation.

Best form of protection. The major protection against desiccation must lie in the manner and type of packaging, not only for home unit storage but also for storage in locker plants and commercial warehouses. This is so for the larger plants for various reasons. Most locker plants cannot maintain perfectly constant temperatures. In large commercial ventures, even with constant storage temperatures in the original storage space, the frozen foods are bound to encounter different temperatures in the course of transportation from wholesale to retail storage, and so on.

Heat removal. Heat transfer takes place in three general ways: *conduction, radiation,* and *convection.* Conduction is the transfer of heat from one body to another or from one part of a body to another by direct passage through the material from particle to particle. An object placed in contact with a warmer one would receive heat by conduction through the points of actual contact.

If, however, the object were placed at some distance from the warm body it could not receive heat by conduction. But the warm body would send some of its heat to the cold body by radiation. This is similar in form to the transfer of light from a source. Heat radiation passes from the source to other bodies in straight lines and may be stopped by the interference of other bodies or objects between as a screen stops light. Radiation causes heat transfer only in small quantities at low temperatures and with small temperature differences, but may play a significant role in "cavity ice" or frost formation within the frozen-food package during prolonged storage.[2]

When the warm and cold bodies are separated, the third form of heat transfer may come into play. Air surrounding the warm body, being heated by contact or conduction, becomes lighter or less dense and rises, while air surrounding the cold body is similarly cooled and settles downward. If the two bodies are in an enclosed space, this process will produce a circulation of air called convection. The cooled air moves toward the bottom of the warm body to replace the warmed air that rises, and the warmed air moves to the top of the cold body to replace the cooled air that settles downward. Thus, heat is transferred from the warm body to the air and from the air to the cold body. Convection can be carried on similarly in all fluids, whether liquid or gaseous. Immersing a cold body in a pan of water over a fire results in just such a process. Water cooled by the cold body sinks, to be heated by the hot pan, while the already warmed water flows in to take the place of that which was cooled. Thus heat is carried from the hot pan to the cold body by convection, while the heat moves to or from the water by conduction.

In the freezing process various of the foregoing or combinations of these three methods of heat transfer take place. One method used commercially for freezing foods is immersion in an ice and salt bath. The brine produced in this manner is at a temperature well below that of freezing water, and may be as low as 0°F. or lower. Thus foods immersed in such a mixture would very readily give up heat to the solution by conduction, while the low temperature of the solution would be kept constant or nearly so by convection as long as there was ice present. This means of chill-

[2] C. I. Sayles, W. A. Gortner, and Frances Volz, Frozen food packaging: a preliminary study of cavity ice. *Food Freezing* 1, 430 (1946).

ing foods is one of the best, if not the best, from the point of view of rapid heat transfer. It has certain disadvantages, however, that are discussed in Chapter 17 under commercial methods of freezing by immersion.

More commonly, the heat removal in the freezing of foods is accomplished by some conduction through partial contact, together with some convection. Such is the case where packaged foods are laid on a refrigerated surface. Heat passes by conduction at the points where the two bodies are in contact. At the same time air warmed by the relatively warm package of food rises and gives way to air chilled by the cold surface. As the surface of contact is usually small, most of the heat transfer must take place by convection. It is advantageous, therefore, to arrange for as great a circulation of air as possible. Spaces should be left between packages, and packages should not be stacked directly on each other if at all practicable. A common arrangement for freezing by this process is the use of shelves consisting of pipe-coil or plate-type evaporators as described in Chapter 13. The spaces between the pipes of the pipe-coil shelves permit ready circulation of air and so promote natural convection currents.

Effect of air in motion. Heat transfer varies with the rate of circulation of air. In the case of flat plates or surfaces heat transfer varies almost directly as the air velocity over the surface. For example, the rate of heat transfer would be nearly doubled if the air velocity was doubled. When banks of pipe or tube are used with four or more rows, the heat transfer varies a little more rapidly with the air velocity.[8] It is evident then that imparting velocity to the air that is to carry the heat from one body to the other will increase the rate of heat transfer. Therefore, the installation of fans or blowers has become more and more common. Simple, household-type fans placed in a freezing room will help slightly. However, the air velocity obtained in this manner is not uniform in different parts of the room, and may not be of great enough magnitude to accomplish much. A better though more expensive arrangement is that of using motor-driven blowers of considerable power in conjunction with banks of tube evaporators. These can be installed in such a manner as to blow chilled air over

[8] *Refrigerating Data Book,* New York, American Society of Refrigerating Engineers, 1942.

every part of every package placed in the freezing chamber. Such an arrangement is to be found in a blast freezer.

Desirable freezing rate. The preceding discussion of the freezing process has taken no account of the actual time required to freeze. The curves *A* and *B* in Fig. 38 indicate that the food was frozen in that particular case in about 8 hours after its temperature reached the freezing range. It was in the freezer for a considerably longer period, for somewhere around 3 hours were required to bring the temperature of the food down to the point where freezing actually began. This preliminary period cannot be avoided, and, therefore, should be included in almost every case in the so-called freezing time. Hence the freezing time of the illustrated article was not 8 but 11 hours more or less. If it is desired to keep the foodstuffs in the freezing space until their temperature is down to or nearly to that of the storage space as much as 8 to 10 hours more might be required, as in the slow-freezing case illustrated, making a total of around 18 or 20 hours.

For the home freezer such a prolonged period might be quite satisfactory. The chilling period of 3 hours more or less would probably meet the requirements set up in connection with bacterial growth. Chilling the processed foods to as low a temperature as possible before packaging will reduce the length of time before the foodstuffs reach the freezing point. The over-all period of 18 to 20 hours will probably fit in quite well with the normal use of such a home unit, as the homemaker should rarely plan to place more than one batch of foodstuffs in the freezer per day. The batch placed in the freezer should be limited to the maximum amount designated by the manufacturer. Otherwise, if an excessive amount is placed in the freezer at one time, the preliminary chilling time may become so long that injurious bacterial growth, enzyme activity, and other deteriorative effects may take place before freezing can begin. Overloading with food to be frozen may also overload the condensing unit and cause the temperature in the storage compartments to rise above normal, with possible bad effects on frozen food already stored.

Economics and the freezing rate. In large-scale commercial freezing of food and even in freezing in the locker plant the time element enters the picture from the point of view of economics as well as that of quality of product. Actually, as has been pointed out in Chapter 6, freezing in a period as short as 12 to 14 hours may be rapid enough for good quality, provided that proper handling and processing have preceded the freezing process. However, in large plants, a freezing time no less than 12 hours would mean that the freezing equipment would have to be large enough to accommodate at one time one half the total foodstuffs processed per day. A reduction in freezing time to one half of this would, obviously, reduce the required amount of freezing equipment to one half. And a further reduction in time would still further reduce the size of equipment. Hand in hand with such reduction in size of equipment would go the initial cost or overhead of the plant. To attain high rates of freezing with consequent reduction in cost of installation, very low temperatures or high air velocities or modifications of the immersion method are variously used. These are discussed in some detail in later chapters.

Practical freezing rates. The results of tests [4] on samples of meat under various conditions of temperature and air velocity have made possible the plotting of the curves shown in Figs. 39 and 40. These are the results of such a limited number of tests that they cannot be construed as absolutely correct, but they are certainly indicative and can probably be used with a fair degree of accuracy in predicting the freezing rates of packaged meats. In these results the freezing rate was expressed in terms of the distance that freezing penetrated into the meat in inches per hour, measured by inserting a number of thermocouples into the meat samples at known depths from the surface. The temperature variation of each point was then recorded from potentiometer readings taken at frequent intervals of time. From this record the rates were calculated.

Figure 39 shows that freezing penetrates into a piece of meat at a rate almost directly proportional to the temperature difference between the air and the meat at or near the freezing temperature. It is interesting to note that the curve, if extended, would show a zero rate of penetration at about a temperature of 32°F., as should be the case. Figure 40 shows that freezing progresses with zero air velocity (measured velocity did not include natural convection) at about the same rate as that shown for the temperature of −6.1°F. in Fig. 39. But with increasing velocities of

[4] J. R. Donnalley, Jr., Performance characteristics of commercial home freezers, *Cornell Univ. Eng. Expt. Sta. Bull.* 34 (1944).

air the rate of penetration is seen to increase rapidly. The velocities indicated on this graph were not measured directly at the meat sample, and, therefore, only show the relative increase in freezing rate.

An illustration of the use of these freezing-rate factors may make them clearer. A package of meat measuring 2.5 inches at

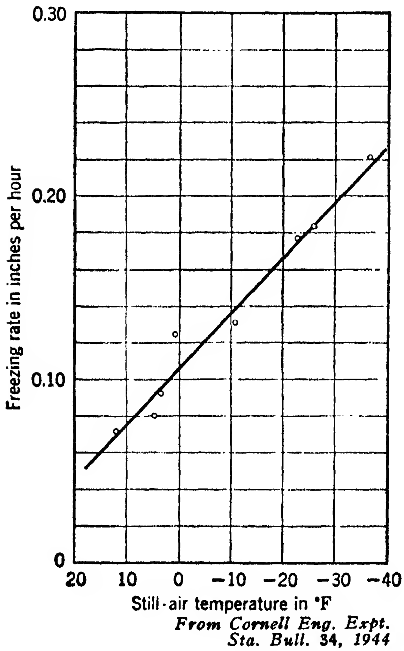


Figure 39. Variation of freezing rate with temperature of still air.

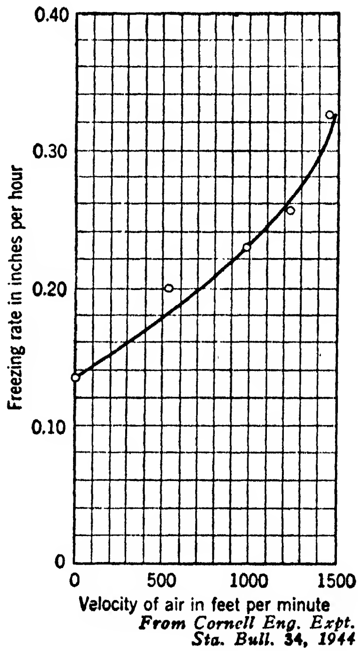


Figure 40. Variation of freezing rate with velocity of air at about −6.1°F.

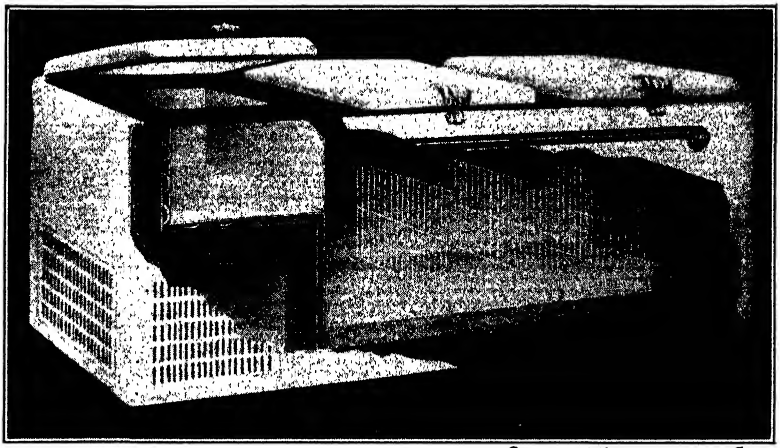
the thickest point, placed in still air in a freezer with air temperature of −20°F., might be expected to freeze at a rate of 0.167 inch per hour. This is assuming that the package is exposed to air on all sides. The maximum depth of penetration would then be half of the 2.5 inches or 1.25 inches, and the time necessary for complete freezing would then be 1.25 divided by 0.167 or 7.5 hours. At an air temperature of −6.1°F. the rate would be about 0.13 inch per hour, making a total time for freezing of 9.6 hours. Were the air velocity to be increased to the order of 1200 feet per minute with the same air temperature, the rate would be doubled and the time halved. And if the air velocity were to be increased to approximately 1600 feet per minute the rate would be tripled and the time cut to one third of the still air time, or 3.2 hours.

Air in motion versus low temperatures. The use of very low temperatures has the serious disadvantage that the compressor must operate in a pressure range where its performance is not very efficient. The lower the suction pressure the less efficient the compressor becomes. Also, the lower the temperature, the more insulation is needed, or else the more heat leakage will occur. Hence, it would appear that the better way to obtain rapid freezing rates is by means of air in motion at moderately low temperatures. Actually this is common in commercial freezing.

Chapter 15

FREEZING EQUIPMENT FOR THE HOME

Freezing equipment for farm and home use includes everything from the smallest units, intended merely for the storage of small quantities of frozen foods to large-capacity walk-in storage spaces having special provision for freezing as well as storing frozen



Courtesy Victor Products Corp.

Figure 41. Cutaway view of a typical top-opening home freezer. The outside shell of sheet metal serves as the vapor barrier. A coil of tubing surrounds the liner and provides the necessary refrigeration. The condensing unit is housed in the well-ventilated space at the lower left, while directly above is the freezing compartment.

food. Also, included in this category are the dual-temperature refrigerators, that is, refrigerators having both storage space above freezing for fresh foods and some space at a temperature below freezing for the storage of frozen foods. All these have in common a construction such as that specified in Chapter 12. This includes an outside shell with some means of preventing water-vapor infiltration, suitable insulation, and an adequate refrigerating system for maintaining the necessary temperatures (Fig. 41).

Portable home units. Home units are built in a variety of shapes. Some of the smaller units are built in cylindrical form, with top-opening lids, as Fig. 20. Others are rectangular with front-opening doors or top-opening lids. Still others combine the features of both the ordinary household refrigerator and the freezer and are known as dual-temperature units.

Top-opening units. Units of the cylindrical form are available with one or two compartments. The condensing unit is placed in an enclosure at one side of the single cylinder. In the double unit the machinery is located in a rectangular cabinet connecting the two cylinders.

The majority of home units have been of the top-opening type but rectangular in shape. Such units are built in portable styles in capacities up to 40 cubic feet. They are equipped with one or more lids or top-opening doors ranging in size from lids as small as those of ice-cream cabinets to lids as large as the top of the cabinet. The latter type makes for the greatest ease in getting at the foodstuffs stored below. The larger the unit, the easier should be the matter of locating foodstuffs that are desired, for with the greater size should go the preservation of larger quantities of each variety. And with large quantities of any one kind of food it should be possible to allot a separate part of the space to each kind.

Condensing units for top-opening rectangular cabinets are usually mounted at one end or in a recessed space under the cabinet. In large cabinets the recessed space would be under only a portion of the cabinet. There the cabinet is made shallower by the amount necessary to house the machinery (Fig. 41). For ease of servicing it is advantageous to have the condensing unit at the end. For the sake of eliminating noise and for better cooling and care of machinery it is often advantageous to place large condensing units in separate rooms.

Front-opening units. The third form of portable home unit, the front-opening cabinet, looks much like the conventional household refrigerator. It differs from the refrigerator in that it is insulated for lower temperatures and is equipped with a larger-capacity refrigerating machine.

Dual-temperature units. Dual-temperature units are so called because they contain two compartments, one at the ordinary household refrigerator temperature for ordinary short-time storage, and the other at a much lower temperature intended for the storage of frozen foods. The temperature of this second space should be kept between 0° and 10°F. Such space is primarily intended for temporary storage of commercially frozen foods bought at retail. However, it is quite within the realm of possibility that foodstuffs bought for use at a certain time may be forgotten or intentionally left for use at a later time. In either case the quality of the foodstuff may deteriorate rapidly if the temperature is much above 10°F.

In a dual-temperature refrigerator the frozen-food storage space is usually located at the top of the cabinet. It may be similar to an ice cube compartment, with additional space intended for making ice cubes. In some refrigerators an entirely separate compartment is located away from the higher-temperature compartment and is equipped with a separate door. In any case such storage space must be limited in size. More insulation should be used around those portions of a dual-temperature unit that are to be at the low temperature. In some cases, it appears desirable to have some insulation between the two compartments. This, however, will depend on the relative sizes of the spaces and the temperatures to be maintained.

Much thought and research has gone into the question of relative size of the two parts of dual-temperature units. Inasmuch as the frozen-food storage space can only be small at best and, therefore, can serve to hold only small quantities of frozen foods at one time, there seems to be no need for more than one to two cubic feet of space. This can serve only the urban dweller who does not attempt to raise or freeze supplies of his own or the locker patron who stores in quantity at the locker plant and needs only room for a week's supply at home.

Walk-in freezers. Large-capacity home-storage space must inevitably go beyond the bounds of portable cabinets and into permanent structures that are large enough for the owner to enter. Unless such built-in freezers open into 34° space they require some aisle space so that the owner can enter and close the door behind him while he works at loading shelves, cataloguing supplies, and the like. The minimum aisle space should be about 2 by 3 feet, and the minimum height inside should be 6½ feet. Thus a volume of about 39 cubic feet is required for aisle space in addition to that provided for storage. Shelves as narrow as 18 inches might be built on two or three sides of this aisle space, providing 60 to 100 cubic feet of storage space as about the minimum for this type of freezer. Any capacity greater than that can easily be built. Making the shelves 2 feet deep instead of 18 inches would increase the capacity by nearly 50 per cent.

Construction of home units. The construction of home freezers calls for all the care and precautions that are required in the case of larger low-temperature space. First there must be a substantial outside shell. This may be of one of the shapes previously mentioned. The material of which it is made depends largely on whether it is home-built or factory-built. Home-built units may have the exterior constructed of wood or sheet metal. Most commercially built units are made with a welded sheet-metal shell. This exterior must be designed to meet the requirements of the service to which the cabinet is to be put. If it is to be portable, the maximum width cannot be greater than 30 inches in order that it can be carried through doorways. If the cabinet is to be top-opening, the outside height and the interior depth should be such that the average person can lean over and reach the bottom without too great difficulty. An outside height of 33 inches above the floor or, if necessary, above steps, seems to be best. The length of the unit will be governed by the cubic-foot capacity that is to be built into it. The length cannot be made too great if the unit is to be portable and if it is to fit into any normal-sized room. The front-opening type has a marked advantage over the top-opening in the matter of capacity. As much as twice the volume can be built into a front-opening cabinet *per square foot of floor space* as can be built into the top-opening type. However, as has been pointed out, for really large capacity it is necessary to resort to special units of the walk-in type.

The type of construction will depend to some extent on the size of the unit and the type of insulation that is to be used. Factory-built units made with sheet-metal shell and liner require little else of a structural nature. A few braces between shell and liner suffice to give rigidity to the cabinet. Almost any type of insulation can be used with this type of construction. Home-built units, on the other hand, lack the advantages of factory-formed parts and must rely on a rather complicated piece of cabinet work. Good materials that will not shrink or warp with age and that will carry the load without sagging must be used. The interior floor and walls should be supported rigidly and yet with a minimum of structural material in order to reduce heat transfer. This is especially true if the insulation is of the loose-fill type. If, however, the insulation is to be of a block type with considerable rigidity of its own, it may be possible to reduce the number of supports considerably or to eliminate them entirely.

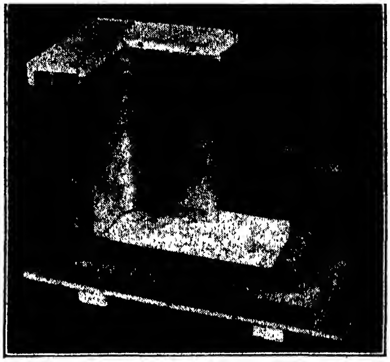


Figure 42. A model illustrates one method of construction of home freezers. This method was designed for home builders. The cabinet structure is built of an outside layer of cellular glass block and an inner layer of corkboard, all bonded with hot asphalt. A sheet-metal liner, with a tube coil soldered to it, serves as an evaporator providing refrigeration and inside protection to the insulation.

A combination of rigid Foamglas and somewhat less rigid corkboard can be used without any other structural material, as a wall made of these materials, properly bonded with hot asphalt, serves both to support itself and as insulation at the same time. Figure 42 illustrates such a construction.[1] Suitable outside and inside finishes must be used to protect the surfaces of the insulation. In units of the walk-in type constructed in this manner, rigid supports must be used for doors in the form of wood or steel posts anchored securely to floor and ceiling of the room in which the unit is placed. And all shelves should be supported on the floor rather than by the walls in this type of construction.

Doors. Doors present a problem in all types of cold storage. They must be insulated to prevent heat leakage. They must fit tightly to prevent the infiltration of moisture vapor. Their construction must, therefore, be relatively heavy. This, in turn, necessitates their being built rigidly to prevent warping, and, in the case of doors on front-opening cabinets or walk-in freezers, to prevent sagging.

The simplest door is the ice-cream-cabinet type of lid. This is small in size and, therefore, relatively light. It can be lifted off and set aside for access to the freezer. However, such lids are

[1] F. S. Erdman, Building a home freezer, *Cornell Univ. Ext. Bull.* 705 (1947).

frequently not well enough insulated, which results in sweating. Water then runs from the lids and may freeze them shut or cause corrosion of the cabinet. The small size of the lids also makes for great inconvenience in getting at the contents of the freezer. Lids for the top-opening type of cabinet, whether hinged or not, are more easily constructed than are doors for upright freezers. Doors for walk-in-type freezers are difficult to construct well, and consequently are expensive to purchase ready made. These, because of their size, must be quite heavy, and should be equipped with the best of hardware.

All freezer doors must have *gaskets* of one sort or another to make a good seal against vapor infiltration when the doors are closed. Special rubber gasketing, made for the purpose, is about the best material. It is available in a variety of sizes and shapes. One type of material that is designed for this purpose is made of sponge rubber with a thin rubber sheathing over the entire gasket, so that the cellular structure of the interior is not evident. This insures a more complete protection against passage of vapor than would uncovered sponge rubber and makes for greater ease in cleaning. Two or three strips of rather narrow gasket material may make for better sealing against heat leakage on small doors or lids than a single strip. The dead air space between the strips helps to prevent heat transfer. However, if the outer gasket leaks, there is likelihood that ice will form at the inner gasket, causing sticking of doors or injury to gaskets. For this reason several manufacturers of refrigerated equipment have adopted the practice of using only one gasket.[2]

On large doors, especially for walk-in freezers, some type of positive closing device must be used to compress the gasket and make a good seal every time the door is closed. Without such a positive closing device, or where it does not function properly, there is sure to be condensation of atmospheric moisture around the door. This turns to ice that builds up and increasingly prevents proper closing. Or it may freeze the door shut so that it is extremely difficult to open without damage to the door or gaskets. Grease or oil from hands or other sources coming in contact with rubber gaskets will render them useless through rapid deterioration.

[2] C. E. Lund, Technical phases of home freezer development, *Refrig. Eng.* **51**, 513 (1946).

Insulation. Insulation in general has been discussed previously in Chapter 12. Four to five inches of insulation equivalent to corkboard is most common in commercially built home units. Ideally the insulation should be of a thickness great enough to prevent the exterior of the cabinet from becoming as cold as or colder than the dew point of the atmosphere under the most adverse weather conditions. Under most conditions this thickness is about 5 inches of cork or the equivalent. If the insulation is insufficient, there will be condensation on the outside of the cabinet in warm humid weather which will be injurious to the cabinet because of rusting and may be a great nuisance because of the puddles formed on lids and floor and the icing of doors.

Vaporproofing. As has been previously emphasized, all insulation of low-temperature space must be protected against the infiltration of water vapor from the atmosphere. In many commercially built units this is accomplished by the use of the all-welded sheet-metal shell which is itself a vaporproof barrier. Where the exterior is perfectly sealed in this manner, the interior shell can be attached directly to it and can also be completely sealed by soldering or welding after the insulation has been put in place. If, however, the exterior of a home freezer is constructed of any material that is not vaporproof of itself, one or more layers of asphalt-impregnated paper must be added to form a vapor barrier. This should be well bonded to the outside shell, with all joints well lapped and sealed with hot asphalt or its equivalent. The insulation is then applied inside the vaporproof barrier. Lastly the inside shell or liner is installed. If there is any chance that moisture may get into the insulation from outside, there should be some small openings left in the liner to permit the moisture to pass on eventually into the interior where it will condense on the evaporator coils. This will protect the insulation from becoming saturated only if there is very little chance of moisture filtering in. Moisture-filled insulation is very poor in its ability to withstand heat leakage.

Liners and evaporators. The interior surface of all home freezers, whether small cabinets or large walk-ins, must be protected against injury during the course of years of service. Commercially built cabinets usually have a sheet-metal lining or liner. Home-built units may have plywood or plasterboard or some similar material placed on the inside of the insulation to protect it.

Larger units, especially those using block-type insulation, may use an asphalt emulsion as an inside coating or a cement or gypsum plaster. The emulsion can be painted with special paint, and the plasters with ordinary paint. Paints should be of good quality, that dry rapidly and are odorless after drying. They should be washable.

In some types of commercial cabinets the liner is constructed of sheet metal embodying the evaporator as a part of itself. Copper-tube evaporator coils may be soldered on the outside of the liner, or a double layer of sheet metal is formed so that a sinuous passage is left between the layers for the passage of refrigerant, much as if there were a tube coil. This eliminates tube or plate evaporators from the interior of the cabinet. Other types, however, make free use of plate evaporators set in the cabinet to accomplish the refrigeration. These are sometimes set around the sides. More often they are placed, in top-opening cabinets, at one or both ends as well as between to form partitions dividing the box into several sections or compartments. The shelves in side-opening cabinets are usually made of plate evaporators. Here the evaporators serve a double purpose and provide space for freezing with partial contact as well.

Custom-built walk-in freezers are refrigerated by means of evaporators ranging from pipe coils on the ceiling to tube coils on the walls or to plates used for shelves in all or a part of the room. In larger units where plates are used, the evaporator surface required may be less than the shelf area desired. The remaining shelves may then be made of any suitable material. Where other evaporators than the plate type are used, all the shelves may be of any convenient material. Pipe-coil shelves could be used, as described in Chapter 13 under Evaporators.

Freezing in the home unit. No matter how large or small the home-freezer unit may be, and regardless of the fact that it may have been designed only for storage of ready-frozen produce, the home user will undoubtedly freeze foods in it. Some persons use the ice-cube compartments of their old-style electric refrigerators for freezing and storing small quantities of foods. Cabinets should be used according to manufacturers' recommendations, which usually specify the maximum amount of food that may be frozen at one time without overloading the condensing unit.

A special portion of the space in many top-opening cabinets is designed for freezing. It is generally at one end, surrounded on two or more sides by evaporator plates. Thus there is more plate surface per unit of volume in this space than in the remainder of the box. The quantity of food that may be frozen at one time depends on the size of the condensing unit. Foodstuffs to be frozen must be placed so that there is ample space between packages for free circulation of air. Generally packages should be stacked in a single layer around the freezing well in contact with the refrigerated surfaces. A small fan is provided in some units to increase the air circulation.

In side-opening cabinets and walk-in freezers equipped with plate-type evaporators or pipe-coil shelves freezing can be accomplished on any shelf. However, the shelves near the point of admission of the refrigerant are frequently preferred for freezing because they are always amply supplied with refrigeration. Even though freezing may not be accomplished any faster, it is well to reserve a certain space for freezing so that warm foods do not cause temperature fluctuation in the frozen stored foods. The freezing space can be used for storage as well as freezing when all other storage space is filled.

The space reserved for freezing in the unit with pipe-coil refrigeration other than shelves should be as near the coil as possible. Keeping all frozen foods segregated from warm unfrozen foods should protect the frozen foods from temperature fluctuations. Where relatively large quantities of foods are to be frozen, as in a farm walk-in, a large household electric fan, placed where it can blow air over the food will help to chill and freeze all the packages at about the same rate. All packages should be placed apart with space for air circulation between.

Condensing units. Every freezer should be equipped with a condensing unit of ample size to carry the refrigerating load (Chapter 13). The size of the freezer, the type of insulation, and the amount of freezing to be done at any one time determine the refrigerating load. A condensing unit should accomplish its work in 16 to 18 hours per day under normal hot-weather conditions. That means that there is then a reserve capacity of 25 to 33 per cent available for freezing or for the unusually hot weather that is apt to occur occasionally. Many small home cabinets can be satisfactorily operated with condensing units rated at ¼ horsepower. There are some home-built cabinets of as much as 40 cubic feet capacity that are operated satisfactorily with condensing units of that size. However, these cabinets are more heavily insulated than are the commercially built ones. A poorly insulated cabinet of only 6 to 8 cubic feet capacity might need a condensing unit of ¼ horsepower.

Load. In planning a home-built unit it is necessary to determine the probable heat leakage through the walls and doors and the probable freezing load, all in terms of British thermal units of heat per 24 hours. A condensing unit is then chosen that will handle the load under worst conditions in the 16 or 18 hours of intermittent operation previously mentioned. The capacity of the unit is checked further to make sure that it will carry the freezing load in the 6 to 8 hours remaining. It is generally desirable to plan on freezing any one batch within a 24-hour period.

In purchasing a commercially built freezer the only way to be sure that it is equipped with a proper-sized condensing unit is to observe its operation. Certain performance should be guaranteed by the manufacturer, such, for example, as that a temperature of 0°F. or lower would be maintained in the box up to a point not more than 2 inches below the lid in top-opening boxes and throughout front-opening boxes when the room temperature is 90°F. and with not more than 18 hours' operation of the condensing unit out of 24. It should be borne in mind, however, that it may take a considerable period of continuous operation to bring the temperature of a new warm cabinet down to the normal operating temperature of 0°F. Only after this temperature has been reached and held for some time, should a new freezer be checked for its performance.

Home processing. The owner of a home frozen-food cabinet may use it exclusively for storing foods that have been frozen commercially or that have been custom-frozen for him at a near-by locker plant. However, anyone who owns a freezer that has refrigerating capacity enough to do even a little freezing and who has access to fresh produce, either fruit, vegetable, or meats, should not hesitate to process and freeze some food for himself. With the aid of instructions that can be obtained from a variety of sources[8] he should be able to preserve foodstuffs in a manner

[8] See bulletins or movies of various universities, agricultural experiment stations, and freezer manufacturers.

that equals the commercially packed frozen foods, because of the advantages inherent in home processing. The time element is of great importance, as is also the handling of the foodstuffs between harvesting or slaughtering and freezing. The home grower of such foodstuffs can pick fruits or vegetables in quantities that are small enough to be processed from garden to freezer in a much shorter time than that required in a commercial plant. And home handling can be much easier on the foodstuffs than is the machine handling required by commercial-scale operations.

Equipment. Equipment found in ordinary kitchens is satisfactory for processing small quantities of foodstuffs at home. The ordinary kitchen tools are sufficient for the preliminary preparation of foods for freezing. The shelling of peas can be done quickly and easily by using the motor-driven wringer rolls of some types of washing machine. One or more persons can feed pea pods into the wringer as fast as they can be handled. The empty pods are carried through the wringer, while the shelled peas fall into a container placed on the entering side. Lima beans can be shelled in a similar fashion if they have been scalded in the pod. Small home-sized machines can be obtained for pea shelling, slicing string beans, cutting corn from the cob, pitting cherries, peeling apples, and slicing peaches, as aids to handwork.

Equipment required for scalding vegetables includes one or more 4- to 6-quart pans, such as deep-frying or canning kettles, in which water can be boiled vigorously. Colanders, wire-mesh strainers, or squares of cheesecloth, in which 1 or 2 pounds of the vegetable can be placed at a time, are necessary in order that the batch may be immersed in the boiling water for the proper length of time and then all removed at once.

Plenty of cold running water or pans of cold water should be provided for quick cooling after the scalding process. Ice in the pans may be desirable. As soon as the food is cooled, it should be put into the containers. A funnel especially suited to the type of container shortens the processing time. A rectangular funnel with a stand to support it is useful for cartons with bag liners. The funnel should be adjustable in height and should hold the carton in an upright position while being filled. An ordinary canning funnel may be used for other types of container, including bag-lined cartons. Paper or cardboard funnels can be improvised for temporary use.

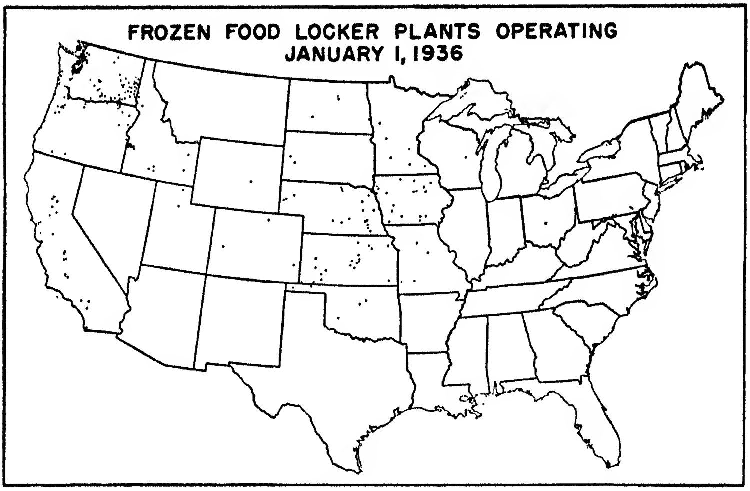
An electric curling iron or warm flat iron may be used to seal liners and prevent spilling of liquids and to seal in as much of the moisture as possible. With vegetables, where the contents are not liquid, it may be sufficient to fold over the tops of the bags two or three times to make a seal. As much of the air as possible should be pressed out of the package before sealing to help prevent drying out of the contents during storage.

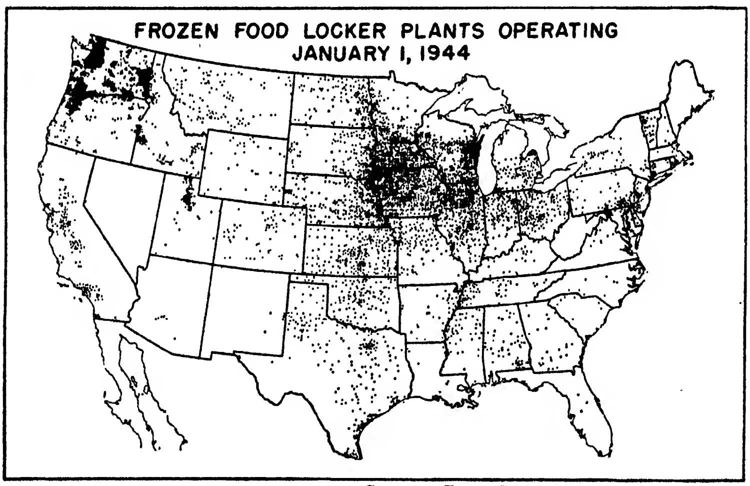
Chapter 16

LOCKER PLANTS

From humble beginnings that were in some degree accidental grew the locker-plant industry which has assumed very large proportions and is very widely spread throughout the United States, serving the frozen-food needs of communities of all types and sizes. Figure 43 shows graphically the rapid increase in numbers of plants. The facilities and services of locker plants vary considerably, from those of small plants having nothing but a refrigerated locker room where patrons can store home-prepared foods, to those of large more recently built plants having facilities for rendering all known services having to do with the freezing preservation of foods. A locker plant can then be described as an establishment having a frozen-food storage room as the principle feature, with space and facilities surrounding it for the preparation of different foods for freezing.

The planning of locker plants. In the early years of locker-plant development plants were built without the benefit of much considered planning. Often they were placed in old buildings and made to conform to the shape of the space available without much concern for convenience or efficiency. Standards of operation and maintenance, as well as of sanitation, were often below desirable standards. Lack of adequate information as to requirements for good operation was usually the cause of low standards. Many universities or members of the faculties of universities have taken an active interest in the locker-plant industry and its development, and they have contributed much toward raising the standards. These contributions were largely in specialized fields, according to the major interests of those making them, as in meat cutting and wrapping, fruit processing, vegetable handling and processing, choice of variety. Little thought was given to the plant as a whole except through the trade journals devoted to this field, where plans of outstanding plants were frequently repro-





Courtesy Farm Credit Administration, USDA

Figure 43. Two maps show the rapid increase in numbers of locker plants in the United States between 1936 and 1944. Since construction of plants was resumed, with the lifting of restrictions in 1944, the number of plants in operation has further increased rapidly.

duced for the benefit of prospective operators and others. Much has been contributed also by manufacturers of equipment, especially in the refrigeration field, who have helped in developing special equipment and in planning new plants.

In 1943 a committee was set up at Cornell University for the purpose of making a study of the locker-plant industry in all its phases and then drawing up recommendations which might be of help to the industry. From observations of installations, equipment, and methods in a broadly representative group of plants throughout the country and other research was drawn up "Recommendations for Frozen Food Locker Plants."[1] This was later supplemented by "A Beginning Inventory,"[1] an exhaustive list of equipment and supplies with which a new plant might be stocked when first opening.

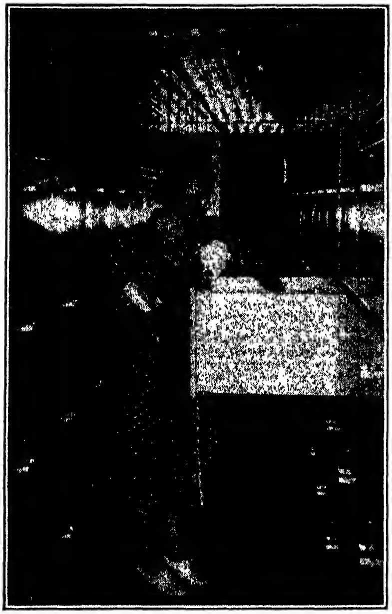
The following discussion of locker plants and their facilities is based largely on the committee's recommendations and subsequent findings.

The locker room. The heart of a locker plant is the locker room, for it is there, in the locker rented by the patron, that the patron's foodstuffs are stored after being frozen. This room is carefully insulated and is usually kept at 0°F., the temperature that has been found to be most desirable from the point of view of both economy and reasonable length of storage. The low temperature is maintained by means of pipe-coil or plate evaporators (Fig. 44), or some form of air-blast cooling system. The patron normally has access to the locker room and may remove his foodstuffs from his locker at will. For the convenience and safety of patrons it is desirable that the locker room be well lighted and have some kind of alarm bell with a push button placed just inside the patron door.

The *lockers* may be of any one of several makes and shapes. They are generally made of sheet steel, enameled, as in Fig. 44. Usually the two or three lower lockers in each tier are in the form of drawers. The upper lockers are in the form of small cupboards with doors. The higher door lockers can only be reached by climbing a ladder. Because the drawer-type lockers are low and, there-

[1] Published in mimeographed form and in several publications, namely: *Locker Operator* 6, no. 7 (Feb. 1944); *Western Frozen Foods* 5, no. 4 (Feb. 1944); *Can. Refrig. J.* 10, no. 9 (1944); 1944 *Guide Book of the Frozen Food Locker Industry*, Locker Publications Company, Des Moines (1944); and the same for 1945.

fore, more accessible, they usually rent for more than the door type. The net cubical content of the drawers is less than 80 per cent of the net content of the door lockers in some cases, in spite of the fact that the gross dimensions of the drawer lockers are greater than those of the doors. This results in a very much higher cost (nearly double in certain cases) per unit of storage volume in drawers than in door lockers.



Courtesy Locker Operator

Figure 44. A modern well-designed locker room. This room has well-built and well-kept steel lockers and broad aisles. Tiers of four-drawer-type and two-door-type lockers each are used. Stepladders must be used to reach the upper lockers. Refrigeration is supplied by means of bare pipe-coil evaporators.

Some locker plants use as many as seven or even eight lockers in a tier. This necessitates a higher ceiling than otherwise. From the point of view of insulation it is advantageous, as the amount of insulation needed per cubic foot of space is least for space that is nearest the shape of a cube. However, such tall tiers of lockers make the top lockers inconvenient of access. Where tiers of seven or eight are installed, the top row is sometimes intended only for surplus or overflow storage and is rented to patrons on a monthly basis to supplement their regular locker space.

In addition to the storage space in lockers many plants find it advantageous to have zero space for *bulk storage* of frozen foods. Such space is useful for patron overflow or for the storage of frozen foods for institutions or of commercially frozen foods intended for sale to patrons or others.

Many locker plants, either through lack of experience or in an effort on the part of the owner or builder to save space, have been built with narrow aisles between rows of lockers. These narrow aisles caused inconvenience both to the patrons in removing food from their lockers, and to the operators in servicing the lockers. The Cornell committee recommends a minimum width of 3 feet.

Little comment need be made here on the matter of insulation of the locker room, as this is fully covered in Chapter 12. Too much emphasis cannot be placed, however, on the importance of protecting the insulation against the infiltration of water vapor by means of some form of vaporproof sheathing on the warm side.

Meat handling. In the early days of frozen-food storage attempts at preserving fruits and vegetables met with little success because the special methods of processing necessary for satisfactory products had not as yet been developed. However, meats were frozen and kept with a fair degree of success without any treatment. Whole carcasses were sometimes frozen and pieces sawed or chopped off as desired. This was soon largely discarded in favor of cutting before freezing. The earliest wrappings were newspapers or butcher paper. Experience led to the realization that desiccation or freezer burn could be diminished when better wrapping materials were used. Thus the principal efforts of early plants were devoted to the handling and storage of meats.

It was soon found by locker-plant managers that the handling of meats for the patrons was very profitable in a number of ways. Not only could a charge be made for the cutting, wrapping, and freezing, but also the bones and trimmings could be sold for a profit if the owner did not want them.

TABLE 22. AREAS FOR MEAT-CUTTING ROOM

Approximate Size of Plant, no. of lockers	Minimum Space, sq. ft.	Recommended Space, sq. ft.	Space Considered Desirable by Some, sq. ft.
167	140	175	276
333	170	212	393
500	200	250	450
667	300	375	500
833	330	412	540
1000	360	450	590
1200	390	487	650

Many patrons who did not produce their own meat engaged the locker-plant managers to act as purchasing agents. On such transactions there was an added profit to the plant. Plants equipped with slaughtering facilities were able to add still further to their income. Charges were made for the slaughtering, and profits were derived from the handling of hides and edible and inedible offal.

Courtesy E. G. Spencer, Houston

Figure 45. A small well-equipped meat-processing room. The owner of this plant, being a dealer in glazed tiles, made extensive use of them in the finishing of surfaces in various parts of his plant. Cleanliness is an essential easily attained with glazed or enameled surfaces.

Hence it is not surprising to find that the emphasis in most plants is on the handling of meats and that the plant facilities are planned with that in mind.

The *meat-cutting* or *processing room* is probably the most important and most-used processing space in the locker plant. It should, therefore, receive much careful thought in its planning. Table 22, giving areas recommended by the Cornell committee for this space, was compiled from the replies to a questionnaire sent to a representative group of locker operators, supplemented by studies by the Cornell committee. The latitude between the various figures reflects the differences of opinion among different persons consulted. However, it was the committee's observation that large, well-lighted, and well-arranged meat-processing rooms were conducive to cleanliness and orderly performance. And that in turn led to good results, other factors being the same.

A meat-processing room is equipped (Fig. 45) with cutting blocks, cutting tools, including an electric band saw and meat grinder, as well as scales, and facilities for wrapping and properly marking packages. In short, the meat-processing room is a small-scale custom packing plant, where carcasses are reduced to the cuts desired by the patron and packaged for freezing.

Courtesy Agricultural Advertising and Research, Inc.

Figure 46. A 35° to 38° curing room. Hams and sides of bacon are cured on shelves after being pumped with a curing solution and rubbed with special salt mixtures.

The cutting of pork is preferably done in a separate place because of the excessive amount of fat. In connection with the handling of pork products, many plants are equipped to cure and smoke hams and bacon (Fig. 46) and to render lard. Where a considerable amount of pork is produced, this is a very desirable service from the point of view of both the patron and the plant. Invariably some time elapses between the completion of such processing and the time when the patron calls for the processed commodities. This necessitates storage at 35° to 38°F. If smoked products are stored, as is often the case, in the main chill or aging room, the smode odor tends to flavor the other meats in the room. It is, therefore, strongly recommended that a separate space be provided for such storage. But experience has shown that such space must be located in the plant where it is easily accessible for making deliveries to the patrons.

Poultry handling. In regions where much poultry is brought to the plant, it is well to provide a separate room (Fig. 47) equipped with killing cones, scalding kettle, and mechanical picker. Such equipment makes it possible for two operators to kill and pick birds at the rate of 40 to 50 per hour. After chilling for 24 hours

Courtesy Life

Figure 47. A poultry handling room. A well-equipped poultry handling room has killing cones, a scalding kettle with thermostatically controlled gas burner, and a mechanical picker. The operator can remove most of the feathers in a few seconds on the picker.

in the chill room to firm the flesh, the birds should be cleaned, cut, and packaged for freezing. For best results chilling should be done in a room used only for poultry in order that the birds acquire no unpleasant flavor from odors of other foods. This, however, is practicable in only a few plants.

Slaughtering facilities are included in many plants. For this purpose a moderate-sized room is required. At one side there should be a knocking pen from which animals can be dropped to the floor. A hoist, either electric or manual, is needed for raising the animal for bleeding and skinning. Plants intended for handling hogs require, in addition, a scalding tank as special equipment. Well-planned drains and ample supplies of hot and cold water are necessary for proper sanitation.

Beef carcasses can be cut into halves when they are hung on rails placed at a height of 12 to 16 feet. If the chill room of the plant is made to accommodate tracks of this height, the sides can be run in immediately. However, most locker plants have chill rooms with tracks at the standard height of about 8 feet. Whole hogs can usually be handled on rails at this height, but beef carcasses are cut into quarters before chilling.

The location of the slaughterhouse is sometimes subject to local ordinance. Some city ordinances make it impossible to have such facilities as a part of the locker plant. However, from the point of view of sanitation and the elimination of animal pens and waiting animals, it is desirable to have the slaughtering done at a distance from the locker plant. In some places it is permissible to have the abattoir as a part of the locker plant. Such a location is convenient and may be satisfactory when kept scrupulously clean at all times.

Chilling and aging. Of prime importance is the provision of facilities for chilling the freshly slaughtered meat as rapidly as possible, whether slaughtered by the plant or by the patron on the farm. This is especially necessary in warm weather and in warm climates to prevent loss by spoilage, so often experienced with farm slaughtering in the past. A *chill room* for this purpose is therefore provided in many locker plants. It is an insulated room with refrigeration capable of maintaining a temperature between 35° and 40°F. Here warm carcasses are cooled to about 40°F.

When the carcasses are cooled, they should be moved to the *aging room.* The aging room is larger than the chill room but of exactly the same type of construction and refrigerated to the same temperature. It is preferable that warm carcasses not be placed in this room as some moisture from them would condense on the already cold carcasses, causing conditions tending to promote the growth of molds and slime. The aging room (Fig. 48) is used to hold meats till they can be cut and wrapped for freezing. Not only can certain meats be held for some time, but also such meats as beef, mutton, and venison are improved by such holding. Other meats, such as pork, poultry, veal, and lamb, should be held only till they are thoroughly chilled.

The recommendation by the Cornell committee of 0.6 square foot of space per locker in the chill and aging rooms combined was based on Government requirements connected with the building of locker plants during the war period. However, it seems to be a fairly satisfactory figure, possibly on the low side.

Courtesy Locker Operator

Figure 48. Part of the aging room of a small locker plant. Overhead tracks are essential to easy handling of heavy pieces of meat. A height of 8¼ feet is necessary to keep large hog carcasses from touching the floor. Beef must be quartered.

The processing of large quantities of poultry in the Ithaca plant, some not for freezing, and the chilling and aging of some meat from a local abattoir for the local retail market have taxed the space considerably at times. If such services are to be expected, provision should be made to care for them adequately.

A suitable overhead track system should be provided as accessory equipment to the chill and aging rooms and the reception of meats into the plant. This should lead from the receiving entrance platform to the chill room and on into the aging room, with ample side rails for hanging all the unfrozen meat that may be in the plant at any one time. A hoist, either electric or manual, at the receiving end of the track system is a great help in handling heavy pieces of meat. Track scales should be included and located near the entrance so that all meats coming into the plant can be conveniently and accurately weighed before any processing is started.

Fruits and vegetables. Some plants have considered it of value to their patrons to provide equipment for processing fruits and vegetables. For this purpose they have set aside a certain amount of space for a kitchen where patrons can prepare their own fruits or vegetables for freezing.

Freezing facilities. It is vital, as has been pointed out before, that all foods be frozen before they are placed in the lockers along with foods that have been previously stored there. The effects of thawing and temperature fluctuation have been discussed elsewhere. They should be avoided whenever possible. The correct procedure is to freeze foods as soon as they are packaged and before they are distributed to the storage lockers or other storage space. A number of methods of freezing are available and in common use in locker plants. Freezing in still air is undoubtedly the most common method. Freezing by partial contact and still air is in use in small modern plants. The air-blast system of freezing is being used in others.

Freezing in still air is usually carried on in a small heavily insulated room adjoining the locker or storage room, having access to the meat-processing room. Such a room may be provided with an evaporator on the walls or ceiling and wooden shelves on which to place the foodstuffs while freezing. More often, the room is fitted with shelves made of rows of pipe which are themselves connected to form the evaporator, as in Fig. 34. The temperature in such still-air freezers is usually maintained at −10° to −20°F. Freezing is easily accomplished under such conditions within a day, so that food processed one day may be removed for storage the following day, making way for that day's freezing.

Some freezers of this type, that is, with shelves, use a modified form of still-air freezing. The refrigeration is accomplished by means of unit coolers which have a blower for circulating the air to be cooled through the finned coils. This results in a certain amount of air motion in the freezing chamber. But this air motion is not of high enough velocity nor sufficiently well directed to reach all parts of all packages. This type of freezing cannot, therefore, be classed with blast freezing.

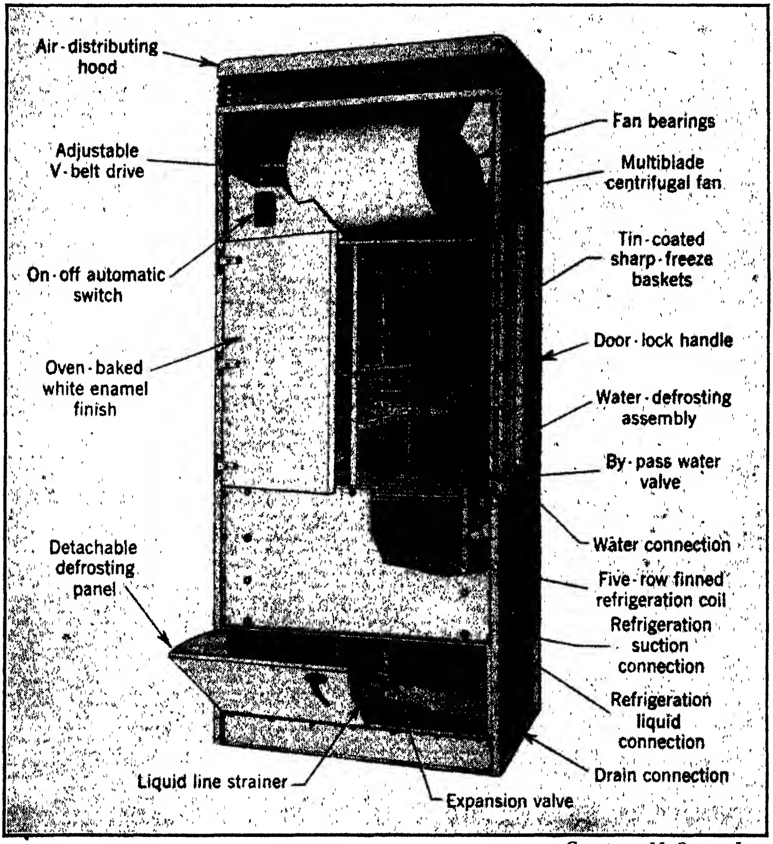
Contact plays a part in the freezing of foods where plate evaporator shelves are used. There the packages may be in partial contact with the plate surface on one side, permitting conduction of some heat from package to plate. The remainder of the heat removal is accomplished by the so-called still-air method. Plate-type evaporators lend themselves admirably to being used for shelves.

The manufacturers of such evaporators, therefore, provide frames or racks on which their plates can be mounted, or they provide them already mounted and connected in this manner (see Fig. 35). Some even provide them in cabinets of sheet metal of such shapes and sizes that they can be placed directly in the main storage room alongside of the storage lockers. This eliminates the building of a separate freezing compartment and has been found to be very satisfactory in use. Freezing in this manner may take a slightly shorter time than in still air. But the chief gain is in the reduced initial cost to the plant. There can also be a greater proportion of floor space devoted to storage than in the plant with a separate freezing room and having the same total volume of low-temperature space.

Figure 49. A blast freezer. This locker-plant freezer is built without doorsills so that trucks loaded with packaged foods can be rolled in easily. Powerful blowers force air over finned evaporator coils overhead, out through louvers on the left, across the trays of food, and back through the louvers shown on the right to the blowers.

Blast freezing, or freezing by the cold-air blast system, is the most rapid method of freezing in use in locker plants. A large blast freezer requires an extra room, built and insulated especially for below zero temperatures. In such a room (Fig. 49) are installed, usually near the ceiling, pipe-coil evaporators, of either bare or finned pipe, with powerful blowers driven by one or more electric motors. Suitable sheet-metal ducts and enclosures make it possible for the blowers to circulate the air of the room repeatedly across the evaporators and over the foodstuffs placed in the room for freezing.

One of the major advantages of this system is that the food can be placed on the shelves of small hand trucks that are pushed into the blast freezer and left there until the food is frozen. Then the trucks are rolled on into the locker room where the foods are transferred directly into the proper storage space. Thus two han-



Courtesy McQuay, Inc.

Figure 50. A small-sized cabinet blast freezer. Such a freezer is designed to stand in the locker room and provide refrigeration for the locker storage as well as freezing the foods.

dling operations normally encountered in still-air freezing systems are eliminated, the placing of packaged food on permanent shelves in the freezer, and then removing it to trucks for distribution. In a large plant this can mean the saving of a substantial amount of labor. The other major advantage of the blast system which justifies it economically for larger plants is that freezing can be accomplished rapidly enough so that the freezing space can be utilized more than once in 24 hours. The time required for freezing may be as little as 4 to 8 hours. Hence the space devoted to freezing by this method can be considerably less than that required for still-air freezing.

For small plants a modified blast system, such as that shown in Fig. 50, may be used. This lacks the advantage in laborsaving of the large blast freezer where trucks can be used, but it does have the advantage of freezing in short time. The cabinet freezer illustrated is designed to be set in the locker room, not only to freeze the foods, but also to provide refrigeration for the locker room as well. The evaporator coil, as may be seen, is of the finned type. A water-spray defrosting system is included as an integral part of the unit. The motor-driven blower at the top draws air in from the locker room at the bottom, up over the finned-coil evaporator, on through the food in baskets, and out again at the top into the locker room.

Freezing capacity. The provision suggested by the Cornell committee of freezing capacity capable of handling 3.5 to 4 pounds per locker patron or home-unit patron per working day is on the high side. During the first year's operation of the Ithaca plant the peak load encountered was just under 3.5 pounds per locker per day. But it is well to have ample capacity in this part of the plant to care adequately for peak loads that usually come in warm weather when certain fruit or vegetable crops are ready for processing in addition to meats. Also ample facilities for freezing will permit expansion of processing services as demand increases from owners of home units, or as branch plants are added to the system.

Refrigeration of locker plants. In many plants the refrigeration of the chill and aging rooms and any other so-called high-temperature space is handled by one condensing unit, while the low-temperature space is handled by another unit. This dual arrangement calls for the simplest control system. Other plants use a single compressor to handle all parts, and depend on special control devices to provide refrigeration at the different temperature levels. The initial cost of the single-compressor arrangement, as well as the power cost, is probably somewhat less than that of the dual arrangement. The single compressor must be a larger unit, it is true, but the cost of the two units of combined equivalent capacity required by the first system is greater.

Stand-by units. In addition to the motor and compressor used for normal operation it is very wise to have a stand-by unit to provide refrigeration in the event of a breakdown of the main unit. This need not be so large as the main unit, for during repairs to the main unit the activities of the plant can be curtailed to a minimum. With such an added unit also the main unit need not be so large as might otherwise be required, for the stand-by unit can be used together with it for the handling of peak freezing loads. A battery of compressors such as this for the low-temperature work of the plant and another for the high temperature would be both complicated and expensive. The method suggested, of using one compressor or set of compressors for all refrigeration at different levels, is then the more desirable (see Chapter 13).

Condensers. Adequate condensing capacity must be installed. In small plants the refrigeration requirements may be met by some type of condensing unit which includes the necessary water-cooled condenser along with the compressor and motor. In larger plants it is usually necessary to install machinery of a size larger than what is assembled in the so-called condensing units. This involves the use of separate water-cooled condensers. In a system using the same compressor or battery of compressors for all refrigeration, a single condenser is sufficient. Where different compressors are used for the different temperatures, at least two condensers are required. The type of condenser will be determined largely on the basis of the water supply available for cooling. If only water supplied by the municipal system is available, the cost of cooling is usually prohibitive with the ordinary shell and tube or coil type of condenser which uses a great deal of water. However, if well water is available, this type of condenser is probably the most satisfactory, as it makes possible relatively low discharge pressures from the compressor. Where the water supply is limited, it is advisable to use the evaporative type of condenser. This type is described in Chapter 13.

Machine room. A room of ample size should be provided for the installation of all refrigerating machinery. Its location should be such as to facilitate the moving in or out of heavy pieces of equipment. At the same time it should be so placed that the plant operator can have easy access to it for the purpose of checking performance at frequent intervals.

The lobby. A lobby is a convenience for patrons. It need not be large unless it is intended for use as a showroom of some sort in addition to its normal function of serving as a waiting room and aisle between front entrance and locker-room door. For the sake of ease in conducting business with patrons, it is desirable that the operator have his office next to the lobby, and not, as some persons recommend, at the rear of the plant.

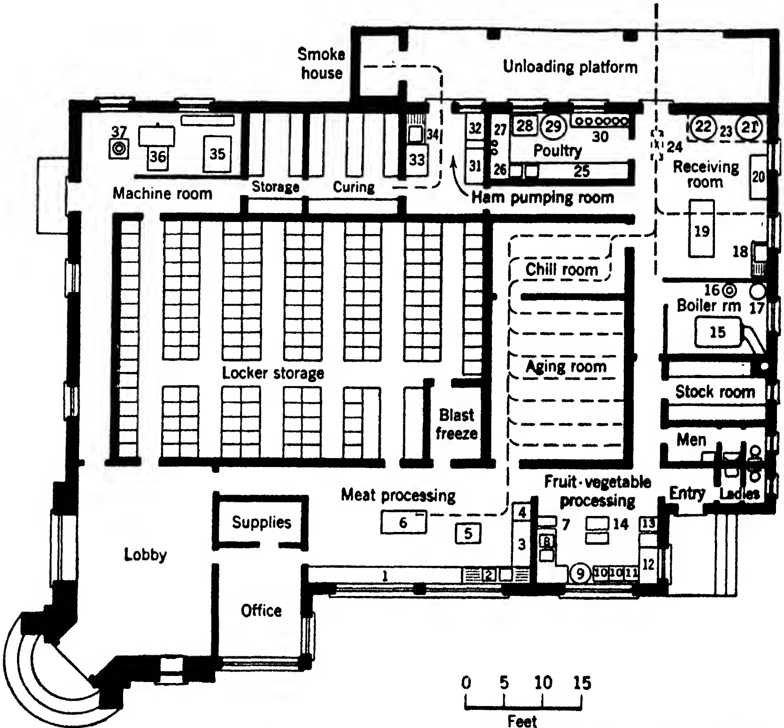
Locker-plant floor plans. Plans for locker plants cannot be standardized because of the wide variation in special requirements of each plant. Many representative floor plans have been published, chiefly in the various trade journals dealing with food freezing.[2] Study of a number of such plans in the light of the special needs of a proposed plant should prove to be very helpful in arriving at a satisfactory arrangement. Figure 51 illustrates an attempt to include in one plant most facilities associated with locker-plant operations.

Branch locker plants. It sometimes happens that small communities, not large enough to support locker plants themselves, are located relatively near a town in which there is a plant. If there are as many as 50 to 100 patrons or prospective patrons in one of the outlying centers, a happy solution is for the established plant to expand by adding a branch plant in each center. Branch plants can be placed 10 to 15 miles from the main plant. The locker-plant service is thus brought within easy reach of the patrons, frequently without the need for any changes in the main plant.

Facilities. A branch plant need have no facilities other than a properly constructed locker room of sufficient size for the community served and the necessary refrigerating machinery. Although often housed in a specially constructed building, it may be located in part of some building such as the back part of a grocery or other store. With automatically controlled refrigerating machinery such a locker room, like a household electric refrigerator, requires little attention. The branch plant, in some cases, is never locked so that the patrons have access to the locker room at any time. Each patron has the key to his own locker. In some cases a key to the building is issued along with the locker key so that

[2] *Locker Operator* and *Locker Operators' Guide Book* for different years, Locker Publications Co., Des Moines; *Quick Frozen Foods*, E. W. Williams Publishing Co., New York; *Recommendation for Freezer Locker Plants*, North Carolina Ext. Circ. 282 (1945).

patrons can enter at will. When branch plants are located in stores, access to them will usually be governed by the store hours.



Courtesy Cooperative GLF Exchange

Figure 51. A sample of locker-plant planning. This plan includes most facilities to be found in such plants, except a slaughterhouse. Key: 1 Wrapping table; 2 Sink; 3 Trimming table; 4 Meat grinder; 5 Meat saw; 6 Meat block; 7 Receiving table; 8 Sink; 9 Hot-water kettle; 10 Cold-water trays; 11 Ice-water tray; 12 Draining table; 13 Wrapping table; 14 Worktable; 15 Boiler; 16 Sump pump; 17 Auto. hot-water heater; 18 Sink; 19 Cutting table; 20 Worktable; 21 Lard-rendering kettle; 22 Lard press; 23 Ventilating hood; 24 Track scales; 25 Wrapping table; 26 Sink; 27 Eviscerating table; 28 Poultry picker; 29 Scalding tank; 30 Killing cones; 31 Worktable; 32 Pumping table; 33 Worktable; 34 Sink; 35 Compressor; 36 Compressor; 37 Well pump.

Services. The branch plant, having no processing facilities, must depend on the main plant for all such services. The method commonly used is to set one or more days a week when patrons can bring to the branch plant food to be processed. At the appointed time on that day the main plant sends a truck to collect the foods, and they are then processed at the main plant. When they are ready for storage in the frozen state, they are shipped back, preferably in insulated containers, to the branch plant and placed in the proper lockers, just as would be done at the main plant. Any patron desiring processing on other days is at liberty to deliver his commodities to the main plant. They will then be returned to the branch plant and placed in storage there on the regular day. Patrons having animals to be slaughtered by the plant or whole animals slaughtered and ready for processing are usually required to deliver them to the main plant. The main plant then returns the processed meat to the branch plant. However, some locker plants have a pickup service connected with their slaughtering service which collects from the farms any animals that are scheduled to be slaughtered.

In some cases branch plants are not owned by the main plant but by the storekeeper in the small community. He then contracts with the central plant for the necessary processing services.

Chapter 17

FREEZING FOR COMMERCE

Although the locker-plant industry, with its freezing and other facilities, is a commercial venture, still it does not as a general rule freeze foods on a commercial scale. The freezing of foods in locker plants is almost entirely done on a custom basis in relatively small lots. In rare instances only are foodstuffs processed and frozen in locker plants for sale either in the retail market or to the locker-plant patrons. Commercial freezing is here defined as the freezing on a large scale of various foods primarily for distribution to institutions or to the consumers through retail markets. This chapter is intended merely to introduce the reader to the basic aspects of commercial processing and freezing without attempting a detailed discussion of the methods or equipment used.

PROCESSING AND EQUIPMENT IN A COMMERCIAL PLANT

In addition to the necessary freezing equipment, which is discussed later, a commercial freezing plant must have much equipment for the processing of the different kinds of food to be frozen. To date, the foodstuffs frozen commercially have been chiefly fish, poultry, eggs, fruits, and vegetables. However, the freezing of cooked foods and retail cuts of meat is beginning to assume importance in the commercial field.

Processing fish for freezing involves different amounts of equipment, according to the method used and the form in which the fish are to be frozen. The simplest method used is that of freezing the fish whole. For this only scaling, gutting or eviscerating, and washing are necessary before freezing. Scaling may be accomplished in cylindrical scaling drums where brushes and sprays of chlorinated water aid in the process. Plenty of clean water should be available for thorough washing at various stages.

Gutting may be done by hand or with the aid of strong streams of water played in the opened belly cavities. The fish are then placed in an orderly manner in pans for freezing. After freezing the fish are removed in a block by slightly warming the pan. Large fish, like salmon, are often frozen whole and separately by laying them on trays. They are then either wrapped in vaporproof material to protect them from desiccation and oxidation during storage, or they are glazed by being dipped in very cold water. The glaze, or ice coating, is usually produced by dipping repeatedly, with intervals between to permit the water to freeze solid. Such a coating, varying in weight from a very small percentage of the fish to as much as 25 per cent, affords a good protection against both desiccation and oxidation during storage. It is too brittle to be of much value when the frozen fish are to be handled much or moved from one place to another during the storage period. Furthermore, the glaze must be renewed at frequent intervals, in some cases as often as once a month.

Much fish at the present time is filleted before freezing. The fillets are then individually wrapped in vaporproof paper or vegetable parchment and packed several to a box for freezing. Fillets for institutions such as hotels and restaurants are often frozen in blocks, without being wrapped individually. This is done by placing a predetermined weight of the fillets in a slightly tapered rectangular can. When the mass is frozen, it can be removed after the can is warmed slightly. The block of fish is then wrapped for storage and shipping. Additional cleaning equipment as well as cutting and wrapping tables are required when fish are to be filleted.

Poultry processing. In many poultry processing plants the birds are killed on the spot, killing cones being used to hold them for sticking and bleeding. There are a number of methods by which feathers may be removed. *Mechanical pickers* (Fig. 47) make possible the picking of birds at a very high rate. Such picking requires a light scald in water at about 125° to 130°F. to loosen the feathers. The water must not be too hot lest the bloom of the skin be lost or the skin itself be injured. Some plants use a *wax method* of picking. After the large feathers have been removed from the bird and it has been thoroughly dried, it is immersed in a bath of hot wax. A picking wax may be made of 60 per cent paraffin, 30 per cent rosin, 8 per cent crude gum damar, and 2 per cent fat, lard, or substitute. The wax bath should be between 125° and 130°F.[1]

When the wax has cooled to the point where it is still pliable, it is peeled off, taking with it the small feathers, pin feathers, and hairs (Fig. 52). After picking, the birds are chilled either by hanging for some hours in a chill room or by immersing in water chilled

Courtesy Birds Eye Frosted Foods

Figure 52. The wax method of picking poultry. After dipping, the hot wax is hardened by cold sprays and then is easily removed together with pin feathers.

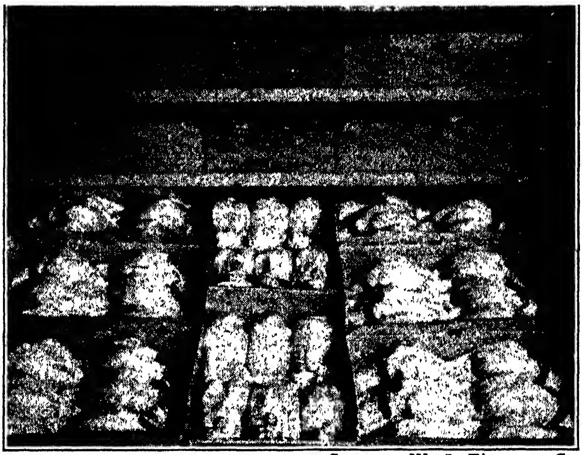
with ice.[2] If picked wet they must be dried and hung in the chill room. When the internal temperature has reached 34° to 36°F., the birds are further processed for freezing. Some packers use the New York dressed method which involves little further labor except, in some cases, wrapping, since the whole bird is frozen without prior evisceration. As better quality is assured in frozen poultry that has been eviscerated before being frozen, the freezing of New York dressed birds is slowly giving way to the freezing of cleaned whole or cut birds, as in Fig. 53. A bird cut in halves

[1] N. H. Grace, The use of wax in the plucking of poultry, *Nat'l Research Council Can. Pub'n* **576** (1935).
[2] W. H. Cook, Precooling of poultry, *Food Research* **4**, 245 (1939).

can be packed in a space somewhat smaller than a New York dressed bird, whereas one that is cut for fricasseeing can be packed in a still smaller space.

As most of the processing of poultry, after the picking, is done by hand, the equipment needed is largely trays, washing pans and tanks, conveyors, and the like.

The packaging of poultry depends on the market for which it is intended. Poultry for the retail trade is being packaged in-



Courtesy W. J. Finnegan Co.

Figure 53. Poultry packed for freezing. Wrapped, eviscerated poultry, packed six to a carton, are arranged on the trays of a truck for freezing in a blast freezer.

dividually, either whole or cut, the latter being placed in convenient space-saving rectangular cartons. Birds intended for institutions or markets are usually packed several to a box. They may or may not be wrapped.

Vegetable processing. A commercial plant designed for processing and freezing *vegetables* requires a considerable variety of specialized equipment. It is important to note that both the equipment and techniques for processing vegetables prior to freezing are similar in most respects to the processing required for canning (Fig. 54). Machinery is needed to reduce vegetables from the state in which they come from the fields to that in which they can be packed (Fig. 55). Viners (Fig. 54) do this for peas and lima beans, taking the whole vines as they come from the harvesting machine and delivering shelled peas or beans. The shelled vegetables are then *graded* as to size by some mechanical means and

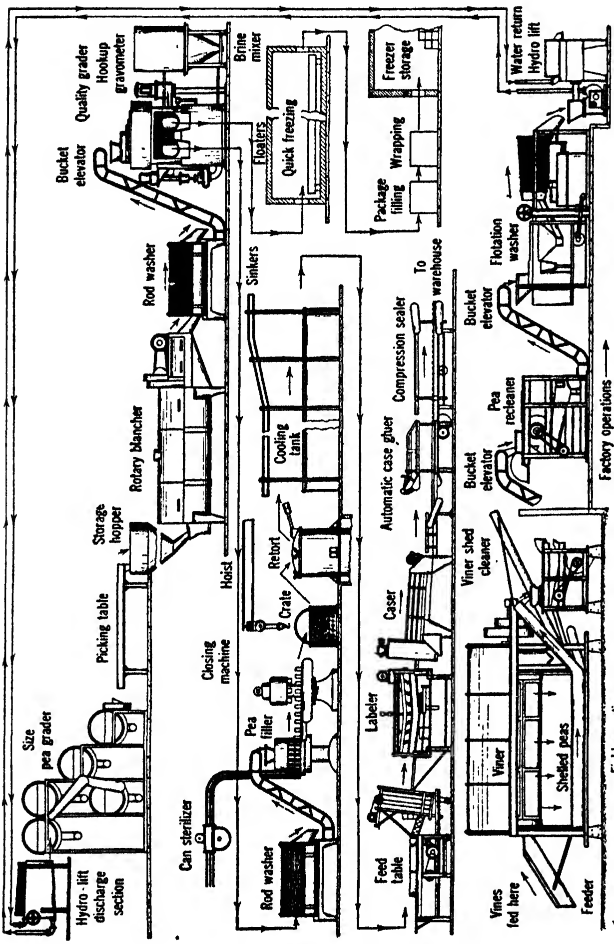


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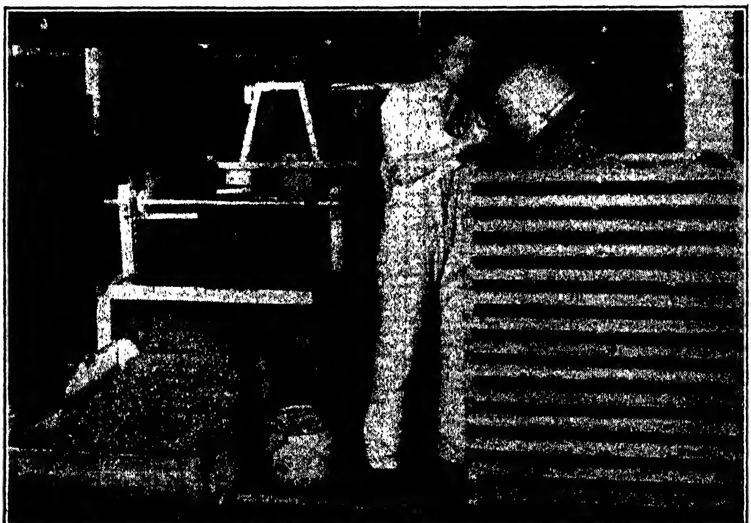
Figure 54. Diagram of a pea-processing plant. The flow chart shows the various pieces of equipment required for the processing of peas from the viner (lower left) to frozen storage. An important feature to be noted is one frequently overlooked, namely, that preliminary processing for freezing is similar to processing for canning. Orderly sequence in the arrangement of equipment such as this is vital to efficient operation.

may be graded for maturity by a flotation method. After thorough washing, the various grades that are suitable for processing are passed through scalding equipment using *steam* or a *hot-water bath.* Usually, for this part of the process, a conveyor carries the vegetables through a chamber filled with steam or a vessel filled with water near the boiling point. The scalded vegetables are then

Courtesy Western Canner and Packer

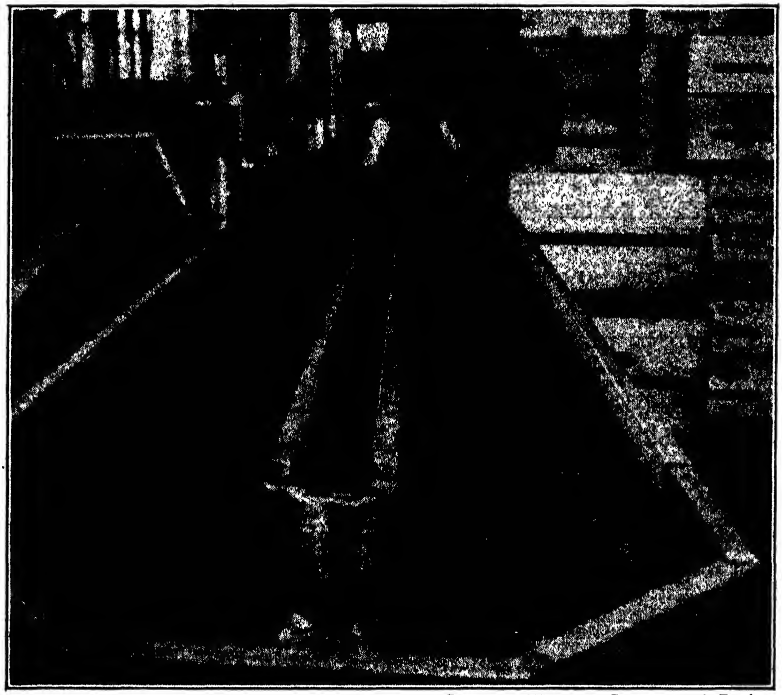
Figure 55. A battery of bean snippers at work. A bean snipper cuts off both ends of green beans. They are then inspected before going to cutters in the background.



Courtesy Western Canner and Packer

Figure 56. The last steps before freezing. Cut beans are spray-cooled after being scalded. A shaker (lower left) removes excess moisture before they are spread on trays for bulk freezing.

passed through *sprays* (Fig. 56) or *chilled water baths.* In some cases, notably for peas for freezing, the quality grader is placed after the blancher. After this separation, the product is then ready to be placed on trays or in pans for bulk freezing or in containers for freezing in retail or institutional packages.



Courtesy Western Canner and Packer

Figure 57. A U-shaped flume. Flumes are used in processing plants for transporting the foods from one place to another. Cooling and washing may be accomplished simultaneously.

Similar equipment is required for performing the various special operations required by the different kinds of vegetables. The scalding equipment used for peas or beans can generally be used for a number of other vegetables as well. In some instances the transportation of the vegetables from one place to another in the course of the processing is accomplished by means of *flumes.* These serve (Fig. 57) at the same time to wash or cool the vegetables as well as being conveyors. Many vegetables must be picked over by hand before packing. This is usually done by having the vegetables on *conveyor belts* pass by inspectors who remove any faulty pieces or foreign matter.

The processing of fruit for freezing varies greatly with the kind of fruit and the result desired. Some fruits, such as berries, are usually packed whole with sugar or sugar sirup. Before being packed in containers the berries must be washed, graded, and picked over. Strawberries must be hulled. Some plants make use of machines for this operation. Thorough washing is followed by grading and picking on conveyor belts to remove imperfect berries or foreign matter. The berries are then packed according to the purpose they are to serve. If they are for the canning or preserving trade or the like, they are packed in large containers, sometimes 50-gallon barrels. They are mixed with suitable proportions of sugar as they are poured into the barrel or container.[3] Other strawberries are sliced by machine, and, after being mixed with sugar, are packed in small cartons for the retail trade. Hence it is evident that machinery is needed for *washing, grading, hulling, slicing,* and *dispensing weighed quantities.* Numerous *conveyors* are required for moving the fruit from place to place.

Larger fruits, such as peaches and apples, are usually sliced and packed with sugar or sirup. *Sorting, grading, peeling, slicing* are some of the steps through which such fruits must pass. Fruits that discolor easily must be treated in some manner to prevent the discoloration.

Ripe fruits that can be *crushed* to form a buttery pulp or purée are mixed with sugar and frozen for use in making ice cream or for use as desserts.[4] Purées retain the original flavor of the ripe fruit very well if special machines are used to crush the fruit in such a manner as to avoid exposure to air and consequent oxidation, including discoloration and marked deterioration in flavor.

Some fruits, notably citrus fruits, are converted to *juice* and frozen in that form. The containers employed are usually cans. Again special care must be exercised to avoid oxidation during the pressing of the juice.

That many forms of special machinery are required for the various methods of preparation of different fruits is evident from

[3] H. C. Diehl, Barreling and freezing of berries, *Oregon State Hort. Soc. Ann. Rept.* 19 (1927).

[4] D. G. Sorber, A new quick frozen fruit product, *Fruit Products J.* 11, 229 (1932).

the brief listing of some of the steps used. Many of these machines are the same as those used in the canning industry, the steps of preparation there being almost identical in many respects.

COMMERCIAL-SCALE FREEZING METHODS

Freezing in still air was the method used almost exclusively for a long time. A well-insulated room was built for this with pipe-coil evaporators installed for the refrigeration. The pipe coils were hung from the ceiling in most cases, though on occasion they were mounted on the walls. Shelves were placed in the room if numerous small packages or trays of food were to be frozen. Where large barrels of fruit were to be frozen, the shelves were omitted and the barrels placed on the floor. In some still-air freezers the pipe-coil evaporators were constructed in the form of shelves. Such an arrangement, shown in Fig. 34, made for better distribution of refrigeration while at the same time providing the necessary shelves and a slight amount of contact between the evaporator and the articles to be frozen. Still-air freezing is still used widely in the freezing of fish and fruits.

Such freezers are generally kept at 0°F. or lower. Under those conditions the time to freeze the products varies widely, according to the size of the individual container and the weight of its contents. Very small packages for retail trade may be frozen in as short a period as 6 to 10 hours, whereas barrels full of berries may require as much as a week or 10 days.

Blast freezing. Blast freezing involves the use of powerful *blowers* that circulate air in a closed circuit successively over evaporator coils and the foodstuffs to be frozen. The high velocity of air motion used makes for extremely good heat transfer both from the foodstuffs to the air and from the air to the coils, resulting in more rapid freezing than possible with still air.

Conveyor type. One type of blast freezer makes use of a series of endless wire-mesh belts.[5] This was designed primarily for use with cut corn which had a tendency to stick to other types of belts. In this freezer a blast of chilled air is blown upward through the mesh belt and the product placed on the belt. Before returning to the cooling apparatus to be rechilled, the air is directed in carefully

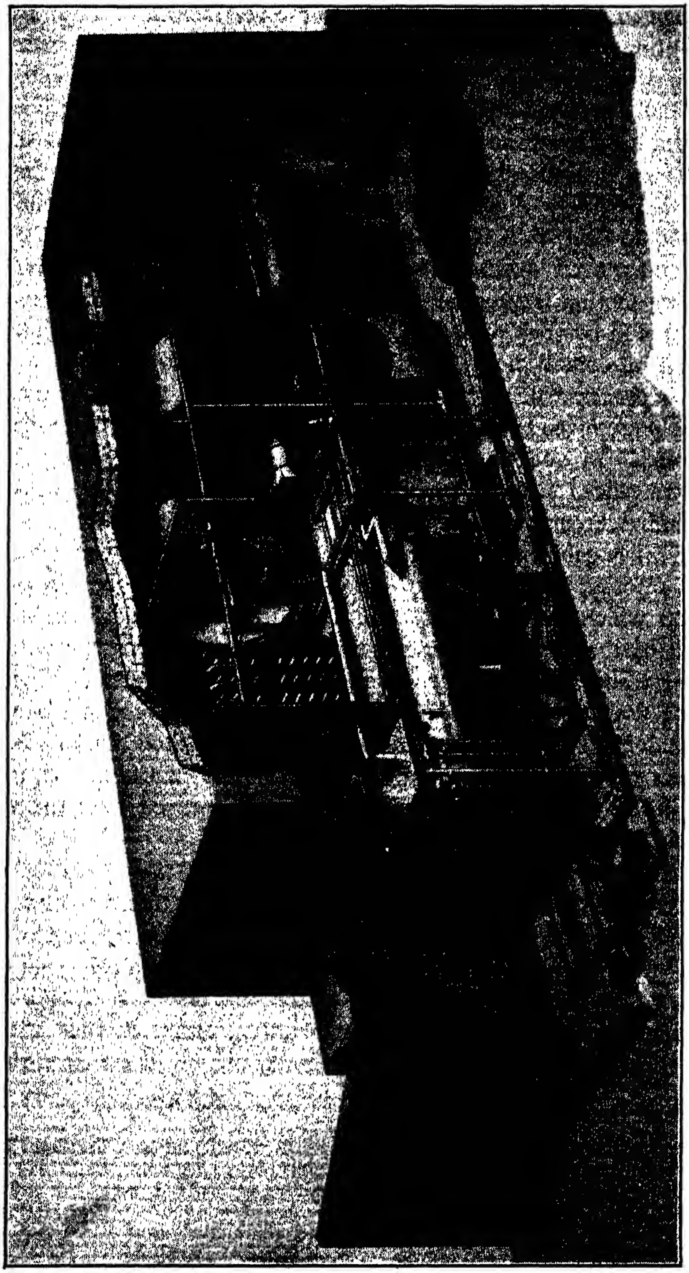
[5] R. Melhart, Corn is loose-frozen by continuous belt freezer, *Western Canner and Packer* **38**, 56 (Feb. 1946).

metered quantities over two chilling belts on which the cut corn is chilled to the point where the moisture at the surface freezes, thereby eliminating further trouble with sticking. Sticking on the chilling belts is prevented by directing the cold air onto the corn first and then down through the belt so that the corn is colder than the belt and does not tend to stick. It is also kept freed by being cascaded off the belts several times as the belts are made to pass over rollers.

Tunnel freezer. Another type of blast freezer, commonly called the tubular or tunnel freezer,[6] is constructed with a central space into which small trucks can be run (Fig. 58). The trucks are loaded with foodstuffs loose in pans or packaged on trays. Pipe-coil evaporators are located either overhead or at the sides together with powerful blowers for circulating air. Passages for the air are so designed that the air is made to circulate repeatedly over the foods and over the coils. Various modifications of this type of freezer are in use. For continuous operation on a large scale, such a freezer can be made long enough to accommodate several trucks at one time. The trucks, loaded with unfrozen food, are pushed in at one end either by hand or by some mechanical device, such as a conveyor chain which advances one truck length each time a truck load is ready for freezing. This automatically pushes the truck at the far end out of the freezer. The length of the freezer is such that each truck remains in it long enough to complete the freezing process.

Freezing by direct contact was first used when fish were frozen by being *immersed* in an ice and salt bath. This method had numerous disadvantages among which was the fact that as the ice melted the brine concentration altered and the temperature progressively changed. Also the foods so frozen tended to absorb salt to the point where they were unpalatable. Modifications of this method, however, have been put into use, where different solutions having low freezing points are used as secondary refrigerants. The solution is chilled by means of a mechanical refrigerating system. In one type of installation it is then *sprayed* on the foodstuffs to be frozen as they pass through an insulated tunnel on a conveyor. In another the foods are immersed in a tank containing the chilled solution. In order to avoid the dis-

[6] W. J. Finnegan, Performance data determined for new food freezing plant. *Food Industries* 12, no. 2, 64; no. 3, 48 (1940).



Courtesy York Corp.

Figure 58. A tubular or tunnel freezer. Powerful blowers circulate air repeatedly over finned evaporator coils and the foodstuffs placed on trucks. The trucks are moved through the tunnel by a motor-driven chain conveyor.

advantage of having salt penetrate into the food during this process, solutions of other materials than sodium chloride have been used. Fruits have been frozen successfully in a 50 per cent solution of fully inverted sugar sirup[7] in one case, whereas in another developed by Bartlett and Woolrich,[8] a solution containing glucose and sucrose is used. In this system the solution is chilled to the point where finely divided ice crystals are formed throughout. The food to be frozen is fed into the solution at one end of the device and moved slowly through to the other end. A constant oscillating motion is superimposed also to assist the heat transfer. Foods frozen by such a method must either be small, like berries, or be cut into small pieces, as sliced or halved peaches.

The *Z process*,[9] developed by M. T. Zarotschenzeff, makes use of a finely atomized spray of chilled brine through which the foods are passed. In one of several methods using this principle the foods are placed either unpackaged (direct contact) or in packages (indirect contact) on trays of wire mesh which are then inserted in a cabinet where the chilled solution is sprayed over them. Another method uses a continuous wire-mesh belt conveyor on which the packaged or unpackaged foods are placed at one end of the device. The belt then carries the foods through a tunnel where the chilled solution is sprayed over them. The speed of the belt is adjusted so that the foods are frozen when they reach the far end of the tunnel. A third method makes use of trucks on which the foods are loaded. The trucks are then placed in a chamber where chilled solution is sprayed over them and their contents.

The chief advantage of the direct-contact method lies in the fact that heat transfer from the surface of a body to a liquid is more rapid and efficient than from a body to air. In this method of freezing the heat of the foodstuffs is transmitted to the cold solution, and that, in turn, transmits it to the still colder surface of the evaporator coil. Motion of the solution, either in the case of the spray striking the foods and running off, or in the case of

[7] H. A. Noyes, Quick freezing with portable units, *Food Industries* **10**, 678 (1938).

[8] L. H. Bartlett and W. R. Woolrich, Polyphase freezing process developed; low cost unit built, *Food Industries* **13**, no. 12, 60 (1941); **14**, no. 1, 62 (1942).

[9] M. T. Zarotschenzeff, Rapid freezing and chilling of fish and meats, *Ice and Refrig.* **77**, 155 (1929); The "Z" process in America. *idem.* **83**, 67 (1932); M. T. Zarotschenzeff and C. J. Coon, The quick freezing and marketing of ducks, *ibid.*, **91**, 51 (1936).

the agitated solution in which the foods are immersed, accelerates the heat transfer and results in very rapid freezing. The forced motion of the solution then carries the heat to the evaporator coil.

The use of a sugar solution in the case of fruits results in a protective coating that helps to preserve color and flavor and eliminates the need for packing with other sugar or sirup.[10] The method also freezes the individual pieces separately so that they can be used in whatever quantity is desired.

Indirect-contact freezing is accomplished when the heat transfer which chills and freezes the foods takes place by conduction from the food to the refrigerating medium through one or two layers of metal or packaging material or both. Among the methods using this principle are (1) the placing of packaged foods between two plate-type evaporators, (2) passing packaged foods through a spray of chilled brine (see the *Z* process), (3) immersing packaged foods, such as cans of fruit juice, in a chilled solution, and (4) freezing unpackaged foods, such as fillets of fish, in cans partially submerged in a chilled solution.

A patented freezing device that is used extensively, particularly in the processing of Birds Eye brand products, consists of a number of plate evaporator shelves (Fig. 59) mounted so that the spacing between shelves is adjustable.[11] Trays of packages of a uniform size are placed on the shelves. Then the shelves are moved upward by an hydraulic device so as to clamp the packages firmly between them. Thus each package is subjected to intimate contact with a refrigerated surface on both top and bottom. To prevent excessive pressure on any packages which might cause distortion, wood spacer strips are inserted on each shelf. Two-inch-thick packages can be frozen in this device in 1½ to 2 hours.

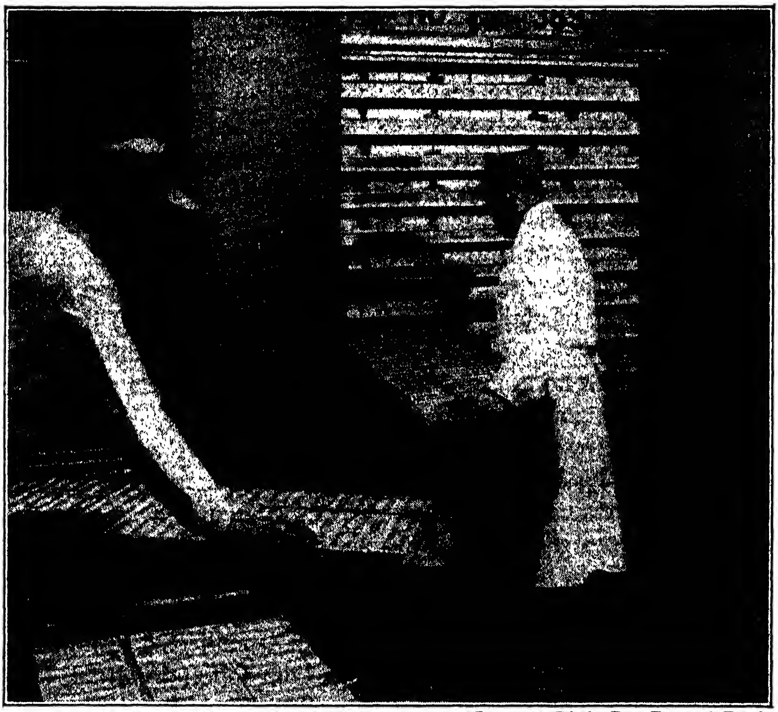
The freezing of fruit juices has been carried on successfully for a number of years by means of the Finnegan Tube Freezer[12] and other methods. The Finnegan machine consists of a series of long tubes into which cans of juice are inserted. The tubes are a little larger in diameter than the cans, and the space between is filled with alcohol. The tubes themselves are evaporators with

[10] A. R. Fisher, Theory and practice of the quick-freezing of berries and other fruits in sugar syrup, *Quick Frozen Foods* **1**, 23 (1939).

[11] C. Birdseye, Portable quick freezing apparatus, *Ice and Refrig.* **82**, 375 (1932).

[12] N. H. Rosberg, Processing and handling quick frozen orange juice, *Refrig. Eng.* **35**, 19 (1938).

liquid ammonia circulating continuously in the shell surrounding the inner tube. The cans of juice are made to pass slowly through the tubes while a slow rotation is imparted to them. The alcohol is also made to circulate from one end of the tubes to the other.



Courtesy Birds Eye Frosted Foods

Figure 59. A multiplate freezer being loaded. Such a freezer can only be loaded with uniform-sized packages of processed foods and is, therefore, only useful in large-scale commercial freezing. When all the shelves are filled, they are raised by an hydraulic device, placing all packages in contact with evaporator plate surfaces on top as well as bottom.

The combination of motions makes for good heat transfer and at the same time causes freezing to take place uniformly from the outside inward.

Freezing of fish is done rather extensively in pans and tapered cans. C. F. Kolbe[13, 14] has developed two methods using pans in

[13] C. F. Kolbe, Why quick freeze?, *Food Industries* **2**, 165 (1930).

[14] T. J. Carroll, A Kolbe installation at the Gorton-Pew plant, *Food Industries* **2**, 169 (1930).

which to place the fish fillets. In one method the pans are covered and then immersed wholly in chilled brine. The cover is so designed that the trapped air keeps the brine from entering. This method produces freezing by indirect contact through the bottom of the pan and by the chilled air between the cover and the foodstuff. In the other method the fish fillets are placed in open circular pans that are floated on a stream of chilled brine. With brine temperatures ranging from 0° to −40°F. the freezing can be quite rapid. The pans are carried from one end of a winding channel to the other by the stream of brine, while at the same time the freezing process is being carried on.

The method developed by P. W. Peterson uses deep rectangular cans into which are placed a known weight of fish or fish fillets which are then partially immersed in chilled brine.[15] The method resembles closely the manufacture of ice. Blocks of fish measuring 2 by 18 by 28 inches are made in this manner. After freezing is complete, the cans are dipped momentarily in water warm enough to free the block. The block is then suitably wrapped for storage and shipping.

DISTRIBUTION

The problems involved in the handling of frozen foods from the time they are processed till they reach the ultimate consumer are many and complex. Figure 2 (p. 16) gives a picture of the various steps included in the distribution pattern. After being frozen in a packing plant, located as near the source of raw materials as possible, the foods are transported by various types of carrier to intermediate points. These may be cold-storage wholesale warehouses located strategically with respect to the centers of consumption, or they may be industrial users. The latter include ice-cream manufacturers, bakeries, or manufacturers of conserves. From the wholesale warehouses frozen foods are further distributed to the retail market or institutional consumers. Each step in the course of the travels of frozen foods requires suitable refrigeration and great care in the handling from one refrigerated space to another.

Storage. Little need be said here concerning the storage warehouses. They must be built according to the needs of the locality

[15] P. W. Peterson, Methods of freezing fish, *Refrig. Eng.* **9**, 7 (1922).

as far as size is concerned, and they must, of course, be adequately insulated and refrigerated for the maintenance of the necessary low storage temperature. The temperature considered desirable for warehouse storage is, like that for locker plants, 0°F. The temperature may be lower and is so held by some concerns. For good results over a normal storage period it should be no higher than 0°F.

Stacking. After foodstuffs have been frozen by any one of the various methods described, there is usually some handling done prior to storing. This may consist of packaging, in the case of loose frozen foods, or placing small packages in shipping cartons, or the like. Such handling is usually done in a cold room. But the temperature is rarely as low as 0°F. Also the packaging materials used are probably not at that low temperature. The result is that the foodstuffs, while well frozen, may not be at the storage temperature of zero. It is, therefore, necessary to use special precautions in placing the frozen foods in the storage space.[16] In stacking cartons of packaged foods, air spaces should be left for free air circulation in order that the temperature of all parts reach zero as quickly as possible and remain there. Wooden strips should be laid on the floor as well as between layers in the tiers. Also the tiers should be placed at least 6 inches from the walls and spaced an inch or so apart. When foodstuffs are moved from one warehouse to another, the same precautions must be observed in order that any heat picked up during handling may be removed once more in the new storage.

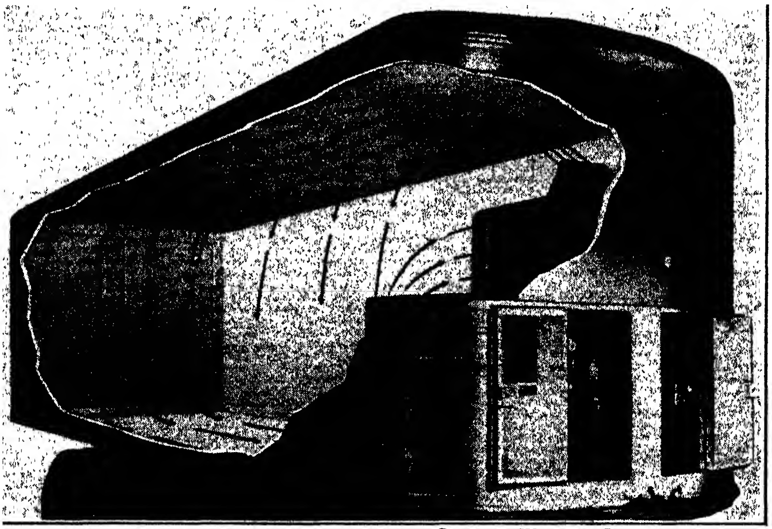
Loading. A frozen-food warehouse should be provided with special facilities for unloading the primary carriers and for loading the trucks used in distributing to the retail market. Provision should be made to protect frozen foods from being exposed to warm surroundings for any length of time during the loading. Also special arrangements are usually required for the refrigeration of the trucks.

Transportation. The moving of frozen foods from the packing plants to the intermediate points of storage or consumption is usually accomplished by means of refrigerated trucks, railroad cars, or ships. Consideration has been given to and some trials

[16] J. J. Antun, Precautions necessary when storing frozen foods, *Food Industries* 10, 319 (1938).

have been made of the use of *airplanes* for this purpose.[17] By precooling the airplane fuselage before loading and then flying at altitudes at which the atmospheric temperature is below zero the cargo can be delivered without the use of artificial refrigeration during transit.

Trucks are very widely used for transportation of frozen foods both in long and short hauls. For long hauls large trailer trucks



Courtesy Western Canner and Packer

Figure 60. A truck designed for transportation of frozen foods. Trailer trucks are much used for transportation of refrigerated cargoes. The cutaway view shows one type of insulated trailer, refrigerated by a blast of air. The condensing unit is driven by a gasoline engine which starts and stops automatically as refrigeration is called for.

are the most economical. These are well insulated and refrigerated by means of gasoline-motor-driven condensing units mounted on the front end or underneath the trailer (Fig. 60). Hauls as long as from Louisiana to New York City are made for delivering frozen shrimp.[18]

For short hauls and for local deliveries from warehouses to retail markets small insulated trucks are in use. The refrigera-

[17] Anonymous, Frozen frog legs flown from Cuba, *Frosted Food Field* **2**, 1 (Jan. 1946).

[18] Anonymous, Transportation of Louisiana shrimp, *Frosted Food Field* **1**, 6 (Dec. 1945).

tion of these trucks varies a good deal. Some are provided with holdover or eutectic tanks containing an eutectic solution of some salt. During the night or idle period of the trucks, the tanks are connected to the main refrigerating system of the warehouse or servicing plant. This circulates either a primary refrigerant such as ammonia or a secondary refrigerant such as a brine solution through the coils in the eutectic tank, both refrigerating the truck and freezing the eutectic solution. The thawing of the eutectic ice provides the necessary refrigeration during the delivery period.

Other trucks have been equipped with means for using "dry ice," or solid carbon dioxide, as the source of refrigeration, a very desirable method for small trucks. A great deal of refrigeration is obtained with the use of only a small space for the refrigerant. "Dry ice" provides about 268 B.t.u. of refrigeration per pound, compared to about 130 per pound of water ice, when used for frozen-food refrigeration. With water ice considerable quantities of salt must be added to depress the melting point from 32°F. to the desired 0°F. "Dry ice" has the added advantage that it sublimates directly into a gas without becoming a liquid, and so eliminates the need for any special means for disposing of it after it has served its purpose.

Railroad cars. Shipments of frozen foods are also made in railroad cars equipped with 4 to 5 inches of good insulation and adequate refrigeration. Before the advent of frozen foods much fresh food was shipped in refrigerated cars. There the temperature was maintained at the desired level by the use of ice alone. For frozen foods it was necessary to add salt to the ice. This has been done, and proper temperatures can be maintained when the correct proportions of ice and salt are used. On long hauls such cars must be reiced at suitable intervals in order to keep the supply of the refrigerating medium adequate to the needs.

Other railroad cars are equipped with mechanical refrigeration.[19] Condensing units are installed, with the compressor under the car driven from one of the car axles. The condenser is located on the roof and the evaporators near the ceiling of the car. Eutectic tanks are used in this type of installation in order to care for refrigeration when the car is stationary for short times or running too slowly to supply the necessary refrigeration from the

19 Anonymous, Refrigerator cars, *Food Industries* 3, 203 (1931).

axle. An electric motor is also installed with provision for connecting it to an outside source of current for driving the compressor when the car is held for considerable periods at stations. Automatic temperature controls regulate the operation of the condensing unit just as in a home-freezer unit.

Still other railroad cars are equipped with a system for using "dry ice" for refrigeration.[20, 21] Bunkers are provided at each end of the car near the roof. The bunkers, in which the "dry ice" is placed, are surrounded by coils filled with a secondary refrigerant such as methyl chloride. The latter circulates by gravity through finned coils placed near the ceiling of the car and conveys the heat picked up from the car back to the "dry ice." A thermostatically controlled valve controls the flow of the secondary refrigerant in such a way as to maintain the desired temperature in the car.

Ships. Probably the first long-distance transportation of frozen food was accomplished on refrigerated ships in the carrying of meats from Australia and South America to England and Europe. Such ships are built with part or all of their hold space insulated like a cold-storage warehouse. A refrigerating plant using carbon dioxide or some other nontoxic refrigerant provides the necessary refrigeration. Such ships can be used for the transportation of any kind of frozen food equally well and no doubt will be so used as the production and consumption of frozen foods spreads more widely throughout the world.

New enterprises. In view of the very great interest in and rapid expansion of the frozen-food industry in all its phases, it is not surprising to find many food industries adding the freezing preservation of foods to their present line. Also many individuals are attracted to the industry as one with a very promising future. Before going into the field of food freezing, however, it would be well for any corporation or individual to study the situation very thoroughly in all its aspects. Almost numberless are the questions and problems that must be answered satisfactorily before such a venture should be undertaken. C. R. Havighorst has tabulated a long series of such questions in an article aimed at helping those interested in entering the field.[22] It would be well to study care-

[20] J. W. Martin, Transportation of quick frozen foods, *Quick Frozen Foods* **2**, 1 (1939).

[21] C. L. Jones, The "dry ice" refrigerator car, *Ice and Refrig.* **80**, 113 (1931).

[22] C. R. Havighorst, So you are going into freezing, *Food Industries* **17**, 1471 (1945).

fully and answer as far as possible all the questions posed by such an article in order that an honest appraisal of the situation may be reached. Such an analysis might bring some to a realization that certain circumstances of their particular situation were not conducive to successful food freezing.

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