PAN BOILERS HAND BOOK

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PREFACE.

White Sugar destined for direct consumption should not only be white and brilliant but should also possess a regular form and a rather large size. This depends on the Pan Boiling.

Sugar Boiling is the art of concentrating in a vacuum, juices and syrups to the point of crystallization where uniform crystals of a predetermined size will be obtained. Unfortunately its conduct still depends on the personal skill and judgment of the uneducated workman who manipulates the various valves which control steam, water and syrups.

The writer has tried to prepare written instructions whereby an inexperienced operator could hope successfully to boil a pan of sugar. The theoretical aspects as well as Practical Hints on Sugar Boiling are well discussed. Details have been given of the "Automatic Control of Pan Boiling."

The writer believes that the reader will encourage the writer by giving him suggestions for making the book more useful to the men concerned.

O. P. TALWAR

25th May 1934.

CONTENTS.

Page.

INTRODUCTION.

Notwithstanding the scientific advances which have been made in the unit process involved in the manufacture of sugar, the operation known as sugar boiling remains in much the same status as that of twenty or thirty years ago. "The art of sugar boiling" is an expression which truly describes the condition of our knowledge of this operation, for its conduct still depends on the personal skill and judgment of the workman who manipulates the various valves which control steam, water and syrups as they are used at the vacuum pan. An array of brightly-polished thermometers, steam gauges and recording instruments of various kinds, as they bedeck a modern vacuum pan, give the impression of a nicety of scientific control, but if these instruments were all removed the operator would continue to boil his sugar without serious inconvenience, his personal judgment and his interpretation

of the various visual indications which have guided his manipulation of vacuum pans in the past would continue as the basis of his operations.

Perhaps the clearest indication of the state of our information on sugar boiling may be obtained from this simple statement: that it is quite impossible for a sugar boiler to prepare written instructions whereby an inexperienced operator could hope successfully to boil a pan of sugar. The recognition of those signs which indicate the maintenance of proper conditions for sugar boiling—the building of regular crystals, the avoidance of "false grain" and concentration to that density which will give the maximum yield of sugar compatible with proper centrifuging characteristics—can come only through experience and personal conduct. Only by trial and error can the operator learn to avoid and correct the mistakes of judgment which even experienced sugar boilers make much too frequently. It is therefore not remarkable that sugar boiling skill and facility should be so highly valued, since it has only been possible to obtain this after many years of experience.

CHAPTER I.

COIL TYPE VACUUM PANS.

The vacuum pans form a very important section of the plant in a sugar factory or refinery and it is of great importance that careful study be given to the design of each individual pan, to their capacity as regards the output of the factory and to their arrangement relatively to the general scheme of the buildings and to the other parts of the plant in connection with which they work.

Vacuum pans have the body, top and bottom constructed of cast iron. In larger sizes—those of seven feet and over in diameter—the body, top and bottom are made in segments having machined flanges. The smaller coil pans have copper coils 3 ins. or 3½ ins. bore but the standard coil for all pans over seven feet diameter is 4 ins. bore. The coils are supported by mild steel bars to which they are attached by brass clips, the steel supporting bars being rigidly attached to the body and bottom of the pan. Each individual coil

or layer of serpentine coils is divided up so as to have several steam inlets and drain outlets.

All coils are connected up to one or more steam manifold having control valves for each coil. The lower ends of the coils outside of pan are connected, by wrought iron pipes, to efficient steam traps of ample size.

The standard discharge valve is of the flap or hinged type, having an easily renewed rubber face, it is operated from the working platform by means of a hand wheel connected to the valve by suitable gear.

Another convenient type of discharge is through an ordinary sluice valve of comparatively large size; this is usually attached to a special casting on the bottom of pan, to which casting may also be connected a cut over valve, charging valves, wash-out valve, etc.

With this arrangement the massecuite is conducted to the crystalizers or centrifugal mixer through a pipe, thus obviating any chance of splashing or messing of massecuite below the pan.

When headroom is very limited, there is a discharge valve having a

door sliding horizontally; this door is provided with a brass fitting strip which makes metal to metal joint with the mouthpiece of the pan; the surface being forced together by stationary wedges which come into operation when the door is nearly closed. This type of valve is operated from the working platform by means of handwheel and gearing.

In addition to these fitting there are other mountings such as :—

Gunmetal air cock and butter cup combined, with copper pipe for inside of pan.

Steaming out valve with copper connecting pipe.

Two circular eye-glasses on top of pan and oblong eye glasses on back and front.

Gunmetal valves with tube connections for steam and water for cleaning glasses.

One or two proof o sticks.

Thalpotasimeter,

Vacuum and pressure gauges with cocks, copper syphons and mahogany mounting blocks.

Valve for water to pan.

Two charging cocks with dip pipes, or alternatively two charging valves attached directy to bottom of pan.
Wash-out valve.
Maindoor.
Each pan is lagged with non-conducting composition.
Cut over valves are also fixed.

CALANDRIA TYPE VACUUM PANS.

The Calandria pans have flat tube plates (which may be of steel, copper or brass) extending right across the body of the pan; this is the type most generally in use. These pans having increased heating surface have a deeper Calandria than those having normal heating surface, which makes it necessary to draw in a greater quantity of syrup or make a larger cut over from another pan before steam can be turned into the Calandria. The standard tube (copper or brass) for Calandria is 4 ins. external diameter. Mostly Calandria pans with flat Calandrias have a coil fitted in the bottom of the pan and have the usual fittings and mountings the same as for coil pans.

Standard Coil Vacuum Pans with Normal Heating Surface.

No.	Dia. of Vac Pan.	Heating Surface Sq. Feet.	Normal Strike Capacity. Massecuite. Tons. 2,240 lbs.	Cub. Feet.
1	4′ 6″	70	2·0	48
2	5′ 0″	100	2·75	66
3	5′ 6″	133	3·75	90
4	6′ 0″	160	4·5	108
5	6′ 6″	195	5·4	130
6	7′ 0″	260	7·25	174
7	7′ 6″	345	9·5	228
8	8′ 0″	400	11·0	264
9	8′ 6″	480	13·5	324
10	9′ 0″	560	15·5	372
11	9′ 6″	720	20·0	480
12	10′ 0″	750	21·0	504
13	10′ 6″	800	22·0	528
14	11′ 0″	860	24·5	588
15	11′ 6″	900	25·0	600
16	12′ 0″	1010	28·5	684
17	12′ 6″	1120	32·5	780
18	13′ 0″	1260	35·0	840
19	14′ 0″	1550	43·0	1030
20	15′ 0″	1770	50·0	1200

Calandria Vacuum Pans

With Normal Heating Surface

No.	Dia. of Vac. Pan.	Heating Surface.	NORMAL STRIKE CAPACITY.	
			Massecuite.	
		Sq. Feet.	Tons. 2240 lbs.	Cub. Feet.
1	6′ 0″	255	5·3	127
2	6′ 6″	310	6·5	156
3	7′ 0″	375	7·8	187
4	7′ 6″	450	9·4	225
5	8′ 0″	550	11·5	276
6	8′ 6″	670	14·0	336
7	9′ 0″	800	16·7	400
8	9′ 6″	920	19·0	456
9	10′ 0″	1060	22·0	528
10	10′ 6″	1210	25·0	600
11	11′ 0″	1360	28·5	684
12	11′ 6″	1540	32·0	768
13	12′ 0″	1680	35·0	840
14	12′ 6″	1850	38·0	912
15	13′ 0″	2000	42·0	1008
16	14′ 0″	2320	48·0	1152
17	15′ 0″	2650	55·0	1320

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CONDENSERS.

Formerly each pan and evaporator had its own jet condenser, generally situated on the top of the air pump; the condensate and cooling water, as well as the air, were discharged through the air pump, which was known as a wet air pump. In recent years the jet condenser and wet air pump are rapidly disappearing, being replaced by Barometric Condensers, from which the cooling water is discharged by gravity through a fall pipe some 36 feet high, the air being evacuated by a dry air pump.

The Barometric Condensers are designed on the counter current principle, as illustrated opposite, in which the vapour enters at the lower part of the condenser where it meets the hotter descending cooling water first: the air finds its way to the top of the condenser after passing through successive cascades of cooling water, being drawn off by the air pump from the top of the condensers where it has last been in contact with the cooler water, thus reducing the volume of the air as much as possible: this reduction of the air to its smallest volume is further assisted by a small spray of cooling water

which is mingled with the air in the air-pipe leading from the condenser, any water spray entrained by the air being separated out in a small cylindrical separator outside the main condenser.

In many cases condensing water is scarce and has to be used over and over again, being cooled by passing over a cooling tower or through spray nozzles. The temperature of water thus cooled rarely comes down to that of fresh river water, and may at times reach as high a temperature as 100° F. or even more.

The temperature of the cooling water is an important point when dealing with condenser problems. With water from a cooling tower, due to its higher temperature, a much larger quantity has to be pumped through the condenser than when using fresh river water, which has usually a much lower temperature. There is generally a difference of about 5°F. between the temperature equivalent to the vacuum in the vapour main and the temperature of the water discharged from the condenser, when using a minimum quantity of water ; so that, in case of trouble occuring through low vacuum, it is well to try the temperature of the hot wells as it is

sometimes the case that, due to some obstruction in the pipe, an insufficient supply of water is reaching the condenser. The temperature corresponding to different vacuum are given here in the Table :—

Temperatures corresponding to Vacuum.

Vacuum in inches of mercury ...	20	20½	21	21½	22	22½	23
Corresponding temp. degs F. ...	161°5	159°3	157.1	155°7	152°2	149°7	146°9
Vacuum in inches of mercury ...	23½	24	24½	25	25½	26	26½
Corresponding temp. degs F. ...	143°9	140°8	137°5	133°8	129°9	125°6	120°7
Vacuum in inches of mercury ...	27	27½	28	28½	29	29½	...
Corresponding temp. degs. F. ...	115°2	108°9	101°3	91°8	79°3	59°5	...

Another table is given showing the quantity of cooling water in pounds, at various initial temperatures, required for each pound of vapour condensed under vacuum. The table gives a range of vacuum from 25 ins. to 27½ ins. It has been compiled on the basis that a difference of temperature of 5°F. exists between the temperature of the hot well and the temperature of the vapour.

Table showing weight of Condensing water required per pound of vapour.

Initial Temperature of cooling water.		Inches of Vacuum.						Pounds of cooling water per pound of vapour condensed.
F°.	C°.	25	25½	26	26½	27	27½	
74	23·3	19	20	22	25	29	35	
76	24·4	19	21	23	26	30	37	
78	25·5	20	22	24	27	32	40	
80	26·6	21	23	25	29	35	44	
82	27·7	22	24	27	31	37	47	
84	28·8	23	25	28	33	40	52	
86	30·0	24	26	30	35	43	58	
88	31·1	25	28	32	37	47	66	
90	32·2	26	29	34	40	52	75	
92	33·3	28	31	36	44	57	88	
94	34·4	29	33	39	48	64	105	
96	35·5	31	36	42	52	73	132	
98	36·6	33	38	46	58	85	177	
100	37·7	36	41	50	66	102	267	
102	38·8	38	45	55	75	126	549	
104	40·0	41	49	62	88	167	...	

In practice 60 times the weight of vapour may be taken as a maximum. It will be observed from the table that with the higher temperatures of cooling water an impracticable quantity is required to give a high vacuum. In making calculations for the amount of cooling water required under normal conditions the best figure to use is 40 times the weight of vapour to be condensed.

The injection water is only one factor in a condenser problem, another and equally important factor is the amount of air leaking into the system. Every care must be taken to stop such leakage; even a comparatively small hole or a number of individually small leaks will cause a considerable fall in the vacuum.

It is pointed out that the Maximum cooling water gives the maximum quantity of cooling water which the condenser can operate with when using water at comparatively high temperature. With a lower temperature of cooling water a correspondingly smaller amount is necessary for the working of the condenser; the capacity of the injection pump would be to suit the quantity of water required. That is, the

size of the condenser is fixed by the bore of the vapour pipe but the quantity of cooling water required is determined by its temperature; the maximum quantity of water which can be utilised by any particular condenser is that given in the table, and is sixty times the weight of the vapour condensed.

For ratio between cooling water and weight of vapour condensed, the previous table may be consulted.

Counter Current Barometric Condensers.

No.	Bore of Vapour Pipe.	Lbs. Vapour condensed per hour.	Maximum cooling water Gallons per minute.	Bore of Injection Pipe.
1	12"	2100	210	4"
2	14"	2700	270	4"
3	16"	3700	370	5"
4	18"	4700	470	5"
5	20"	5900	590	6"
6	22"	7100	710	6"
7	24"	8500	850	7"
8	27"	10700	1070	8"
9	30"	13200	1320	8"
10	33"	16000	1600	9"
11	36"	19000	1900	10"
12	39"	22000	2200	11"
13	42"	26000	2600	12"
14	45"	30000	3000	12"
15	48"	34000	3400	13"
16	54"	43000	4300	15"
17	60"	53000	5300	16"
18	66"	64000	6400	Two 12"
19	72"	76000	7600	,, 14"
20	78"	90000	9000	,, 15"
21	84"	104000	10400	,, 16"

In the table each condenser is listed with one vapour inlet of appropriate diameter. It is, however, often convenient to provide a condenser with several vapour inlets to suit the connections from pans and evaporator. The combined area of such inlets should, of course, not exceed the area of the single inlet given in the table for any particular size of condenser.

In many factories the vapour from all pans and evaporators is conducted to one large condenser, while in others there is a separate condenser for each pan and evaporator, though one air pump may serve them all.

The disadvantage of one central condenser is that on the vapour outlet from each vaccum pan there must be a valve to isolate the pan from the condenser when emptying the pan's these valves being large are somewhat difficult to keep tight ; further, when fresh pan is started up, unless the connection between pan and condenser is opened very gradually, the large body of air admitted to the condenser and air pump will cause the vacuum in the condenser and consequently in the pans, etc., which are working on it,

to drop to an appreciable extent and thus affect their boiling; until equilibrium is again established. There is no actual necessity for this drop to occur if sufficient care be exercised in opening up the by-pass so as to give the air pump ample time to evacuate this extra volume of air; as a matter of fact this time is rarely allowed and therefore the vacuum drops.

A preferable arrangement is to have a separate condenser for each pan and evaporator, especially when the large isolating valves are unnecessary. A single dry air pump may be coupled up to serve all condensers, the air suction pipe being comparatively small the valves for shutting off any particular condenser when emptying the pan are easily kept in order.

Dry Vacuum Pumping Engine.

Diam. of steam cylinder.	Dia. of Pump cylinder.	Stroke.	Revs. per min.	Gross Displacement cub. feet per Hour.
10"	12"	12"	95	8940
12"	14"	12"	95	12180
13"	16"	15"	90	18770
13"	18"	15"	90	23860
14½"	20"	18"	85	33380
15"	20"	18"	85	33380
15"	22"	18"	85	40400
15"	24"	24"	80	60330
17"	24"	24"	80	60330
18"	26"	24"	80	70790
19"	28"	24"	80	82100
19"	30"	24"	80	94250
19"	32"	28"	70	109240
21"	36"	36"	60	152690
24"	40"	36"	60	188500

CHAPTER II.

THEORETICAL ASPECTS OF BOILING.

Pure sucrose is a true chemical compound, and its chemical and physical properties have been studied, so that we are familiar with and can predict its behaviour under such conditions as would be encountered in normal sugar manufacture. Unfortunately in the manufacturing process we do not deal with sucrose in its pure state, and the presence of unknown non-sucrose compounds of varying composition and quantity introduces a variable response to the chemical and physical reactions which we institute.

At a given temperature a fixed maximum amount of pure sucrose may be held in solution by water. No more than this maximum amount will pass into solution as long as the temperature remains unchanged, even though we hold the solution in contact with undissolved sucrose. Further no sucrose will crystallize from solution when equilibrium has once been reached. This, then, is defined as a "saturated solution."

If a saturated solution be cooled, or if a portion of the water should be evaporated without change of temperature, we have in solution for the moment an amount of sucrose which exceeds the theoretical amount which may be held dissolved in a saturated solution, for we realize that the crystallization of the excess sucrose is not an instantaneous process, but requires some time to crystallize and restore equilibrium at the saturation point, the velocity depending on many variables. A solution in which is dissolved more than the theoretical amount of sucrose required for saturation at a given temperature is said to be supersaturated. We are indebted to Cloassen for an expression which proves useful in discussing the degree of saturation of sugar solutions. He offers the term :—

"Coefficient of Supersaturation"= Amount of sucrose in soluion at temperature T ÷ Theoretical solubility of sucrose in water at temperature T.

When a supersaturated solution is produced by either of the methods available —that is, by removal of water by evaporation, or by cooling—there is a tendency

towards re-establishment of equilibrium at the saturation point. This is accomplished by the excess sucrose crystallizing from solution; this reaction is not instantaneous, however, like chemical reactions which result in the formation of an insoluble precipitate. A condition of supersaturation may be likened to an internal pressure, seeking to force the sugar out of solution; opposed to this crystallization pressure may be other forces tending to retard crystallization. We regard viscosity as such a deterrent to crystallization, while the tendency of sucrose to form chemical compounds of weak chemical affinity may also be so regarded. That there may be a great variety of causes which combine to inhibit the free and rapid crystallization of sucrose from solution is a fact which we recognize technically. For example, in the high purity solution found in white sugar manufacture, a very slight supersaturation is sufficient to start the formation of crystals, and the growth of crystals may be affected by a few degrees change in temperature. But when we reach low-purity crystallizer products, we find that we must concentrate to relatively high densities and give a

material time interval before the crystallization will begin. These conditions are well recognised and need no further elaboration.

We can produce in the laboratory a great variety of solutions of sucrose and non-sucrose compounds, with the sucrose exhibiting different solubility characteristics in each case. We find certain non-sugars with the apparent capacity to increase the solubility of sucrose at a given temperature over that shown in a pure solution of sucrose alone, whereas other chemical reagents have the opposite property of decreasing the solubility of sucrose. This condition is then similiar to that we meet in the technical production of sugar, and the presence of non-sugars of varying composition and amount introduces many complications into the control of crystallization operations. This is the most logical explanation of the variations which we find in the degree of exhaustion of final molasses, for variations in the rapidity of crystallization in products of different purity, and for the lack of uniformity in response of the various sugar-house liquors from which we seek to separate crystalline sugar.

As long as the amount of sucrose in solution is equal to or less than the solubility of sucrose at the saturation point for the conditions existing in any technical solution of sucrose and non-sugars in water, there will be no tendency for the formation of crystals. The super-saturation co-efficient is less than unity, and we may consider that there is no crystallization pressure. If we evaporate water from such a solution until we pass the saturation point, we initiate an urge to crystallization. When the crystallization pressure exceeds the effect of the factors retarding crystallization there will be a formation of crystals which will continue to grow as long as the degree of supersaturation is sufficient to overcome these retarding influences. It is recognized that once the initial crystallization has started, the crystals will grow with a lower supersaturation than that requried to start their formation. Once crystals are present in a supersaturated solution, the tendency is for crystallizing sucrose to attach itself to the crystal surface already developed. There is a limit, however, to the rate at which these crystals will grow by the

accretion of the depositing sucrose, and practical observations indicate that this rate is influenced largely by the rate of circulation within the vessel, or more exactly, by the rate at which the crystal surface moves through the supersaturated solution. Since we have no means of measuring circulation, this factor is not capable of definite expression; but we do know that for a given vacuum pan, with its own peculiar rate of circulation as determined by its design, we may determine the optimum concentration, or supersaturation, for a given quality of massecuite which will give the optimum rate of crystal growth. If this rate of accretion is exceeded, due to a too rapid rate of boiling or a rapid decrease in the temperature of the massecuite, we find that instead of depositing on the existing crystal surface, the new crystallized sugar will form a new set of crystals; this secondary group of crystals is known in sugar terminology as "false grain". Its appearance is undesirable because it results in crystals of different size from those initially started, and frequently this size is such as seriously to interfere with the purging character-

istics of the finished massecuite when it reaches the centrifugals.

To summarize the foregoing discussion, we find that the initial charge of material within the vacuum pan; known as the "graining charge", must first be concentrated to the proper density, so that the initial crystals will form in proper number, compatible with the type of finished product we seek to produce; secondly, after the initial grain has been formed we must maintain the proper concentration so that this grain will continue to grow at the maximum rate which can be tolerated without causing the formation of "false grain". Herein lies the sugar boiler's art. By purely personal judgment, which is usually enhanced by the extent of his experience, he must learn to recognize the conditions of density of mother liquor which will give the best results in the two particulars just outlined. Any error of judgment will be reflected in the quality of his results and may require heroic measures to correct these mistakes if a definite economic loss is not to be sustained. Unfortunately, the results of imperfect operation by the sugar boiler are

not directly reflected in tangible figures, though much of the variation in these results as shown by chemical control data probably is occasioned by undefinable variation in procedure. Certainly no one will dispute the statement that more uniform and consistent vacuum pan operation will be reflected by increased recovery and reduced production costs, regardless of whether or not the amount of these benefits may be specifically determined.

CHAPTER III.

PRACTICAL HINTS ON SUGAR BOILING.

Sugar Boiling is the art of concentrating in a vacuum, juices and syrups to the point of crystallization where uniform crystals of a predetermined size will be obtained. Crystals of a prescribed size can only be obtained by splitting the boiling operation in two periods namely grain formation and the growing of the grain. Granulation is obtained by continuing the concentration of the syrup until a supersaturated solution is formed after which sugar must eventually separate, the crystallization taking place in the shape of minute, barely visible grains. In the latter period, juice or syrup is drawn in for the purpose of giving up its dissolved sugar to the grain already formed. The art consists first in producing the right number of grains and second in causing the grains to grow larger without the formation of new grains. But that is not all. In general, the desire is to carry out the boiling operation in such a way

that the further steps of the process, that is, the separation of crystals and molasses shall proceed as rapidly as possible with the least possible consumption of power and the greatest possible amount of sugar product.

It is not sufficient to prepare sugar with a good colour and lustre but one must always take care in the first product at any rate, that the grain is not irregular and specially not too small. This is a fault to which much so calld "Superior Sugar " is liable. For this reason endeavours must be made in the first place not to make the thick juice (syrups) too dense, since this renders difficult the boiling of large and regular grain. A density of 27·5 Be. is sufficient. It should, moreover, not to be forgotten that an irregularly grained massecuite machines with difficulty and demands more water and steam than regular thus finally giving more syrup, so that the fuel advantage of the more concentrated thick juice most likely disappears. Again for a good subsidence the thick juice should not be too concentrated.

For treating the subject of sugar boiling from practical point of view, heating of

the internal surface of the Vacuum Pan with open steam, before it is charged with syrup, is carried out lest the cold sight glasses may break up. This is followed by the production of Vacuum in the Pan to draw in syrup from the supply tank. Steam supply is then made to the coils (or calandria as the case may be) taking care that no coil uncovered with juice or syrup is supplied with steam otherwise too much heating of the liquor at the upper surface will be done and the inversion along with the burning of sugar may be the result. Charges are made frequently until the required quantity of the required Sp. Gravity of the syrup is put in the pan. The syrup at this stage is becoming denser and denser, the Vacuum is rising and the temperature is falling. At the point of supersaturation of the syrup, the fall of temperature will at once cause some of the sugar to crystallize out. This is what is the principle of Granulation.

There, while boiling juice or syrup in the Vacuum Pan, it is noticed as to how great is the necessity of good clarification to control the boiling work in the best

way. If the juice is even slight alkaline, glucose and other non-sugars will be decomposed with the formation of various acids and colouring matter. But that is not all. The acid may decompose further and cause heavy frothing which may in some cases pass into the condenser. The same thing may happen if the syrup supplied to the pan is too much acidic. Besides this, if the syrup is dirty the complete exhaustion of molasses becomes difficult.

The quantity of syrup used for graining is the next important thing. Dependent on the type of the sugar required, the quantity of the syrup used for graining is varied. Evidently the less syrup taken in, the smaller is the number of the crystals formed and the larger will be the size of the crystals obtained in the completion of the strike. The thinner the syrup larger will the crystal become and *vise versa.* The bolder and the more regular the crystals required the weaker the thread and the lower final concentration. When making fine grained sugar, the massecuite should be strongly concentrated before every fresh portion of the syrup is drawn

in, when making large crystals, the syrup should be drawn in, in large portions at a time and when making fine grains the portion should be small but frequent In no case, however, should the supply of the syrup be so large as to redissolve the existing crystals. The more regular and the larger crystals desired, the slower and the quiter has the boiling to proceed, while a brisk boiling is favourable to the formation of small crystals. In the case of large crystals the final concentration may be high and since large grain facilities the spinning off of the molasses in the centrifugal, great care, however, to be bestowed on boiling off as coarse grain massecuites are liable to form false grain between the crystals.

According to the size of the crystals required, the amount of the syrup present in the Vacuum Pan at the moment of the formation of grains should range from 25 to 40 per cent. of the total quantity of the syrup required for boiling. Two-fifths of the total of the syrup taken in as the graining charge will afford a small averaging 0·5 mm. and one-fourth will give a grainy sugar with a side of about 1 mm.

When it is wished to still further increase the size of the crystals as in the manufacture of fancy sugars the operation known as "Washing" is employed. In this process, the sugar boiler, after obtaining the crystals of a certain size, takes in large charges of syrup, juice or even water whereby the smaller crystals are dissolved, the deposit continuing on those that remain. A second device to this end is known as "Cutting" a portion of the contents of the finished strike being retained in the Pan to serve as footing for the next operation.

GRAINING OF SYRUP.

As regards the present practice of graining, the actual process used by the coolie pan boilers and the theory underlying is worthy of attention. As soon as juice has reached a certain concentration in the Vacuum Boiling Pan, sugar begins to separate in the shape of minute barely visible grains. This is, in fact, the most important moment in the process of sugar boiling for at this time the products makes its first appearance in its proper form. The coolie Sugar Boilers sense the momentousness of this first appearance of crystallization which they express in feeling.

In all the hand-books on sugar manufacture are to be found certain maneuvers which the sugar boiler can use to obtain grain, for example the drawing in a small quantity of juice at the critical moment, by shutting off some steam or by introducing more injection water. The writer was therefore surprised to find out that hardly any of the pan boilers in various sugar

factories in India, made any use of the set of the methods proposed in the books for graining of syrup. At nearly all times their secret consisted in simply "waiting" after the syrup is somewhat concentrated up. On the spontaneous formation of grains, further crystallization is broken off by diluting the mass to lower sp. gravity. What happens is this, that by continuing the concentration of the syrup until a supersaturated solution is formed sugar must eventually separate in the form of minute crystals. The detailed theory of the process may be given as follows : with the increase of the density of the syrup in the Vacuum Pan, the amount of the water in the syrup becomes less and less. Since water alone is the medium of taking heat from the coils, with the decrease of the water contents, the rate of evaporation decreases in the Pan. But the power of the condenser attached to the Vacuum Pan, of cooling down the hot vapours and getting out noxious gases etc. from the pan is the same at all times because the temperature of the cold water supplied to the condenser is practically constant and that the speed of the Vacuum Engine is the

same. Hence a definite amount of hot water vapours are cooled down and thus destroyed per minute. But the rate of formation of the vapours is less when the syrup is concentrated up. Hence there will be less amount of uncondensed vapours remaining in the pan at the concentrated stage. The result will be the increase of the Vacuum and the decrease of the temperature. Thus as the syrup in the pan becomes denser and denser, the vacuum rises and the temperature, on the other hand, falls. At the point of supersaturation of the syrup, the fall of temperature will at once cause some of the sugar crystallize out. This is what is the principle underlying the formation of grain by the usual practice in India.

It is worthy to mention that "Boiling to Grain" is far better than "Boiling to string proof". As a general rule boiling in white sugar manufacture should be done exclusively to grain, even with the after products string-proof boiling should entirely be discarded and if the purity of the first or second molasses is too low to build up grain from them, they should be returned to a pan where some first massecuite is already present so as to be desaccharified

oy the existing crystals to the desired point. Not only does boiling to grain produce a better-shaped and more easily curable crystal and give better yields, for that reasons but string proof boiling requires a tedious cooling in crystallization tanks where owing to the acid reaction, there is much danger of inversion and loss of sucrose.

Thus by the method of "Waiting" when the required amount of grains have been formed, introduction of more syrup is made to dilute the remaining concentrated syrup in the Pan and check thereby the formation of any more grains. Then the feeding of the grain is done with more syrup, intermittently. In so doing and controlling the rate of the deposit or of evaporation, the operator is guided by the senses of sight and touch, especially as indicated by the viscosity of the mother liquor, in small samples withdrawn from the pan by the proof stick. Of all operations in the sugar house, this is one that has to be learnt by experience. However, attempt is made to describe the process to some extent. The rate at which the sugar deposits on the crystal is a function

of purity increasing as to the purity increases.

To find out the exact point of the feeding with a new charge, the proof-stick should be well-washed and the sample should be drawn out on a piece of glass. At first while putting the sample on the glass, its flow from the stick to the glass should be noticed carefully for this is the only stage when we are examining the sample at the same temperature as that in the Pan. From this very flow, the sugar boiler should at once mark the density of the massecuite. If the massecuite has become nearly saturated, new charge should be at once made without examining any other condition otherwise false grain may result. If experience is less to mark the flow and thereby the density, put quickly the sample on a piece of glass and by keeping it vertical mark the flow and judge thereby the density. However, if this does not give full satisfaction, try to feel the massecuite by spreading on the glass by the left-hand thumb and notice the presence of "honey-like substance" in it. All this should be done quick enough otherwise the temperature of the sample will fall in contact with the cold atmosphere around

and the sample will become denser showing "honey-like substance" in it, It should be borne in mind that the slight feeling of this honey-like substance proves the formation of nearly saturated solution and requires new charge to be made to dilute the stuff, prevent the formation of new grain and continue the feeding process. However, in the modern time of investigation, various instruments such as "Brasmoscope" etc., have been put on the market and now it is not a difficult job to control the density of the massecuite in the Vacuum Pan.

The Phenomena underlying the feeding of grains is also worthy of attention. When grains of rice are boiled in a sugar solution by the process of diffusion, the solution passes into the internal mass of the grain of rice. The heat supplied makes the water to evaporate off and leave the sugar in and on the rice grain. Same is the principle of the development of sugar grains in the pan. The less denser syrup passes through the inner mass of the sugar crystal by simple diffusion. The water in the syrup evaporates off leaving behind the sugar in and on the crystal and thereby increases its size. On the development of crystal, more juice at a time than before,

can pass in the internal portion of the grain and thus the speed of the growth of the crystal increases. Moreover, when the sprup becomes concentrated, it can no more pass through the crystal. At this stage, dilution of the concentrated syrup is necessary to continue the development of the crystal otherwise the point of super-saturation will reach and new grains may be formed. But on the development of crystal, the time after which the stage comes, goes on increasing. Just after the graining point this stage is reached very soon for the grain is very feeble while the time goes on increasing for making new charges as the crystal developes.

SEEDLING PREFERRED.

White Sugar destined for direct consumption as already mentioned should not only be white and brilliant but should also possess a regular form and a rather large size. This latter point makes it preferable to start the building up of grain from a well-developed seed. In order to obtain this without too much waste of time and of pan capacity it is advisable to have all the pans connected with one another by large pipes provided with valves which permit the contents of one pan to be drawn over into another, while one pan or all of them should have a wide pipe through which a magma of sugar crystals and syrup may be sucked in from outside in order to serve as seed.

This method itself is very old one, seems lately to have been further improved in America. According to Mr. Bourne sugar is sifted through a 100-mesh sieve and drawn in, in the ratio of ½ to 2 quartz per 1,000 cubic ft. of massecuite. However, in no case grains of different size are used

as seeds. It should also be borne in mind that the seed develop very quickly for their body is not so feeble as that of those at the actual granulation. Thus the masse-cuite becomes concentrated in comparatively less time and new charges are required to be made quick comparatively.

In general, the process is of great advantage for if on destroying the false grain, some other crystals be also dissolved up leaving less quantity of crystals than necessary the number of crystals can be increased by supplying in some seeds.

FALSE GRAIN.

The one danger against which the sugar boiler has to guard is the formation of "False Grain" or of a second independent granulation. This may occur through a sudden fall in the steam pressure or by a sudden increase in the Vacuum, both causes acting through a fall in temperature of the contents of the pan. It may again be caused by the introduction of too large a charge which does not mix well with the material already in the pan and is always more likely to occur when the circulation is faulty due to bad design, the cause of another nature happens when making sugar of large grain as there is a limit to the size to which the crystal can be grown unless the rate of deposit is proportionately decreased. However carelessness also introduces false grain when the massecuite is heated to the supersaturated point in the pan after granulation period.

Let us now think how false grain is noticed. Its answer is not far to seek.

The increase of grains per unit of area of the massecuite indicates the presence of false grain. On the other hand, the regularity and equality in size of the grains are the sure tests of the absence of the undesirable grains. This is best seen by making a thin layer of the massecuite, on a piece of glass or between the thumb and the adjoining finger of the left hand. The comparatively smaller new grains are better noticed sparkling in the thin layer of the samples made between the thumb and the adjoining finger of the left hand generally because in so doing, it is easy to compare the size of the grains in a thin layer when they are very small in size and when they develop in size it becomes more to see in this way for the developed ones cannot stay in the thin film and have to go towards the fingers leaving the comparatively smaller ones alone in the film like sparkling stars.

OBJECT AIMED AT IN SUGAR BOILING.

The formation of a regular grain of a predetermined size has been mentioned as the object aimed at in sugar boiling. Attempts will now be made to investigate the means which may lead to the attainment of the above-stated object. It is self evident that a regular grain should contain as little fine grain as possible, that is to say, after the grain proper has been formed no new crystallization should occur. But although formation of fine grain may be avoided, it does not follow that grain obtained will necessarily be regular. This depends entirely on the manner in which seed grain has been formed. The period of grain forming therefore occupies the centre of attention. In fact, a regular grain is only to be obtained by shortening the period of grain forming. In simple words, the regularity of grain formed by the "Waiting" method depends on the time elapsed between the appearance of the first and the last of the needed crystals.

The fact is that it is not an easy job to prevent secondary crystallization. Nearly in all massecuites a certain amount of fine grain may be seen. That is something that cannot be avoided in practice. False grain does occur in smaller and larger amount in every massecuite, it is not possible to prepare a massecuite in which the grain will be of the same size. It is well known that secondary crystallization occurs when the supersaturation is carried too far. Too high supersaturation may be due to lack of attention by the sugar boiler. Too coarse grain, too rapid boiling and too high viscosity may be the other causes. But that is not all. Insufficient circulation can be responsible for high supersaturation and thereby for the formation of new grains.

A certain amount of practice is required to keep the supersaturation fixed at a certain degree. It is this that sometimes betray the sugar boiler. So this feature of the sugar boiling operation can be made easier by the use of control instruments.

Something as to how too coarse graining can be the cause of secondary crystallization may be mentioned. A grain that is too coarse indicates that in graining too

few seed crystals are obtained. This is due to inattention on the part of the sugar boiler. The total surface of crystals in this case is too small, their average distance apart is too great, consequence is that the discharge of the mother liquor by the crystals present proceeds at too low a rate in comparison with the rate at which the juice is being concentrated. However, the formation of false grain can be prevented by boiling slow enough.

As regards too rapid boiling, it is sufficient to say that when there is just sufficient surface for the crystallization no increase in the rate of boiling is available.

High viscosity is the most dangerous thing in sugar boiling work. If no obvious fault has been committed in boiling and no other explanation of the false grain suggests itself, it may be ascribed to the viscosity of the mother liquor. Viscous solutions naturally crystallize slowly and easily give rise to dangerous supersaturation.

Insufficient circulation is a cause of false grain that stands in close relation to those already named. As concentration proceeds, the crystals more and more lose their mobility in the liquor that is continually

becoming stiffer, the lower the purity the more especially is this state of thing noticeable in the final boiling off. Practically all of the massecuite which the writer studied contained a little false grain formed in the last stages, here the sugar boiler can do little to help the matters. Often the false grain is so fine that it escapes observation by the naked eye.

But that is not all. Even at low degrees of supersaturation that is not itself dangerous, it is possible for false grain to form. This formation of false grain occurs in the most notable degree when working with turbid juices or syrups. Clear juices often contain a larger or smaller amount of fine solid particles as any one may easily convince himself with the help of the Tyndal Effect if necessary.

It is apparently true that these small particles are the cause of Secondary grain formation at low degrees of supersaturation, the suspended mud particles serving as points at which spontaneous crystallization occurs. There are possibly other causes of spontaneous crystallization which may lead to secondary grain formation at low degrees of supersaturation. This is a further inviting field for new investigations.

Mr. J. G. Thieme has done a lot of work about this. His work is suggested for reference.

Next to this is reported some experience in regard to the removal and avoidance of secondary grain. If the cause of false grain-formation lies in turbid juice, too large grain or high viscosity, attempts to remove this grain are not recommendable because when such causes are at work the false grain will continue to be formed. False grain arising from inattention may be removed by washing, whereby the smallest crystals are again brought into solution. It is accompanied by raising the temperature in the pan by the introduction of more steam or less supply of cold water to the condenser or an excessive charge of juice or syrup. All this is intended to dissolve up the false grain. However, the usual procedure adopted is as follows: make an excessive charge of juice or syrup and also raise the temperature in the pan. The latter can be done by cutting the supply of cold water in the condenser, but in that case, time required for heating up the contents of the Pan, is too much to wait. The best is to increase the temperature by introducing air in the Pan and thereby lowering

the vacuum and increasing the temperature. This is done very cautiously with a minimum speed, noticing the rise of temperature carefully. If the rate is too high it is possible that the whole of the grain may be dissolved up. Moreover, the moment, the dissolving of the false grain begin the supply of the air to the pan should be at once cut off for the higher temperature does not fall at once and the high temperature if maintained may dissolve up more of the grains than required. But that is not all. The period immediately after washing, when the original vacuum is restored is the most dangerous. New false grain may easily be formed. For this reason, vacuum is allowed to increase slowly, at the same time diluting by drawing in juice or syrup.

Moreover, one should be very cautious in dissolving the false grain when the other crystals are very feeble as just after the granulation period otherwise more of the crystals may not be dissolved up. In fact, it is much more rational to prevent the formation of false grain than to try to get rid of it.

Another policy of the sugar boiler is worthy of consideration. It is well known

that the lower the degree of saturation the less is the danger of new crystallization. For this reason, many sugar boilers keep the massecuite very thin. However, they often go too far in this direction, a certain degree of supersaturation is necessary otherwise the time of boiling is unduly prolonged. When working too thin, the pan becomes full too soon and the main part of the work has to be done in final stage, of boiling off. During this stage, howover, the supersaturation can no longer be controlled by drawing in juice or syrup and there is generally no time available for boiling off slowly. The result is, that while false grain is avoided during the drawing in period, it occurs during the last period of boiling off.

FORMATION OF COARSE CRYSTALS.

If coarse crystals are to be made, which is the case in the manufacture of granulated plantation whites, the graining must be done "Low down" in order to give the crystals time and space to grow to the required size. Graining "low down" cannot be done in a calandria pan, unless special arrangements are made, *e. g.*, calandria could be constructed in two pieces with an empty space between them, but a common calandria occupies so much room and reaches so high that a rather large amount of syrup must be in the pan when steam is admitted to the calandria, to prevent the hot surface from protruding above the level and charring the drops of syrup drying there. (Better get calandria with one coil at the bottom).

In a coil pan the difficulty is overcome by only admitting the steam in those coils which are covered by the syrups and then one is able to grain as low down as desired, by only admitting the steam in

the lowest coils and leaving the others cold.

It is clear that owing to this procedure the greater part of the heating surface remains unemployed and that both time and pan capacity are wasted, but if the grain is made in a special pan and has attained a certain size, the whole mixture may be drawn over into the vacuum pan, coil or calandria pan, until the whole heating system is submerged. This can then come into action with its full capacity and thereby the whole power of the pan at its best is utilized.

STIRRING ARRANGEMENT.

When boiling last—product massecuites, which are strongly concentrated, the natural circulation occasioned by the boiling is not strong enough to ensure the proper admixture of the pan's contents and hence the pan in which the after-product massecuites are boiled should be provided with a stirring apparatus. In most cases this consists of a screw revolving in a wide central tube open at both ends. The stiff mass is raised at the centre and induced to flow downwards at the sides while the empty space in the centre is filled by the adjacent mass from the sides, thus creating a slow movement of the contents of the pan.

This circulation is most necessary for several reasons. First, the massecuite remaining stationary at the same place may cake against the coils, by locally over-heated, and become coloured by the too elevated temperature. A second reason is that the crystals in the stiff mass are not free to move, and thereby cannot grow regularly

which is one of the first requirements for a good white sugar for direct consumption. Finally the lack of circulation may give rise to the circumstance that when molasses is returned into the massecuite, as is always the case when after-products are boiled to grain, large portions of the former do not mix with the latter whereby the desired effect of the desaccharification process is totally lost, the result being that a final molasses of too high a quotient of purity is discarded by the factory. For these and yet other reasons the circulation on the vacuum pan should be artificially promoted for which purpose a stirrer as described above will render good service.

Pan in which first massecuites are to be boiled and in which the fluidity of the mass is maintained throughout the whole process, do not need a stirrer; only those for last massecuites require one, but in order to be free to choose whatever pan one likes for the after-products, it is safe to have every pan provided with the stirring apparatus which may be used or left idle at will.

Instead of a screw revolving in the pan, circulation is sometimes promoted by a perforated copper coil at the bottom of pan, through which dry low-pressure steam is

blown into the boiling mass. By this operation the vacuum is not perceptibly lowered and the massecuite is kept in gentle movement. The perforations of the coil should be made on its under-side in order to prevent them being choked with crystals when the pan is discharged. Another good device for promoting circulation is to introduce the syrup and molasses through a bent pipe extending nearly to the bottom of the pan, so that the thin liquids are compelled to force their way upwards through the massecuite and so become thoroughly mixed with it, which is not the case if the molasses is introduced at the top of the massecuite upon syrup already there. The same end is sometimes gained by drawing in the syrups and molasses through a perforated coil at the bottom of the pan. To prevent chokings this coil is likewise perforated on its under-side.

These last devices will render good service in mixing the molasses with the massecuite from syrup, but they are useless after the mixture has already been performed and the mixed massecuite has to be concentrated. That is then where the stirring apparatus comes in and keeps the contents of the pan in motion till the end of the concentration.

FEEDING WITH MOLASSES.

Most of the massecuites to be made will consist of mixtures of a primary massecuite from syrup and of molasses having a certain quotient of purity, which both together have to make up the massecuite wanted. The quantities of the two constituents are determined by their purities and that of mixed massecuite desired, using a very simple calculation, so that the percentage of the primary massecuite which should be in the pan before the molasses is added, is estimated beforehand. In order to facilitate the work, a scale should be printed on the outside of the pan showing percentage of the contents so that the sugar boiler can know exactly how far he has to fill his pan with the primary massecuite to be sure of a final massecuite of good composition suitable for which it is intended.

The molasses, to be added afterwards to the primary massecuite, do not part so easily with their sugar content thereby offering a far smaller opportunity for the crystallization of fine sugar crystals

and therefore this may be drawn into the pan with a higher density even up to 38° Be. measured hot.

The temperature of molasses at all events should be at least equal and preferably higher to that of the massecuite in the pan otherwise the introduction of cold molasses might cause the formation of false grain from the liquid in the pan.

Now when the pan is full, the supply of the syrup or molasses is stopped and the massecuite is heated to a Brix of 92°—93° (a water content of 9—11 per cent) usually at the temperature of 65°C(149°F) and at the vacuum of 28 inches. In other words, at this stage the massecuite is so much concentrated that after cooling down in the crystallizer, it becomes of the minimum workable density. It is not good plan to concentrate the massecuite in the pan to the maximum required density because at that stage, the flow is very slow, and thus much time is required in discharging and that much of the massecuite is caught up by the coils and the walls of the pan and is scaled up there.

When the pan is discharged up, a certain amount of massecuite always remains attached to the coils and to the walls of

the pan which if allowed to stay, would become charred by over-heating and produce dark coloured lumps in the sugar of next strike. It is better to steam the pan thoroughly at this stage and get it cleared.

STORY OF SUGAR BOILING.

The story of sugar boiling is as simple as anything. A required quantity of juice or syrup (depending on the size of the crystal required) is taken in the Vacuum Pan for granulation by short charges at a time. The syrup becomes denser and denser until the point of supersaturation is reached. At this point crystals separate up themselves by the fall of temperature on the increase of the density of the syrup and thereby its vacuum. When the required number of grains are formed up the syrup (better say massecuite) is diluted by new charge to stop the further granulation. By careful addition of more syrup, the grain is allowed to grow regularly, care being taken that the concentration of the liquid (in which the crystals float) does not become as high as before graining since this might give rise to a secondary crystallization. When this happens this is detected by the turbid appearance of the mother liquor in the samples drawn out from the pan and these crystals known as

"False Grains" must be redissolved. To this end, a large quantity of syrup (taking necessary precautions already mentioned) is drawn in the pan and the temperature is raised by breaking up the Vacuum or injection diminished and steam turned on. The fine crystals are thereby redissolved, the original crystals being somewhat diminished in size but by causing the temperature to fall slowly, the latter commences to grow again. Then the feeding of the crystals is done intermittently until the pan is full. The pan boiler must not force the concentration too much at the end of the operation because if false grain is now formed it can no longer be dissolved owing to imperfect circulation.

However, when the pan is quite full, the massecuite is heated to a Brix of 92°—93° and then it is discharged up in a crystallizer.

In the crystallizer nothing but simple feeding of the crystals takes place avoiding the formatian of new grain. The sugar particles directly in contact with sugar crystal are the only ones that enter in its growth. When the film becomes exhausted a diffusion between this and the adjacent film takes place and so on. Since

the greatest impediment to diffusion is viscosity, any condition that decreases viscosity hastens the feeding. The viscosity greatly increases in proportion to the extent of drop in temperature. Stirring brings about equal temperature conditions and an equal density throughout the massecuite. Moreover, too rapid cooling is avoided. So stirring hinders the formation of new grain and keeps the grains already formed equally distributed throughout the mass. It is advisable that the last massecuites which are to be separated into sugar crystals and exhausted molasses, need, a thorough cooling in order to force all the crystallizable sugar to assume the crystalline form for if the molasses in which it is contained were not cooled to a low temperature it might hold sugar in solution which had been disposed to crystallize out, but now is thrown away in exhausted molasses causing loss. The cooling, however, must not be pushed further than 45°C and remain preferably a couple of degrees above, as at that temperature crystallization is finished and below it the natural viscosity of the molasses increases so much that cooling down to a lower point only causes trouble without any compensating advantage.

CHAPTER IV.

MIXED MASSECUITES.

(*Proportion of Molasses and Syrup according to Mr. Spencer.*)

Mixed massecuites should be boiled to a definite purity, depending upon that desired in the molasses to be obtained from them. This formula is sufficiently accurate for practical purposes.

(A)

Let 100 = Total weight of massecuite in the strike.

P = Purity of syrup.

M = Purity of required massecuite.

x = percentage by weight of the strike to be formed of molasses.

$100-x$ = percentage by weight of the strike to be derived from syrup.

p = Purity of the molasses to be boiled in.

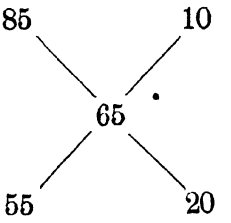
Then $x = \frac{100\ (P-M)}{P-p}$.

This formula may be applied with less accuracy when P is the Purity of a footing

or nucleus upon which a strike is to be completed with molasses.

(B)

This calculation may be made with greater facility by Cobenze's method for mixtures, illustrated in the diagram and example :—



Let 85 be the co-efficient of purity of a syrup and 55 that of a molasses and let it be required to make a massecuite of these having a purity of 65. Arrange the numbers as in the diagram. Subtract the purity number for the massecuite from that of the syrup and the number for the molasses from that of the massecuite and arrange the remainders, as shown in the diagram ; the remainder, 10, is the number of parts of syrup required and 20 that of the molasses. If the percentage of each constituent is required, divide the number of parts of each by the total numbers of parts, and multiply by 100. As in the previous method, using purities only in calculating the mixture, it must be assumed that the densities of the solutions are the same.

This method may be used for all mixtures and facilitates the solution of many otherwise complicated problems. If any three numbers used in the diagram are given the other two are readily ascertained.

CONTROL OF THE SUGAR BOILING.

The control of the vacuum pans and crystallizers requires rapid analytical work of moderate accuracy.

The analysis of the syrup as made in the daily routine work, or in its stead the analysis of the juice, and that of molasses indicate the quantity of the latter to be drawn into the pan to produce a massecuite of a certain purity. These calculations are made by the following formula, with sufficient accuracy for the purpose: —

$$x = \frac{100\,(P - M)}{P - p}\,.$$

Where,

P = Purity of the syrup, or in the case of a cut strike, that of the massecuite left in the Pan.

p = Purity of molasses to be boiled in.

M = Purity of required massecuite.

x=percentage by weight of that part of the strike to be formed of molasses.

$100-x$=percentage of the strike to be derived from syrup or from a previous boiling.

Let 100=total weight of massecuite in the strike.

The proportions of the materials used in making a mixture of a certain purity may also be quickly calculated by the diagram method previously mentioned. It is not feasible in pan-work to base the calculations on actual weights. The approximate densities of the massecuite footing, for example, and the molasses to be boiled in should, however, be considered.

A sample of the mixed massecuite should be brought to the Laboratory immediately the strike is dropped. A portion of this should be dissolved in water to form a solution of about 15° Brix, and its apparent purity should be determined. A second portion should be purged in a laboratory centrifugal and the purity of molasses be determined as above. (Use dry lead Horn's method).

The purity data of the massecuites and molasses samples should be promptly sent

to the superintendent and the pan-boiler. All mixed strikes, especially those of the lowest purity, should be controlled in this way. The relation between the purity of the massecuite and the molasses purged from it in the laboratory, immediately after boiling, is a valuable guide in boiling low-purity mixed strikes.

Very often this method of control will indicate whether the pan-boiling is good or poor. When a low-purity massecuite, yields a high-purity molasses, on immediate purging it indicates poor boiling. A few days' experience with the pans, following the work with these control tests, will usually indicate whether the sugar-boilers are obtaining the best results, the pans and material are capable of yielding.

SYSTEMS OF SUGAR BOILING.

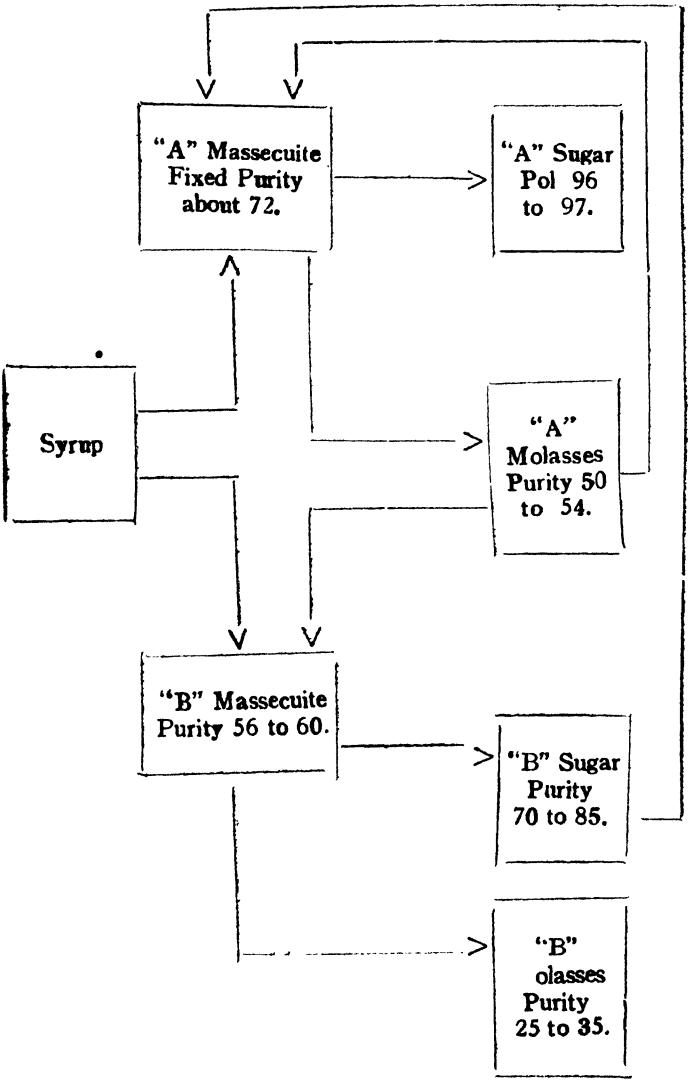
Systems of sugar boiling must necessarily vary in minor details, according to the available equipment and the quality of cane. But there are two systems in fairly general use which may be outlined and a third which have been recommended at some of the controls of sugar.

THE TWO BOILING SYSTEM.

This really requires an infinite number of boiling, since same first molasses is continually returned to a strike of similar purity to that from which it originated. It is called Two Boiling because only two grades of massecuites are produced, one commercial sugar massecuite and one low grade crystallizer massecuite. In this method grains for "B" or low grade massecuite is generally formed from syrups and built up with "A" molasses. The "A" or the commercial sugar massecuites are usually started on a magma of "B" grade seed, built with syrup and finished with sufficient "A" molasses to make up a massecuite of a fixed purity which shall yield commercial sugar and "A" molasses whose purity shall be low enough to boil, mixed with syrup from "B" strikes.

The fixed purity of "A" (mass) may be 72, yielding about 52 purity A molasses, part of which is returned to reduce the purity of "A" strike and part boiled for B massecuite. A modification of this methed is to grain "A" molasses (not syrup) in the "B" massecuite. Here the purity of "A" massecuite should be a few points higher,

THE TWO BOILING SYSTEM.



to raise the purity of "A" molasses by a few points.

With "A" massecuites boiled at a fixed apparent purity of 72, yielding sugar of 97·5 and molasses of 52 apparent purity, each commercial sugar strike will average to yield 44 per cent. of its own weight or it will require 227 tons to yield 100 tons of commercial sugar.

(2) POINEER SYSTEM.

This system differs greatly from the preceding one. In this three or four commercial strikes are boiled, depending upon the initial purity of the syrup. If the purity is very high four strikes may be boiled. On the other hand if the purity is very low, only two strikes are boiled. First strike is started on "seed" and fed by syrup. All the molasses from this, is boiled in the next strike which is likewise started on "seed" and syrup and all the molasses from the 2nd is boilded into a third strike like 2nd one.

Molasses from the third is about 50 to 57 purity and is all boiled for crystallizers "B" massecuites.

In this system no syrup is used for graining low grade strikes but they are started on the footing of undiluted "A 3" molasses and cut until the proper size of the grain is obtained.

Advantages over the Two Boiling System.— The average massecuite purities in this system are considerably higher, since only one of the three strikes is boiled at as low purity as all in the Two Boiling System.

"A" massecuites of 80 purity, yielding 97·5 pol sugar and all three A molasses

of about 60 purity, each commercial strike will yield 53·3 per cent. of its weight of commercial sugar or it requires 187 tons of commercial sugar strike to produce 100 tons of commercial sugar. This system therefore requires less pan and "A" centrifugal capacity (about 20 per cent.)

Disadvantages.—It requires separate storage for all three "A" molasses, (2) with fluctuations in the purity it is sometimes doubtful whether to return A_3 molasses for third strike or for crystallizers. This also effects the purity of "B" massecuites.

(3). COMBINATION SYSTEM.

It is somewhat similiar to the systems used in a number Cuban centrals, with some difference of graining and disposal of low grade sugars. This system has been worked out to combine the advantages of all the systems, *i. e.*, higher purity massecuites, less reprocessing of non-sugars, better economy of steam and equipment, direct graining of low grades (of Poineer system) and the simplicity and constant purity of the Two Boiling System.

A simpler method of maintaining the high average massecuite purities, but using only two commercial sugar boilings, is to start with one or two straight syrup strikes as usual, then boil mixed strike of fixed purity, such that its resultant molasses shall have the same purity as the crystallizer massecuities. The molasses from the mixed strikes is not returned, but is all boiled from the crystallizers.

The fixed purity chosen for mixed strike (A') is 77, depending upon the local conditions, and purity of the molasses yielded is about 57 which is the same as that of crystallizer massecuites. Factories having plenty of low-grade sugar centrifugal capacity should keep the purity a higher by a few points to completely exhaust the final molasses.

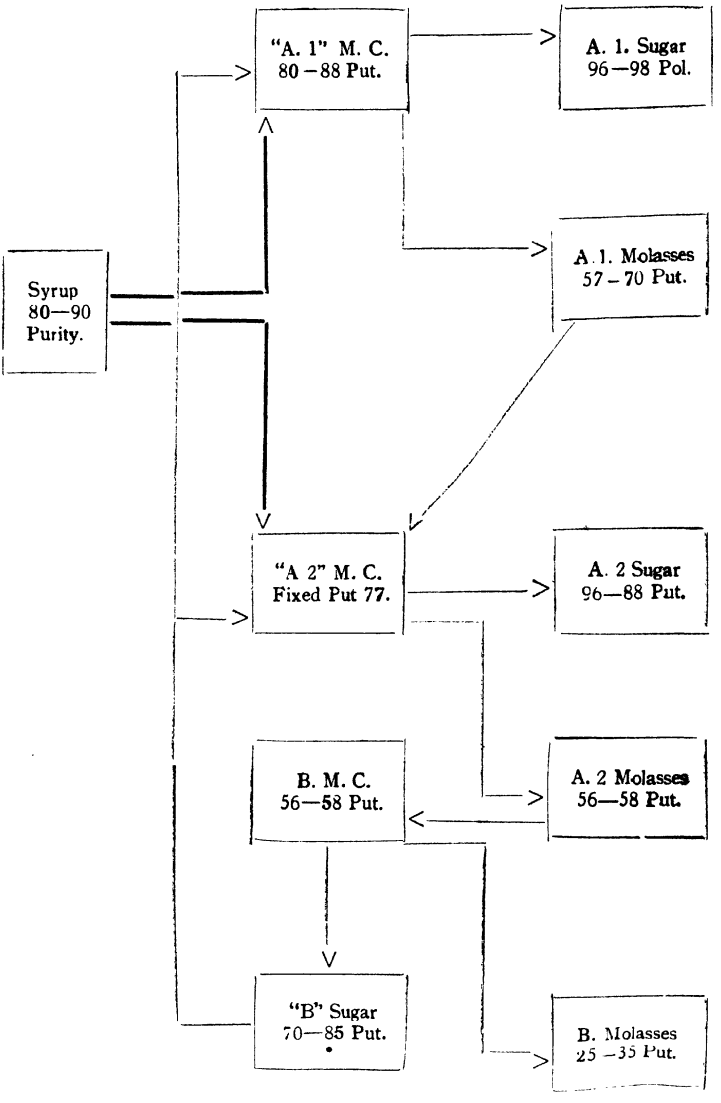
The percentage of A, 1 molasses required for the fixed strikes can be calculated as in two boiling system.

$$\text{Here per cent. syrup massecuite} = \frac{77 - M}{S - M}$$

When S = apparent purity of syrup massecuites and M = apparent purity of A. 1 molasses.

Graining of "B" massecuites.—A small portion of A-2 molasses of 56—58 purity is

COMBINATION SYSTEM.



pumped into a separate tank without dilution, or steam and reserved for seed. This undiluted molasses is full of microscopic crystals formed mostly by the shock and cooling as it is drawn from A_3 sugar in the centrifugals. The remaining A_3 molasses is blown up with steam and diluted to 70—75° Brix.

In starting grain, enough *diluted molasses* is drawn in to cover the calandria of the pan this is concentrated a very little so as not to dissolve the grain to be introduced but is not concentrated to its graining point. *Undiluted molasses* containing natural grain is then drawn in, a very little at a time, until sufficient grain can be seen. The amount of grain required is soon learnt by experience. After sufficient grain has been taken in, boiling is continued with dil. molasses as usual until pan is full. It is then generally necessary to cut either to another pan or to a special tank along side the pan, making 2 or 3 strikes from one graining in order to build up finished masse-cuites with grain of 3 to 5 mm. average length. This method requires a little practice, but is well liked when mastered. It is no use boiling commercial sugar masseçuites at extremely low purities,

getting a first molasses much lower than the required purity of "B" massecuites and raising this purity again by the addition of syrup.

DISPOSAL OF THE "B" SUGAR.

The simplest method where time and steam economy are of more importance than the recovery and quality of sugar, is to make large grained crystallizer massecuite and double purge the resulting sugar or mix it with higher polarization sugar. Low grade sugar, however, satisfactorily grained contains impurities in its crystals, which cannot be removed "*affixations*".

Mixing of B sugar with syrup and using it as seed for commercial sugar is commonest and most economical method. It has the draw-back, that the nucleus of each grain of commercial sugar is originated from the lowest purity massecuite, and low grade sugar, however, thoroughly washed, has a lower filteration rate than sugar of same pol. made from the syrup.

If the best grade of sugar is required, commercial sugar massecuites should be grained on syrup and low grade sugars should be redissolved and reclarified before returning to process. The above procedure is more logical than double purging since

it eliminates suspended impurities at each cycle, while double purging only removes impurities from the commercial strikes and concentrates them in low grade strikes. Unfortunately it is very difficult to remelt and reclarify with ordinary equipment.

METHOD OF SUGAR BOILING FOR ALL SUGAR PURITIES BETWEEN 70—90.

INSTRUCTIONS.

"*Seed massecuite.*—Concentrate syrup till sufficient grain appears for about 4 strikes, depending on size of seed tank. Build up with a little syrup to set the grain and cut over to seed tank leaving enough for one strike in the pan.

"*A*—0" *Massecuite.*—Start with seed made as above and build up with syrup till pan is nearly full. This massecuite is generally too small grained to discharge directly, but used as a footing for either "A—1 or "A—2".

"A—1 MASSECUITE.

Start on cut from "A—0," build up and finish on syrups and dry in centrifugals without washing, finished sugar crystals should average 1 to 2 mm. long.

A—2 MASSECUITE.

As often as sufficient "A—1" molasses accumulated, start with a cut from "A—0", build up with syrup and finish with A—1 molasses. Purity should be 77, crystals 1—2 mm. long.

B—0 MASSECUITES.

Start with dil A—2 molasses to cover calandria, concentrate nor much nor less, bring undil A—2 molasses, until sufficient grain appears, build up with dil A—2 molasses. Cut part to seed "B storage tank".

B—1 MASSECUITE.

Start on a cut of "B—0," build up slowly with dil A—2 molasses, concentrate and discharge to crystallizers.

THREE MASSECUITE METHOD BY MR. SPENCER.

A first massecuite is boiled of the purity of the cane syrup. If the syrup purity is above 87°, it is sometimes, necessary to inject some first molasses into the first pan to obtain a sufficient fall in purity from syrup to molasses. If the fall in purity is insufficient it may be difficult to exhaust the final molasses to a low purity in three stages. In boiling the mixed massecuite, a "cut" of massecuite from a first pan is used as a nucleus or footing, upon which to start the strike. The writer has slightly modified this procedure as will be explained further on. The mixed massecuite should have a purity of from 75° to 80°. The purity of this massecuite is governed by the desired purity of the second molasses for which a purity of 52° is a convenient number. The purity to be given to the second or crystallizer massecuite depends upon several factors; as vacuum pan capacity, crystallizer and centrifugal capacity, and the desired exhaustion of the final molasses. The lower the purity of this massecuite the longer is the time required in boiling the strike. A very low purity massecuite must remain a long enough time in the crystal-

lizers in order to reduce its viscosity by crystallization of the sugar and promote rapid purging, where molasses is sold upon a basis of a certain sugar content, this also must be considered in fixing the purity of the second massecuite. For obtaining final molasses of apparent purities below 30°, early in the season in the Tropics, and from 30° to 35° when the cane is ripe and of very high purity, the massecuite should be reduced to approximately 60° purity. Where the pan, crystallizer and centrifugal capacities are large, the purity may be reduced below 60° with correspondingly lower final molasses purity but this would not usually bring a sufficient return for additional investment and fuel.

The first and second massecuites may be purged immediately after leaving the vacuum pan and should produce the same grade of sugar and molasses of widely different purities. The third or crystallizer massecuite is purged after remaining three or four days in crystallizers.

The main method evolved was :—

(1) *First massecuite*, containing only Syrups or a syrup and a very little molasses. This is therefore a molasses of high purity.

(2) *Mixed massecuite,* containing a footing of massecuite from a first pan and a large proportion of first molasses. This is of medium purity, approximately 75° to 80°. The first and the mixed massecuites will produce the same grade of sugars.

(3) *Crystallizer massecuite,* this is of low purity, usually 60° and upward.

At present in many factories it is only two massecuites that are boiled, *i. e.,* first and second giving first and second grades of sugars respectively. The quantity to be taken of each (syrup, H. or Light molasses) depends upon the quality of sugar to be made etc.

CHAPTER V.

VACUUM PAN CONTROL AND AUTOMATIC SUGAR BOILING

According to Mr. Walter E. Smith the Automatic Sugar Boiling System is based on a well recognized physical principle, that solids in solution will increase the temperature at which the solution boils above the boiling temperature of water at the same pressure. For organic solids, such as sucrose, dissolved in water, this elevation of the boiling point may serve as a quite accurate index of the density, though it does not hold for solids which dissociate freely in aqueous solution. Water boiling at atmospheric pressure will have a temperature of 212° F; if we add sucrose, the temperature of the boiling solution will be greater than 212° F, the elevation of the boiling point increasing correspondingly with the increase in the amounts of sucrose in the solution. Conversely, we may use this boiling point elevation as a measure of the amount of dissolved sucrose, and for practical purposes we should be relatively correct in saying that two solutions of sucrose boiling at atmos-

pheric pressure, or at ary other equal pressure, and having the same temperature, will also have the same amount of sucrose in solution.

This boiling point elevation is affected only by the solids in solution. Sucrose crystals which may be present will not have any influence on the boiling temperature. Thus, the boiling point elevation becomes a measure of the mother liquor density when we are boiling solutions from which crystals are depositing; this is precisely to control sugar boiling operations.

To develop a system of control based on this fundamental principle we require two measurements; first, the boiling point of water at the pressure existing within the vacuum pan, and second, the boiling temperature of the massecuite, or sugar liquor itself. These measurements seem simple enough, but actually some special arrangements must be made in order to arrive at a proper measurement of these factors. Practically all of the many schemes proposed in the past for control of sugar boiling have been based on this measurement of boiling point elevation. But all had one error in common: they took as the boiling point of water a figure taken from steam tables for

the pressure indicated by the vacuum gauge. Steam tables showing the temperature of saturated steam for any given vacuum are usually referred to a barometer of 30 inches, or some such common standard. But obviously the vacuum cannot be taken as an index of the boiling temperature of water unless the barometer at the time and place of measurement is of exact standard, or unless suitable correction is made for variation from this standard by first obtaining the actual barometric reading. For example, the temperature of saturated steam at 26 inches vacuum, referred to 30 inch barometer, is 125.—38° F, so that if a sugar solution is boiling under of exact 26 inches of vacuum when the barometer stands at 30 inches and at a temperature of 145·38°, the boiling point elevation is 20 degrees. If the barometer falls to 29·8 inches (and at this point it may be remarked that a variation of this extent is probably a matter of more than daily occurrence under quite normal atmospheric conditions), the boiling point of water at 26 inches vacuum as determined with a mercury column would change to 123·5°. Under the foregoing conditions the boiling point elevation would actually be 21·8 degrees,

whereas by our method of arriving at this figure by the use of steam tables we would obtain the same figure as formerly; that is 20 degrees. Thus, if we continue to assume the same boiling point for water by obtaining this factor from tables, we immediately introduce an error of 1·8 degrees. It will be shown later that boiling control based on the measurement of boiling point elevation cannot tolerate an error of this magnitude. So we see that systems which calculate the initial boiling point of water from steam tables may be in error from two to five degrees. Obviously, this error would introduce countless inconsistencies in results which would make such a system valueless.

The writer avoids this error by the simple expedient of actually obtaining by measurement the temperature of water boiling at the pressure existing within the vacuum pan. A small tank is fitted to the vacuum pan at some convenient point; this pot is connected to the top of the pan vapour space by a pipe line of suitable size, so that exactly the same pressure exists in both the pot and the vacuum pan. By means of a small open steam coil, this water is heated to the boiling point and a

supply of heat continuously furnished. Thus, regardless of changes in the vacuum or in the barometer, the water continues to boil at the actual absolute pressure of the vapour space of the vacuum pan and there is no need to make assumptions; the temperature of this water is the boiling point of water at the pressure then existing in the pan.

Next comes the measurement of the temperature of the boiling massecuite. Heretofore it has been customary to insert a short-stemmed thermometer through the wall of the pan. Usually such a thermometer has a stem about six inches in length, which is thus immersed in the stream of massecuite rising at the outer surface of the vacuum pan. Circulation within the vacuum pan is obviously upward on the outside, since this is the location of the heating surface, and downward in the centre of the pan where the centre well is located. But it is obvious that this circulation is initiated largely by convection currents set up by the difference in temperature between the hotter outside portion and the cooler inner portion, hence we may presume that temperature measurements at these points would give distinctly differ-

ent results. Because of the static head, it is possible for material below the surface of the massecuite to be heated above the boiling temperature corresponding to the pressure existing in the vapour space. For example, at a point 6 feet below the surface of a massecuite at 92° Brix, the pressure would be 18 inches vacuum when the vacuum of the vapour space above the massecuite was 26 inches. Thus, the massecuite temperature would need to be 44 degrees higher to cause ebullition at this point than at the surface of the massecuite. Assuming now that we have set up a condition of super-heat at a point below the surface as compared to the boiling temperature at the surface of the massecuite, the convection current set up will bring this super heated material to the top. A point will be reached at which the temperature is sufficient to cause ebullition, and the material will then boil—that is, it will give off actual vapour—and by this flash evaporation the material will cool to the boiling point corresponding to the pressure. The point of least pressure will be at the surface, so that once the ascending material reaches the surface it will give up its super-heat and reach its lowest

temperature for the existing pressure. Because this material is now cooler than the ascending stream, it will tend to gravitate to the bottom, thus setting up a distinct convection current which we call "circulation." Pan design is based on a recognition of this principle, and we provide a section in the centre of the pan in which there is little or no heat transfer, and consequently no tendency to produce an upward rising current to oppose the downward flow of the cooler massecuite or liquor. But this downward-flowing material has risen to the top and released its super-heat, the temperature in this current must be virtually the boiling temperature of the massecuite at the pressure of the vapour space, so we may measure this temperature and use the result as our second factor in determining the boiling point elevation. In practice, therefore, we immerse the thermometer in the down-flowing current in the centre of the pan, and call this temperature the boiling point of the massecuite at the vapour pressure of the pan.

Measurements of the temperature of the ascending and descending columns of massecuite by means of short-stemmed and long-stemmed thermometers showed that

the difference between these two columns varied from two to about eight degrees, according to the stage of boiling. During the early part of the strike, when circulation presumably was at its maximum, the difference would be as low as two degrees. Later, this would increase to about eight degrees as the massecuite level became higher and the density greater. This temperature measurements in the outer zone do not serve as a reliable index of actual boiling-point temperature, while the temperature of the centre zone seems more indicative of the true condition.

This is all speculative reasoning, and not conveniently subject to direct proof. But if we base a system of boiling control on the assumption that measurements of the points selected correctly represent the respective boiling points of water and massecuite at the vapour pressure existing within the vacuum pan, and find in practice that the results obtained are consistent and give us a thoroughly workable basis on which to form opinions as to conditions within the vacuum pan, may we not rightly conclude that for practical working purposes our assumptions are substantially correct? In view of the fact that we have

been able to boil sugar of all grades with the boiling point elevation measured as described as the only guide, without reference to any of the indications which are used by sugar boilers under present methods, the writer maintains that the foregoing basic principles become thoroughly substantiated.

EQUIPMENT AND OPERATING RESULTS.

We may now turn to a description of the equipment used in the practical operation of the proposed method of boiling control.

One of the most accurate methods for measurement of temperature is the use of electric resistance thermometers. Such equipment is made up of a resistance coil of suitable materials, and operates on the principle that the resistance of this coil is proportionate to its temperature ; by measurement of this resistance with suitable equipment we may obtain a very accurate measurement of temperature. Electric resistance thermometers are available in many types, including a recorder which may be calibrated and designed for any particular range. By a further change in construction, such an instrument may

be designed to record the difference between two temperatures which are being measured by two resistance thermometers. Such a device may then be used, inserting one thermometer in the boiling-water pot and the other in an appropriate position in the centre of the pan, and the record produced will show the actual difference in temperature or we may arrive directly at the boiling point elevation.

This instrument may be carried a step further. By the use of suitable auxiliaries it may be made to function as a controller, actuating a moter-driven valve on the feed line of the pan so as to regulate the feed and so maintain the density of the massecuite to correspond to any selected boiling point elevation.

The equipment used in these experiments was constructed by the Leeds and Northrup Company of Philadelphia. We shall refer to the actual apparatus hereafter as the "Micromax Pan Controller."

The experimental development of this system was made in a sugar factory, where the equipment was installed on the finishing commercial sugar pan. The boiling system followed is to make seed from low-grade sugar in another pan, cutting the

proper charge to the finishing pan where the crystals are built up and the massecuite concentrated to proper density for the centrifugals. The first strike of each series may be called "A" strike, made up of low-grade-sugar seed and syrup ; the following "B" strike takes back the molasses from this "A" strike. When syrup purities require it, a third or "C" strike is boiled, from which the molasses is boiled for crystallizers. The usual method of boiling was intermittent feed ; that is, at the proper time a charge of syrup or molasses was admitted to the pan and the feed valve closed until the massecuite was boiled to the density at which additional liquor was required.

A typical record was produced by the Micromax pan controller during the boiling of the "A" strike. The fluctuations in the record indicated variations in the boiling point elevation, corresponding to similar fluctuations in density of mother liquor. The high points represented points of increased density, while the low points showed the minimum density reached after admitting "drinks" of syrup to the pan. An interesting condition was also marked. The density reached a point corres-

ponding to a boiling point elevation of 20·5 degrees, and it was noted that at this density false grain appeared. In order to redissolve this false grain it was necessary to thin out mother liquor with water or syrup, the resulting condition of density being shown quite clearly by the greater than normal depression of the boiling point elevation curve beyond this point. This condition was repeated later at another point, say B, though it may be noted that at this second point a considerably higher boiling point elevation was reached before false grain appeared. We know, of course, that at this stage in the boiling the mother liquor purity was lower than during the early point of the strike, and apparently a higher density was required to produce a supersaturation coefficient enough to cause the formation of false grain. Again at some point B it was necessary to "wash out" the false grain, and low density was indicated by the valley in the curve.

The practice of intermittent feeding of the pan had been followed at the factory because the operator considered it was easier to avoid false-grain formation. With the Micromax pan controller chart before the operator to guide him, it was thought

it would be easier to control the density, so the next step was a change to continuous feed, by which we mean that the syrup was admitted in a continuous stream. The density was then maintained at a higher point continuously, at what we considered the optimum point for crystal building, but lower than the point at which false grain would be formed.

The record was produced when the pan operated under continuous feed, and the chart was used as a guide by the sugar boiler. It was noticed that there was a different condition maintained. Starting with a boiling point elevation of 17·5 degrees, the density was maintained at practically a constant point, though slowly building up to 20 degrees by the time the feed was closed and the pan concentrated to discharging density. The variations are very small, and at no time there was any material momentary change in massecuite density. Then a record was maintained at a slightly higher range than before. Both charts are typical of good operation, showing remarkably good adherence to the predetermined programme laid out for the sugar boiler.

These charts illustrate what we mean by the ability to prescribe the operating conditions under which the vacuum pan should be operated. At the end of two weeks of observation we were able to designate definitely the conditions we wished to maintain as to density, expressed in terms of boiling point elevation. Sugar boiling instructions should be reduced to the following formula :—

For "A" strike: Bring the cut over charge to 18 degrees boiling point elevation before opening the feed valve. Then adjust the feed valve to maintain this figure, gradually and slowly adjusting the feed so that the boiling point elevation advances 20 degrees by the time the feed valve is closed as the massecuite reaches the top working level of the pan.

If these conditions were maintained the grain would grow properly, without formation of false grain. It thus became possible for the sugar boiler to control the vaccum pan without having to examine samples taken from proof stick. After the first few days the sugar boilers became satisfied that the record actually gave them a reliable indication of massecuite density which agreed with their own opinions based

on their visual observations, and consequently they were able to base their manipulations of the feed valve on the instrument record, without bothering to draw proof samples from the pan. Because of the strangeness of this procedure, and because of life-long habits, the sugar boilers would occasionally examine the proof, but at no time did the condition of this proof sample indicate the need for adjustment of the feed in contradistinction to the indications of the instrument record.

Another typical record was obtained when boiling a "B" strike. Here the conditions which must be maintained were slightly different as to the actual magnitude of the boiling point elevation. Instructions for boiling "B" strike follow:—

For "B" strike: At the start, while boiling with syrup, gradually advance the boiling point elevation to 20 degrees after the syrup has all been taken into the pan. When boiling molasses, advance the boiling point elevation so as to reach 25 degrees after the pan is full.

By following these simple directions an inexperienced operator who understood

the function of the steam and liquor valves would be enabled to boil sugar without fear of obtaining unsatisfactory results.

EXPERIMENTS WITH AUTOMATIC BOILING.

Assuming that we have selected the range of boiling point elevation required for the proper boiling of a massecuite of given quality, be it A, B, or C, the next step would be to manipulate the feed valve automatically. The Micromax pan controller may be fitted up with suitable cams and contacts so as to govern the operation of a motor-driven valve on the feed line. By means of a dial on the front of the instrument these control contacts may be set for any special boiling point elevation and made to actuate the feed valve in a suitable direction as changes in density require it. For example, suppose that at the start of the boiling we wish to maintain 18 degrees boiling point elevation. The pointer on the control dial is set for 18 degrees, and when the record is below this point the valve will close so as to reduce the feed and bring the massecuite to the higher density desired. Conversely, when the record exceeds 18 degrees the control will

cause the valve to open, thus reducing the massecuite density to the proper point.

Obviously the response of the density of massecuite to change in rate of feed is not instantaneous, so provision must be made to allow a given change in feed to take effect. This was done by inserting an interrupting device in the control circuit; by means of an electrical clock the circuit to the motor valve was closed at two-minute intervals for a brief period, so adjusting it as to allow the feed valve to open or close to any desired extent. Thus after making a change in the amount of valve opening a two-minute period was allowed for this change to take effect, two minutes later, if the first change had not brought the density indication within the range of the control point, a further resetting of the valve would be made. If the record was at the proper point, no change would be made in the valve setting. A certain amount of preliminary work was required to find the proper amount of valve movement per cycle, but when this had once been established it became possible to operate the pan by automatic control of the feed valve.

CONTROL WITH LOW GRADE PAN.

Compared to the difficulty of producing satisfactory work in the low grade pan, the task of controlling commercial sugar pans is much simpler in every respect. Size of commercial sugar grain may vary throughout a considerable range without causing trouble; further, any effect on molasses purity, occasioned by a variation in the quality of boiling may always be rectified in the following strike so that the effect need not appear in the operating results. But such leeway does not exist in boiling low grade massecuites. Trouble here may result in poor purging characteristics of the resultant massecuite, and may finally cause an increase in molasses purity, thus actually reducing the recovery of salable sugar. There can be no question but that the boiling of low grades represents the most difficult part of sugar boiling operations, and that herein lies the biggest field for improvement which can be reflected in final operating results.

Preliminary investigations on low grade boiling indicated the need for improvement in the distribution of the feed when boiling on continuous feed. Principal among these troubles was the tendency for

thin liquor to rise to the top of the massecuite, where it would lie stagnant for a considerable period, after which it seemed to mix in all at one time, thus causing rather extreme variations in massecuite density not compatible with the extent of the feed valve opening.

During the process, the attention was first turned to the method of graining, which is the first important operation. The "shock-seeding" method was used first ; by this we mean boiling the graining charge to the proper density, or condition of supersaturation, and then inducing crystallization by introducing a small quantity of powdered sugar. We consider that this acts as a "shock" to the supersaturated liquor and initiates the formation of crystals. The value of "shock-seeding" has been the cause of much discussion for many years, and the writer had been sceptical as to the actual value of this method as applied to low-purity products. Our tests proved to our satisfaction that "shocking" of low grades was infinitely superior to any other method, and gave most consistent results.

Incidentally, it may be noted that for any given purity of graining charge it was

clearly established that as the boiling point elevation at the time of shocking increased, the number of crystals produced also increased while the size of the crystals was correspondingly smaller. Further, as the purity of graining charge was increased, the same number and size of crystals could be produced at a lower boiling elevation. At 52 purity it was found necessary to boil to a density corresponding to a boiling point elevation of 25 degrees, while at 60 purity the same quality of crystals could be produced at 21 degrees elevation. By further reducing the boiling point elevation we greatly increased the size of the crystals in the graining charge, reaching the limit at about 16 degrees. At this value it is possible to produce a sufficiently small number of crystals for the boiling of a strike of proper grain size without cutting out part of the original grain. Below this point "shock-seeding" would not cause crystallization. During the course of these experiments one further feature was introduced which was found most helpful in graining. We installed a small quarter-inch air cock, then, after introducing the powdered sugar for "shocking", the steam was shut off, maintaining

at the same time the vacuum on the pan, and opening the air cock. This allowed a small quantity of air to be drawn into the pan through the four liquor inlets, and this was sufficient to set up a definite circulation within the pan. The air bubbled up through the tubes in four separate areas, causing a flow upward through the tubes (and downward through the centre well) in the same way that water is caused to flow from artesian wells by the release of compressed air at the bottom of the well.

After this circulation had been maintained for from fifteen to twenty minutes a definite crop of crystals was obtained. At the end of about forty-five minutes these crystals had shown very definite growth, and if pan time permit to keep this circulation on for an hour or two there will be continued crystal growth.

Following the development of the grain, it was the practice immediately to start boiling with continuous feed. No further measures were taken to effect the grain; none was washed out with water, and it was not necessary to dilute mother liquor to stop grain formation. The number of crystals formed was definitely determined by the boiling point

elevation (that is, the degree of supersaturation) which existed at the time of "shocking" variations in the size and number of crystals could be controlled by variation of the density at which the "shock" was made.

Thus it has been possible to perform the most difficult operation in low grade boiling, the establishment of the original grain, by procedure which could be prescribed before-hand. Nothing was left to the judgment of the operator, and meanwhile a record was provided which showed plainly whether the prescribed instructions had been followed.

One troublesome factor enters into low grade boiling control which does not appear with commercial sugar boilings. This is the effect on the record of sharp drops in vacuum. The rate of heat transfer in the low grade pan is apparently rather low, particularly when the massecuite level is more than halfway up in the pan. If there is a sudden disturbance of the vacuum system due to cutting other pans into the system, resulting in a sharp drop of an inch or more in vacuum, we suddenly have a condition where the temperature of the pan is below the boiling temperature for

its density and the new vacuum; hence ebullition immediately stops and the rate of circulation apparently slows down materially. Meanwhile the temperature of the water in the boiling pot has quickly adjusted itself to the new boiling temperature for the changed pressure, this adjustment being complete long before the massecuite temperature has increased sufficiently to restart ebullition and boiling. As a result there is sudden reduction of the temperature difference between the water and the massecuite, and the record shows a quick decline. At this moment the boiling point elevation is not a true indication of the density of the mother liquor, for by definition the temperature difference which indicates density is the difference between the temperatures of water and massecuite boiling at a given pressure, and at this moment the massecuite is not boiling and several minutes will be required before the temperature of the massecuite can be brought up to that required for boiling at the lowered vacuum. Fortunately the shape of the fluctuation in the record is very distinctive, being a straight-line drop of five or ten degrees, which cannot possibly be mistaken for a

change in the density of the massecuite. It is again most fortunate that these fluctuations do not appear to take place in the opposite direction, for increases in vacuum cannot be as sudden as the drops, and in addition the massecuite will cool off by flash evaporation to accommodate itself to increased vacuum much faster than it can be heated up. Thus, upper limit of the record continues as a safe guide for control of densities in the upward direction ; this is the direction in which lies the danger of false grain, so we may disregard the momentary drops in the record at times of vacuum change without endangering the quality of boiling and still retain a safe indication of dangerous high densities which would produce false grain. While the record produced with low grade boilings in pans connected to a central vacuum system may not be free from fluctuations, a proper interpretation of the record will serve as a thoroughly reliable guide to boiling control.

The situation as to sudden vacuum drops may be improved by use of small lines which by-pass the main valves on the individual non-condensible gas lines to bring up the vacuum more slowly before

putting the pan on to the main vacuum pump. In cases of insufficient pan capacity the delay so occasioned may sometimes not be permissible ; if so, the vacuum may be brought up to about 25" by use of booster steamjet evacuators. Sudden drops in vacuum amounting to one or two inches are much more important than would at first appear, for they cause a reduction in the rate of boiling on all pans connected to the system and result in sudden increases and decreases in massecuite temperatures which may be very harmful from many standpoints. The question deserves serious consideration at factories operating with so-called "central vacuum system."

SUMMARY AND CONCLUSIONS.

Studies of sugar-boiling control, as described in some detail in the foregoing paragraphs, indicate clearly that the sugar-boiling processes and technique may be subjected to a nicety of scientific control which takes the operation from the field of personal judgment and individual skill.

The all-important factor in boiling control, the density of mother liquor, can be measured with sufficient accuracy for all practical operating purposes by determination of the boiling point elevation. The

method described heretofore appears accurately to determine this factor.

The boiling point elevation can be determined under conditions which yield satisfactory operation with conventional control: and conversely, satisfactory operation may be duplicated, in turn, by reproducing the boiling point, elevation which existed. at corresponding times when the boiling was being performed under the best obtainable degree of control with the conventional methods. Thus, the temperature conditions which form the basis of any prescribed method of operation are not arrived at from theoretical calculations, but are obtained by actual measurement under known conditions of operation; preferably they should be obtained as averages, thus compensating for the variations which occur under the best operation by conventional methods. Such data may be obtained by each operator, working with his own particular vacuum pan and the actual materials at his factory, thus compensating for peculiarities of equipment or materials. According to the best knowledge available so far there is no indication that daily or hourly variations in materials will greatly influence these results, if in

deed they have any effect at all. Perhaps some slight effect may occur seasonally, but, if so, due allowance can be made as may be required.

It appears entirely feasible to prescribe definite temperature elevation conditions for the boiling of various qualities of massecuite. Except in the matter of graining, the normal variations in purity appear to have no important effect; in graining, such as in low grade pans, a little preliminary study will permit the operator to determine what correction to apply for variations in the purity of his graining charge; this purity can of course be readily determined in advance.

Automatic control of boiling, by which is meant mechanical operation of the feed valve through electrical circuits, has been actually accomplished and presents no great problem. The writer feels, however, that the essential feature of the whole problem discussed in this is not that of developing a method of automatic control but of providing a means whereby definite knowlege may be obtained as to conditions within the vacuum pan, such information to be capable of expression in definite physical terms and in no way dependent

on the individual judgment of the operator. The development of such a method is far more important than the incidental fact that this system is capable of functioning through automatic equipment.

The equipment used in this system of boiling control was manufactured by the Leeds and Northrup Company. This equipment has proved thoroughly reliable, accurate and of great sensitivity. An essential feature of the equipment is its ability to indicate and record the temperature differences with an accuracy within a few tenths of a degree of the results obtained with most sensitive thermometers. This, of course, is a fundamental requirement, as the difference between danger and safety or between good and bad results can be obtained by a variation of not more than one degree in temperature difference from the prescribed value. The success of results is largely due to the ability accurately to reproduce temperature difference measurements and the implied existing conditions. Since this work was first started the Leeds and Northrup Company have co-operated to work out additional features of the equipment and now there is a standard specification ; this

standard instrument can be used as a simple recorder with control contacts which will operate signal lamps to warn or advise the operator of the status of existing conditions as compared to any selected value for which the control is set. These same control contacts may be used to actuate the automatic control valves. Thus, with this standard instrument a control system may be started wherein the Micromax pan controller is first used as a research instrument, and as a guide to the operator who adjusts the feed manually. Later, automatic control equipment may be installed and the same instrument can be used without furthur change. Means have been provided for checking the setting of the instrument, so that measurements may always be made with a fixed reference basis; this is a valuable feature and assures consistency in results at all times.

CHAPTER VI.

CRYSTALLIZERS AND THE PRINCIPLE OF CRYSTALLIZATION IN MOTION.

In all modern Sugar Making Plants the principle of Crystallization in Motion is being adopted in preference to the older method, where the massecuite was discharged from the vacuum pan into crystallizing tanks or waggons. This change is amply justified, through scientific experiments backed by practical experience, as the following will show. The danger of forming "False" grain during the boiling of the vacuum pan has been fully described; however, that danger is by no means over when the massecuite is discharged from the pan. While the massecuite is hot it contains more sugar in solution than it is able to hold after cooling, so that during the process of cooling the sugar in solution begins to crystallize out, and if the whole body of the massecuite is being kept in gentle motion the crystallization will take the form of building upon the existing crystals, but if the massecuite is

in a stagnant mass the sugar will form new crystals, thus "False" grain is found among the massecuite, which is a cause of serious loss of both sugar and time during curing.

PRINCIPLE OF "CRYSTALLIZATION IN MOTION."

In crystallizers, the feeding of crystals is done avoiding the formation of new crystals. The sugar particles directly in contact with sugar crystal are the only ones that enter in its growth. When this film becomes exhausted, a diffusion between this and the adjacent film takes place and so on. Since the greatest impediment to diffusion is viscosity, any condition that decreases viscosity hastens crystallization. The viscosity increases greatly in proportion to the extent of drop in temperature. Stirring brings about equal temperature conditions and an equal density throughout the massecuite. Moreover too rapid cooling is avoided. And that stirring hinders the formation of new grain and keeps the grains already formed equally distributed through the massecuite.

The modern crystallizer is made either the "Open", "Semi-closed" or "Closed" type. In the "Open" and "Semi-closed"

types the massecuite is led from the pan discharge valve into the crystallizer by an open gutter. There it is kept in constant motion by means of stirrer gear revolving in the crystallizer, and is finally discharged into the receiver over the centrifugals, either by gravity or by means of a pump or elevator. Crystallizers are frequently provided with a jacket round the lower part of shell, into which steam or cold water may be admitted at will, in order to increase or decrease the rate of cooling.

The "closed" type of crystallizer consists of a cylindrical vessel, with a manhole and cover on the top, a discharge valve on the bottom, and is like the "Open" type, frequently provided with a jacket. In operating this design of crystallizer massecuite may be discharged from the vacuum pan by means of a gutter, through the manhole into the crystallizer, which when filled is closed by means of the manhole cover. The cooling then takes place under a partial vacuum, a connection to the air pump being made from each crystallizer. The discharging of this type of crystallizer is occasionally assisted by compressed air.

GENERAL SPECIFICATION OF "OPEN" AND "SEMI-CLOSED" TYPE CRYSTALLIZERS.

Shell or vessel.—This is made of mild steel plates, the cylindrical part being in sections. The end plates are each in one piece, machine flanged, and riveted direct on to the shell.

Revolving Stirrer Gear.—Each vessel is fitted with stirring gear, consisting of angle steel arms or blades, evenly spaced between the beadings of the centre shaft, and to which they are securely clamped. The outer ends of each group of blades are joined together by flat steel bars, forming a spiral scraper, which when in motion passes close to the inside of shell plates, thereby causing the colder outside massecuite to give place to a fresh quantity, at a higher temperature, which again changes its place when the next scraper comes round.

The Centre Shaft.—It is made of mild steel and is square in section. It is supported inside crystallizer by cast iron pillow blocks, carried by channel steel beams fixed by knees to shell, and covered by a cast iron V-shaped coping, in order to prevent massecuite lodging on top of the

channel. The ends of shaft are supported by cast iron bearing blocks, which are bolted to end plates. All the bearings are provided with grease cups, carried, in the case of the inside bearings, above the level of the massecuite, upon wrought iron tubing, clipped to vessel.

Driving Gear.—The driving gear consists of a worm wheel, keyed on end of stirrer gear, engaging with a worm on cross shaft. The teeth of worm wheel and worm are machine cut and oil is provided for worm. The cross shaft is fitted with fast and loose belt pulleys and ball thrust washer and is carried by two pillow blocks which are bolted to the underside of the main bracket.

Discharge Valve.—This is arranged at the opposite end of the vessel from the driving gear, and consists of a strong cast iron frame bolted to end plate with sliding door.

Particulars of Open Type Crystallizers.

Working Capacity		Size.
Tons.	Cub. ft.	
4·15	100	3′ 0″ × 3′ 6″ × 13′ 6″
8·3	200	3′ 6″ × 4′ 0″ × 19′ 9″
12·5	300	4′ 0″ × 4′ 6″ × 22′ 9″
16·65	400	4′ 6″ × 5′ 0″ × 24′ 0″
20·80	500	5′ 0″ × 5′ 6″ × 26′ 6″
25·00	600	5′ 6″ × 6′ 0″ × 24′ 6″
29·15	700	6′ 0″ × 6′ 6″ × 24′ 0″
33·3	800	6′ 0″ × 6′ 6″ × 27′ 6″
37·5	900	6′ 6″ × 7′ 0″ × 26′ 6″
41·65	1,000	6′ 6″ × 7′ 0″ × 29′ 3″
45·8	1,100	7′ 0″ × 7′ 6″ × 28′ 0″
50·0	1,200	7′ 0″ × 7′ 6″ × 30′ 6″
54·15	1,300	7′ 6″ × 8′ 0″ × 29′ 0″
58·3	1,400	7′ 6″ × 8′ 0″ × 31′ 0″
62·5	1,500	8′ 0″ × 8′ 6″ × 29′ 6″
66·65	1,600	8′ 0″ × 8′ 6″ × 31′ 3″
70·8	1,700	8′ 6″ × 9′ 0″ × 29′ 6″
75·0	1,800	8′ 6″ × 9′ 0″ × 31′ 6″

Particulars of Closed Type Crystallizers.

Working Capacity		Size.
Tons.	Cub Ft.	
4·15	100	3′ 6″ dia × 12′ 6″ long.
8·3	200	4′ 0″ „ × 19′ 0″ „
12·5	300	4′ 6″ „ × 22′ 0″ „
16·65	400	5′ 0″ „ × 24′ 0″ „
20·8	500	5′ 6″ „ × 24′ 6″ „
25·0	600	6′ 0″ „ × 24′ 6″ „
29·15	700	6′ 6″ „ × 25′ 0″ „
33·3	800	6′ 6″ „ × 28′ 0″ „
37·5	900	7′ 0″ „ × 27′ 6″ „
41·65	1,000	7′ 0″ „ × 30′ 6″ „
45·8	1,100	7′ 6″ „ × 29′ 0″ „
50·0	1,200	7′ 6″ „ × 31′ 6″ „
54·15	1,300	8′ 0″ „ × 30′ 0″ „
58·3	1,400	8′ 6″ „ × 29′ 0″ „
62·5	1,500	8′ 6″ „ × 31′ 0″ „
66·55	1,600	9′ 0″ „ × 29′ 6″ „
70·8	1,700	9′ 0″ „ × 31′ 0″ „
75·0	1,800	9′ 0″ „ × 33′ 0″ „

CENTRIFUGALS.

Centrifugals are supplied for belt drive, water drive, or electric drive. All types are self-balancing and fitted with ball and roller bearings and conoidal buffers.

Belt Drive.—Each centrifugal is driven by a separate friction pulley mounted on a counter-shaft usually placed behind the centrifugals, so that the belts are not over the operator. The friction pulley can be easily adjusted to vary the rate of acceleration within certain limits, and all parts are accessible.

Water Drive.—There is an entire absence of belting and gearing in this type of machine, and there are no parts requiring lubrication except the ball bearing carrying the spindle of the revolving basket, which only requires a little grease.

The machines may be placed in any desired position without regard to the location of the driving engine or other source of power. The space occupied is defined by the actual size of the centrifugal itself. They are absolutely safe, there being no possibility of the speed rising above the safe limits.

The pump which supplies the water at the required pressure may be placed in any

convenient part of the building. A small tank is placed near the pump, from which it draws, and the water returns by gravity from the machines to the tank to be used over again. One important feature of the water driven machine is its perfect adoptability to the treatment of all classes of sugar.

Each machine is fitted with automatic cut-out gear, which automatically closes one of the water valves when the machine has reached full speed. The accessory machinery may either be driven by a water motor, steam engine or electric motor.

Electric Drive.—Electrically driven centrifugals are supplied for direct current or alternating current, but when the latter current is used only certain sizes of centrifugal s can be adopted, because the speed of a direct connected electrically driven centrifugal depends on the periodicity of the current and the number of pairs of poles in the motor. The standard arrangement of coupling between the motor and centrifugal is of the slip type which permits the motor to rise to full speed very quickly, the motion being imparted to the centrifugal by means of slippers, attached to the motor spindle, but in some instances

the motor spindle and centrifugal spindle are direct connected through a flexible coupling.

The switch and brake are interlocked, so that it is impossible to switch on the current while the brake is on or apply the brake while the current is on.

Each motor has its own elevating gear, and with this gear, the motor may be raised and swung round clear of the centrifugal spindle, thus giving easy access to the bearing and buffer.

The hinge-post of the gear is hollow, and as the cables between the motor and switch pass through the hollow post, it is not necessary to break any electrical connections before raising the motor.

Cycle of Operations in a Centrifugal.—In curing of sugar in centrifugal, the cycle of operations is as follows :—Charging, accelerating, running at full speed, stopping and discharging. Often the charging and accelerating will take place simultaneously. The full time of a cycle will depend upon the design, especially on the power of the prime mover and on the nature of the material being dried. In sugar house-work, the nature of the material varies usually in terms of "Purity" but between material

of the same purity much depends upon the skill of the sugar-boiler and on the nature of impurities. Referring to well-boiled massecuite of 75 purity or thereabouts, the time occupied by the various operations will be approximately:—charging and accelerating, one minute to two minutes, the time depending on the power available, running at speed, two to three minutes, stopping, half a minute, and discharging half a minute. The cycle, in all, occupies rather less than five minutes and at least twelve charges should be worked in an hour unless the massecuite is badly boiled or unless the molasses is very viscous.

As regards low massecuite of 55 to 60 purity the cycle is quite different and is almost entirely occupied with running at speed. Fifteen minutes as the over-all time taken for drying one charge probably below the average and is not advisable to reckon on more than three complete cycles to the hour.

Description of each operation:—

(*i*) *Charging.*—The massecuite should be added little by little so that the total amount to be taken can be well controlled. The amount of massecuite which can be added without any risk of its getting out of the

basket is about half-full of a basket.

End point of the removal of molasses.—Make a little mark on the massecuite in the centrifugal machine after a few minutes of charging and try to see the colour of the internal layer of the massecuite, white colour indicates the removal of molasses while black colour shows its presence.

Washing.—Crystals retain a very thin layer of molasses on them when the whole of the rest of molasses has been separated up in the centrifugal machine. This thin layer can only be removed by the use of water. However, the minimum quantity of water should be used to get the maximum whiteness. To achieve this object, water supply should always be made in the form of spray. The spray should be distributed uniformly and with the least possible amount of time so that the thin layer of molasses be completely removed and that desolution of crystals be minimum. Specially care should be taken in washing the massecuite present at the top and the bottom layers in the basket for these require a little more water than the other portions.

Washing of the basket.—After discharge, the washing of the basket is required to

remove any sugar crystals attached to its surface. This is done by supplying in steam from the external portion of the basket to the inner portion. The washed up magma can be run out from the machine.

Steaming.—If false grain has been formed in the massecuite while boiling in the pan, the massecuite will not depart its molasses easily. Steam is supplied from the external surface of the basket to its inner side. The steam loosens the massecuite, dissolving the smaller grains and this enables the molasses to depart easily.

SUGAR DRYER.

Sugar Dryers are a necessary adjunct of every factory where it is desired to produce dry crystals of a sparkling appearance.

Each Dryer consists of a mild steel plate shell supported on rollers by means of cast iron rings, and rotated by a spur or friction ring of cast iron.

The moist sugar is supplied to Dryer by an elevator or a feed conveyor, the speed of which can be accurately regulated through conical belt drive. Falling into the drum, the sugar is picked up by longitudinal shelves or buckets and showered down into the hot air passing through Dryer. The air is drawn through a heater of large heating surface by means of

a powerful fan and forced or drawn through Dryer.

When desired, a screen is attached to the delivery end of Dryer shell to separa te the lumps from the sugar which passes to sifter. The sifter, which is placed below Dryer consists of a revolving wooden framework, having screens of wire gauze, each screen being easily removed without dismantling the rest of the machine. The sifted sugar falls through hoppers into the bag filling and weighing machines, any coarse lumps being thrown out at the lower end for re-treatment.

DRYER.
Dimensions and Capacities.

Dia. of Drum	Length of Drum	Sugar Dried Per 24 Hours.
36	23	¾ to 1
42	23	1¼ to 1¾
48	23	2 to 2½
54	23	2½ to 3
60	23	3 to 3½
72	23	4 to 5

CHAPTER VII.

WHITENING OF SUGARS.

Hydrosulphite of soda.—It is a white crystalline compound formed by the further reduction of sodium bisulphite. In its dry condition, it is stable ; but it rapidly oxidises when exposed to moist air and solutions of it are unstable when exposed to the atmosphere.

The avidity with which Hydrosulphite of soda combines with oxygen makes it one of the most powerful reducing agents known, and this property has brought it into great and increasing demand in industries in which a strong bleaching agent is required. So small a quantity effects so great a reduction that the amount of bye-product—which is of a harmless character is negligible.

The best method of its application is to make the addition to the sugar syrup in the vacuum pan during concentration.

The advantage of Hydrosulphite of soda consists not only in its decolorising

action, but also in its property of diminishing the viscosity of the syrup, thus improving the crystallization.

"*Sumazine*" *Blue.*—It comprises a scientific blend of colours, which well neutralizes the yellowish tinge possessed by some sugars ; consequently it has a considerably greater whitening effect than ultramarine, etc. Being acid-fast it is excellent for the blueing of plantation white sugars which have to be stored for some time.

DIRECTIONS FOR APPLICATION IN THE VACUUM PAN.

Addition of Sumazine to the pan is the mode of application generally favoured, being easily, uniformly and economically performed. A trial or two will indicate the quantity to use for imparting the optimum whitening effect to the sugar. For use simply dissolve the total charge of "Sumazine" for the pan in about 10 litres of hot water, stir well, and draw this blue solution into the vacuum pan just before graining point. It is, however, very necessary to make certain that the " Sumazine " is completely dissolved, and to ensure this the hot solution should be well stirred before use. Another point is that " Sumazine " should not be used in conjunction with hydrosul-

phite. It entirely dispenses with that bleaching agent.

DIRECTIONS FOR USE AT THE CENTRIFUGALS.

A small tank holding about 200 litres is erected on the floor or stage above the centrifugal machines, and is provided with a small outlet pipe leading down to the level of the centrifugal platform, a small cock being fixed to the end of it.

A spraying can is filled from the nozzle of the outlet pipe. This charge of blue water is added to the sugar in the centrifugal when the basket is in full rotation, just before the brake is applied, and of course after the water spray. In this way the maximum penetration of the heap of sugar is secured and none of the blue water in swung out of the machine. Complete mixing of the sugar is later effected in the dryers. A trial or two will establish the amount to be used.

INDEX.

A

B

C

G

H

I

L

M

O