PRO-56-1

Circulation in Vacuum Pans

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This paper has for its object an exposition and discussion of new facts brought out in consequential tests and studies of the design and operation of vacuum pans in the sugar industry, and the logical consequence of these data in the readoption of the rather old and generally discarded principle of mechanical circulation.

It is demonstrated by actual observations that the heating of the heavy and viscous masse-cuite circulating through the tubes of the pans is not at all uniform, as has generally been assumed. During critical periods of operation, streamline flow obtains and the liquid is heated only at the skin. Recorded differences of temperature in the masse-cuite show observable variations of fully 30 F, with all indications of unobservable differences of as much as 50 F. With mechanical circulation, as proposed by the author, these variations are cut down to about one-fourth of their intensity.

This radically different operation makes possible new and interesting results, among which may be mentioned uninterrupted growth of sugar crystals, uniformity of products, greatly decreased formation of conglomerates, absence of false grain, faster operation, lower-steam pressures.

One of the very interesting developments also brought out in the paper is a method of cooling low-grade strikes in the pans themselves in the short period of four hours, thus eliminating the time-honored crystallizer from the raw-sugar industry.

THE subject of circulation in vacuum pans has been badly neglected and the explanations offered by the average sugar boiler reveal this fact. He will assure you that this or that pan has good or bad circulation, and makes good grain or bad grain, as the case may be. He will also tell you that good circulation is indispensable, that you cannot work without it, and so on. Then you ask him how fast must the circulation be to give good results. This is another story. It must be fast, good, uniform, active, etc., but how fast he does not know. His chief does not know. The man who taught his chief does not know. As a matter of fact, nobody knows.

Why not? If circulation is as important as it is supposed to be, somebody should be able to tell how fast it is. There is nothing in the literature about it. There are many data relating to almost everything except circulation, which is always described in terms of glittering generalities. And yet, every one agrees that it is the one most important requirement of any pan. The truth of it is that it is almost impossible to measure the speed of circulation, and that statement applies to evaporators as well as to vacuum pans.

Determining the Speed of Circulation

In attempting to determine the speed of circulation some thorough tests were made on a good standard calandria pan, in which all determinable facts were recorded. One of these was the rate of evaporation in pounds per hour observed at ten-minute intervals. Since the circulation is not measurable, it was decided to estimate it as follows:

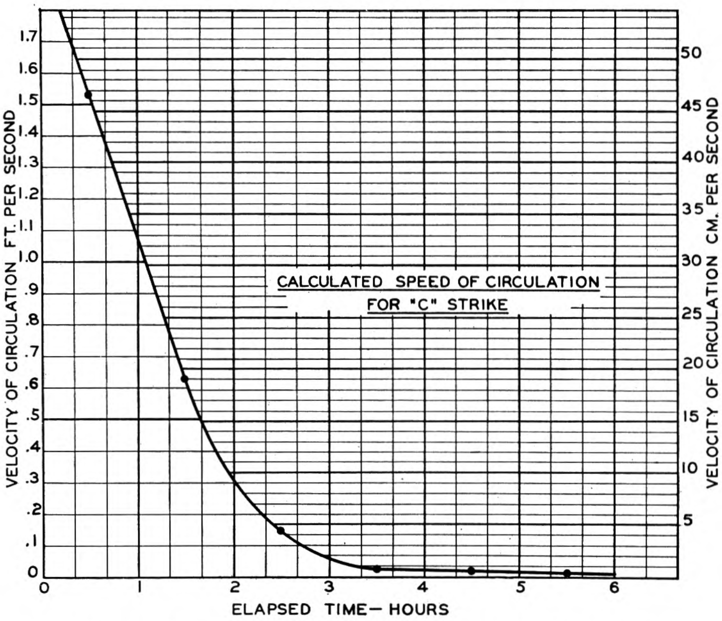

Fig. 1 Calculated Speed of Circulation for "C" Strike

It was assumed that on the average masse-cuite is heated in the tubes, goes up to the boiling surface, releases its heat by flashing, and returns below the calandria through the downtake for a new circuit. The temperature at the boiling surface and the temperature as the masse-cuite left the tubes were known. The difference between the two gave the temperature rise. The specific heat of masse-cuite and the rate of evaporation, which is the same as the rate at which heat is absorbed by the masse-cuite as it passes through the tubes, were also known. It was therefore easy enough by simple arithmetic to arrive at the weight of masse-cuite per unit of time passing through the tubes, and from that, the volume, since the specific gravity was known. Having the total cross-section of the tubes, the speed of circulation in feet per second was easily calculated, not with absolute precision, but certainly closely enough. The results are shown in Fig. 1.

This chart was an eye opener! It shows that at its best, the circulation in vacuum pans is very poor. At its worst, it is not circulation at all but stagnation, in which there are all sorts of undesirable heating effects.

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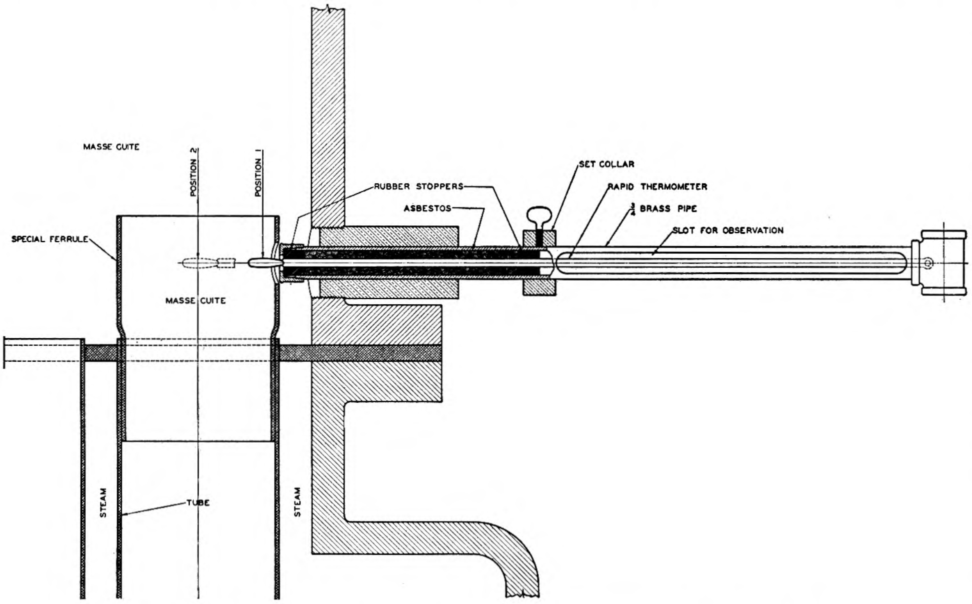


Fig. 2 Mounting of Experimental Thermometer on Vacuum Pans

Further evidence appears in a paper by J. C. Keane and E. K. Ventre presented before the International Society of Sugar Cane Technologists at San Juan, Puerto Rico, in 1932. Mr. Keane found that on low grades, sugars obtained from the pan when full, but before final concentration, showed 100 per cent higher filterability than sugars obtained after final concentration, during which time the circulation is poorest, and the heat injury, therefore, greatest.

Is the Heat Uniform?

There is another point about heating viscous masses moving slowly through large-diameter short tubes such as exist in vacuum pans. How can it conceivably be assumed that this heating is uniform throughout the masse? There is no justification whatever for any such assumption, for, in the first place, the heat conductivity of the material must be very low due to its viscosity, and, furthermore, at these low speeds, streamline flow must exist, in which case there would be very little mixing.

Temperature Conditions

It was decided, therefore, to embark upon a special investigation to determine as far as possible just what temperatures could be found in the tubes of these pans during operation. After much thought, it was decided to confine observations to one tube in the pan. The scheme finally adopted was to attach a ferrule to a tube nearest the shell of the pan, this ferrule extending perhaps 6 in. above the upper tube sheet. See Fig. 2. Then a very accurate and sensitive thermometer was mounted in a proof stick and lined up centrally with the tube in question and as close to the tube sheet as practicable. An opening was made in the side of the ferrule permitting the free passage of the thermometer and its mounting. With it the temperature of the masse-cuite as it left the tube and in any part of the stream could be observed.

Observation Procedure

After the usual preliminary runs, it was decided to observe only three temperature positions, namely: (1) just inside the tube to show the skin-heating effect, (2) at the center of the tube to show the probable minimum temperature, and (3) outside the tube in the body of the masse-cuite. The instrument has its limitations, since the mercury bulb is about $^7/_8$ in. long and, therefore, any reading shows the average for this length and not that at the local points to which particular interest is attached. It is, therefore, evident that in every case neither the maxima nor the minima could be obtained. In addition, when the thermometer is thrust to mid-position 2, there is bound to be a warping of the streamlines whose influence on the readings must be appreciable. Moreover, while the reaction of the mercury was rapid, it was far from being instantaneous, and, for that reason, a certain lag was inevitable.

A standard procedure was used to compensate as much as possible for the forementioned inadequacies. Three positions were accurately fixed, and templets were provided by which any one could be spotted instantly. In all cases the instrument was allowed to remain at each station for a period of two minutes, with readings every ten seconds, after which a quick shift was made to the next, and so on, rotating definitely to the three positions for the entire duration of the strike.

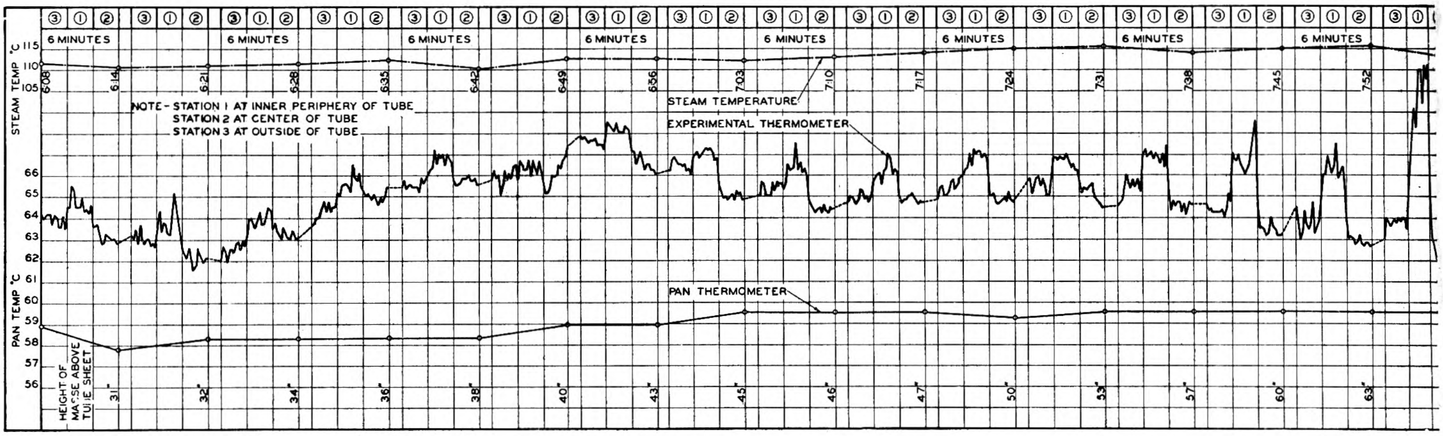


Fig. 3 Temperature Observations

The Results

The procedure in making the tests was laborious, involving thousands of readings. While these were being taken, other pan observations were made at regular intervals, so that these data could be correlated to other pertinent facts.

These tests occupied several months, as they were made on a number of different pans, operating under all conceivable conditions, and the data are entirely too numerous to be reproduced completely in this paper. Therefore, only those that have a direct bearing on the subject of this discussion will be included.

Fig. 3 shows the results of a test on a 12-ft standard calandria pan, having 5-in. No. 14 copper tubes 48 in. long and a central downtake 72 in. in diameter, while making a "C" or low-grade strike. This downtake diameter is not a mistake. It was made that way—one-half of the pan diameter—especially designed for *good*, *fast*, *uniform* circulation, as required by all the experts. All the experts agree that this pan has wonderful circulation, so that the results shown are really better than those obtained in the average pan.

The abscissas in Fig. 3 represent clock time. All the other data are given as ordinates, and are: height of masse-cuite above upper tube sheet; readings of the pan thermometer; readings of the experimental thermometer; and steam temperatures.

The numbered spaces at the top show the positions of the experimental thermometer. After the completion of each round of observations, one minute was allowed for reading the other instruments. That interval is shown as a dotted line in the experimental-thermometer curve.

Examination of Results

Let us now examine the results. It must be remembered that the experimental thermometer was read every ten seconds, giving twelve readings at each station. The temperature was constantly changing, making the taking of readings difficult. The instrument was a standard Clerget thermometer, graduated to tenths of a degree centigrade. Evidently, from the beginning, while vigorous boiling was going on in the tubes, the reading at station 1 was consistently higher than at the other positions, but the excessive turbulence made it difficult to observe.

The one point of interest is that the average reading of the experimental thermometer is consistently well above that of the pan thermometer, both instruments having been calibrated as correct. The maximum difference between the two is about 7 C. The difference between adjacent stations at the experimental thermometer is small, perhaps one to two degrees.

As the strike progresses, two things happen: The readings at station 1, or at the inner periphery of the tube, increase more and more as compared with those at station 2 in the center of the tube. This difference attains a maximum at the very end of the strike, when it reaches 17 C, or 30.6 F, which is almost unbelievable. Bearing in mind the limitations of the instrument, it will be realized that the actual difference between the temperatures at stations 1 and 2 is no doubt much greater than indicated as it is impossible to get a true reading. As an intelligent estimate, based upon experience and information, 30 C (54 F) is the probable figure.

The other interesting development is that the readings of the experimental thermometer at station 2 in the center of the tube gradually approach that of the pan thermometer, and actually drop below it at two points. Theoretically, it should go materially below the pan thermometer, but, as explained before, instrument limitations prevented from getting the minimum as well as the maximum, and the results are about what might be expected.

It will be noted that the average reading of the experimental thermometer is much higher than that of the pan thermometer. No particular significance can be attached to this fact, since it is known that the average of the experimental thermometer does not necessarily indicate the average temperature of the masse-cuite in the tube. This average masse-cuite temperature is indicated by the pan thermometer.

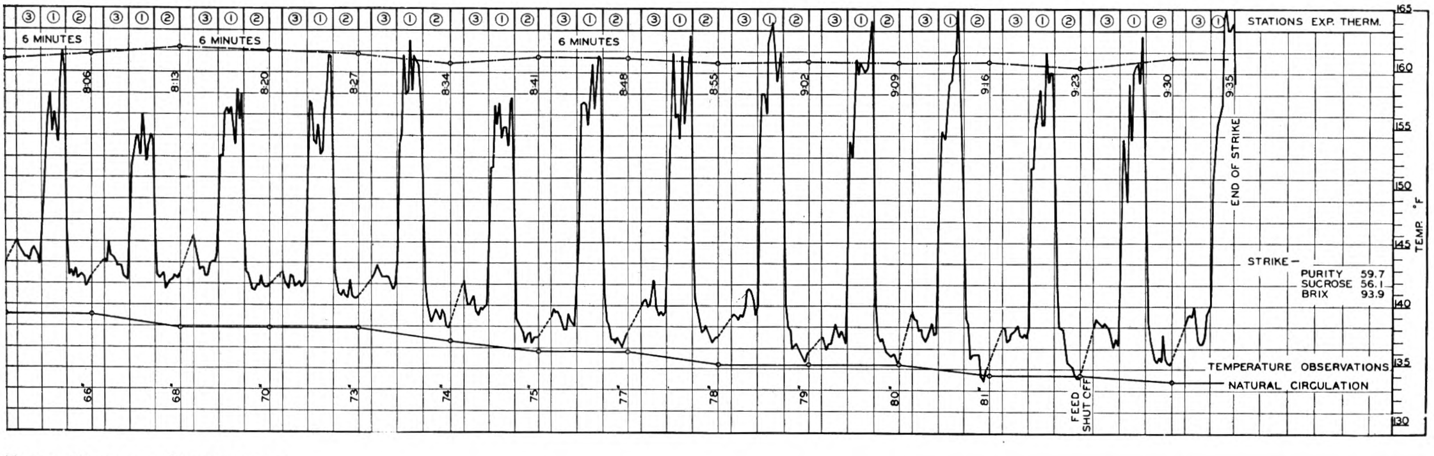
The fact that has been established is that masse-cuite, as it passes through the tubes, is not uniformly heated. In it there are local variations in temperature as great as 50 F at the end of the strike. The task is to appraise the true significance of this fact.

Interpretation of the Results

What are the consequences of the data that have been referred to?

In the first place, what causes circulation in vacuum pans? When the level of the strike is low, there can be no doubt that circulation is induced by the formation of vapor bubbles in the tubes of the calandria, thus reducing the specific gravity of the masse as a whole as compared with the balancing column in the downtake, which has no vapor bubbles. The difference in weight of these two columns causes upflow in the tubes, accompanied by a corresponding downflow in the downtake. This is circulation.

It is claimed by some that circulation takes place by convection due to the fact that the masse is hotter in the tubes and above them than in the center of the pan and the downtake. It is hard to conceive of any force brought about by temperature differences that is adequate to cause an appreciable movement of the



Under Natural Circulation

masse. It is easy enough to estimate the value of this force as a maximum.

If the foregoing premise is true, then the maximum circulation would be at the end of the strike when the levels are high, and it is known that this is not so. Be that as it may, taking the pan with the masse-cuite six feet above the upper tube sheet, as an example, then consider the following:

The pan thermometer during the test already quoted read 59 C (138.2 F) at six feet. It is also known that the minimum temperature at the boiling surface was about 124.0 F, since the vacuum was 27.3 in. when this observation was made. The minimum temperature in the downtake could not be less than this. The difference, therefore, is 14.2 F.

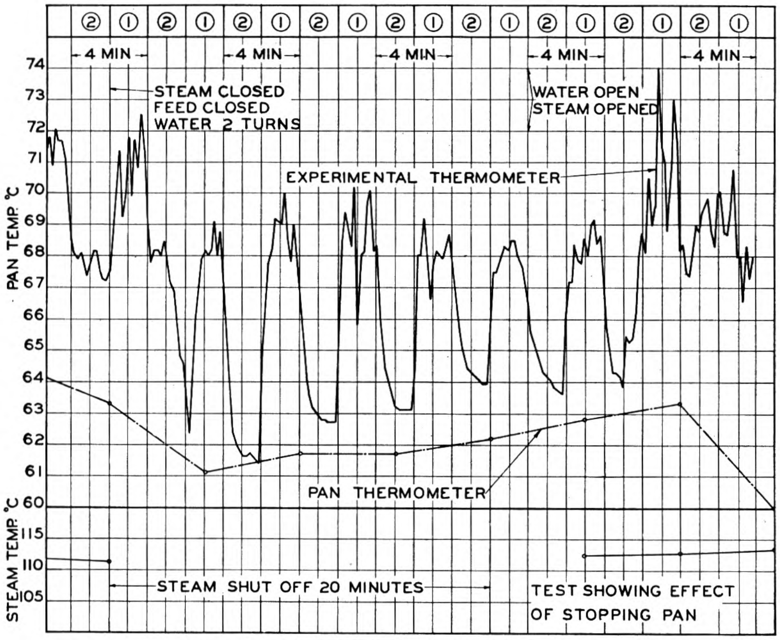


Fig. 4 Test Showing Effect of Stopping Pan

Let us further assume that the change of temperature in the tubes was gradual throughout their length. We can, therefore, say that we have two columns of masse-cuite nominally 8 ft high. The expansion due to this difference of temperature is about 0.83 per cent. In other words, the difference of head between the two columns would be 0.83 per cent of 8 ft, which is 0.0664 ft, or 0.7968 in., as an absolute maximum. Actually, through the tubes themselves it would certainly not be one-fourth of that figure.

How any such difference of pressure could produce an appreciable motion of thick, heavy masse-cuite through the tubes of a vacuum pan is inconceivable, and this hypothesis must be abandoned.

The Real Mechanism of Natural Circulation

It has been shown that masse-cuite as it leaves the tubes of the pan on its way up is not uniformly heated, but, on the contrary, contains many spots at different temperatures, the general average of which is represented by the readings of the pan thermometer. As the masse proceeds upward, even in the tubes themselves, when these spots reach a level where the local vacuum corresponds to their boiling temperature, a flash takes place with the release of a vapor bubble whose size corresponds to the magnitude of the hot spot. This volume displacement causes a sudden readjustment of position, permitting the vapor so liberated to come into contact with some of the cooler masse-cuite, when immediate condensation takes place.

This procedure is repeated on the way up, gradually lowering the temperature of the hot spots by raising the temperature of the cold spots through these little explosions and condensations, ultimately attaining the general average temperature indicated by the pan thermometer. This average exists in uniformity at the level of uninterrupted ebullition, probably limited to a zone extending 12 in. below the surface of the masse-cuite in the pan.

There is no doubt in the author's mind that this is the main motive force causing circulation, for whereas the individual displacements are small in volume and duration, they are of infinite number, and extend from the tubes themselves to the very top of the masse. As fast as one flash bubble condenses, another takes its place near-by. It can be easily seen, therefore, that the weight of this agitated masse-cuite in the outer periphery of the pan is inevitably lightened as compared with the downward moving central stream which is free from flash spots.

The Dangers Involved

Incidentally, it might be noted that these intense volumetric disturbances caused by these so-called flash explosions, within reasonable limits, in no way injure the operation of the pan; quite the contrary, they cause a continual rapid change of position of the sugar crystals in their surrounding molasses or syrup, thus permitting a more complete exhaustion.

There are two dangers involved, however. One is the fact that if local temperatures are too high, there is likelihood of a considerable color increment. The other is that undoubtedly a point of unsaturation is reached, wherein sugar actually redissolves into the molasses or syrup. This is not only a destruction of work already done, but, in addition, is likely to bring about the formation of conglomerates and possibly false grain. There are well-defined limits to all of this.

Conductivity of Masse-Cuite

The probable low heat conductivity of masse-cuite has been mentioned. The author is opposed to laboratory experiments in these investigations, as the change of proportions involves a change of the problem. With the experimental thermometer, therefore, an interesting test was made tending to shed light on this subject, as follows: A standard "C" strike was boiled until the level of the masse was about 4 ft above the top of the upper tube sheet. Then the steam was shut off, the vacuum dropped, and readings of the experimental thermometer were begun, but this time, at stations 1 and 2 only. The idea was to find out how long it would take for the temperature at the inner periphery of the tube to equalize with that at the center. As in the former case, the thermometer was kept at each station for two minutes, and readings were taken every ten seconds. Fig. 4 shows the results, indicating that it would require at least one hour or more for these temperatures to stabilize.

What then is the significance of this new fact? Evidently, the penetration of heat into the masse is very shallow indeed, and there must be purely a skin-heating effect. If such is the case, it is possible to reconcile the data of Fig. 3.

The skin-heating effect brings out another point. What retards circulation is the viscosity of the masse. Viscosity is always an inverse function of temperature. If the skin of the stream flowing through the tube has a greatly reduced viscosity, then we have the equivalent of a lubricant at this point, and the higher the temperature, the greater the lubrication. In the absence of boiling in the tube, then this masse-cuite would pass through as an oiled sausage. This is perhaps an exaggeration, but it gives a better picture of the conditions as they are.

Feed Distribution

Let us now consider the usual manner in which feed is admitted to the pan. This feed is of relatively low density, probably 65 brix, whereas the strike is at 90 brix or better. Syrup is invariably admitted through one large pipe at one point, and it is very difficult to get a complete and rapid mixture. This is one of the outstanding defects, but particularly on low grades. In the absence of an immediate thorough mixture, it is easily possible for some of this light liquid to float at once to the top, thus bringing about a poor operating condition, as the two liquids are certainly not easily miscible.

A much more desirable method would be to introduce the feed through a perforated coil located under the bottom tube sheet so as to compensate as much as possible for the difficulty pointed out, and thus minimize the undesirable results.

Basis of Pan Operation

In view of these new field results, it is now advisable to review carefully the basis on which these pans are operated, so as better to appreciate their true significance, and it would do no harm to start at the beginning.

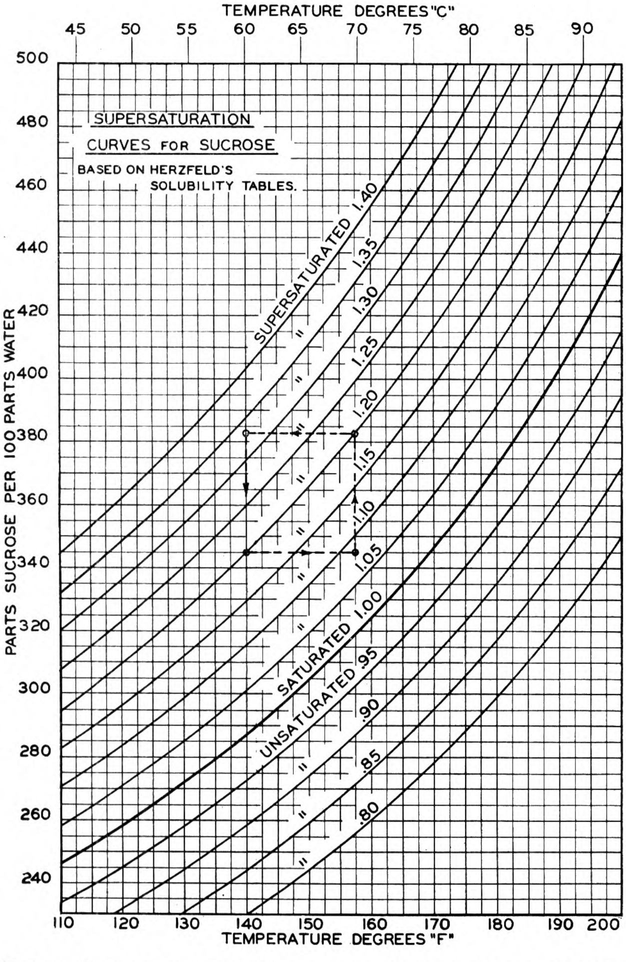


Fig. 5 Supersaturation Curves for Sucrose Based on Herzfeld's Solubility Tables

The vacuum pan works under constantly changing conditions. The first step is to concentrate the syrup in limited quantities until grain is obtained, then to make these individual crystals grow in size, but not in number, until the volume of the full strike has been reached. The fact must be emphasized that the crystals must grow uniformly without the formation of new and smaller ones. It is essentially a batch operation which starts with the liquor level just above the upper tube sheet, and finishes with a strike or a skip whose volume has grown perhaps six or seven feet above the original starting point.

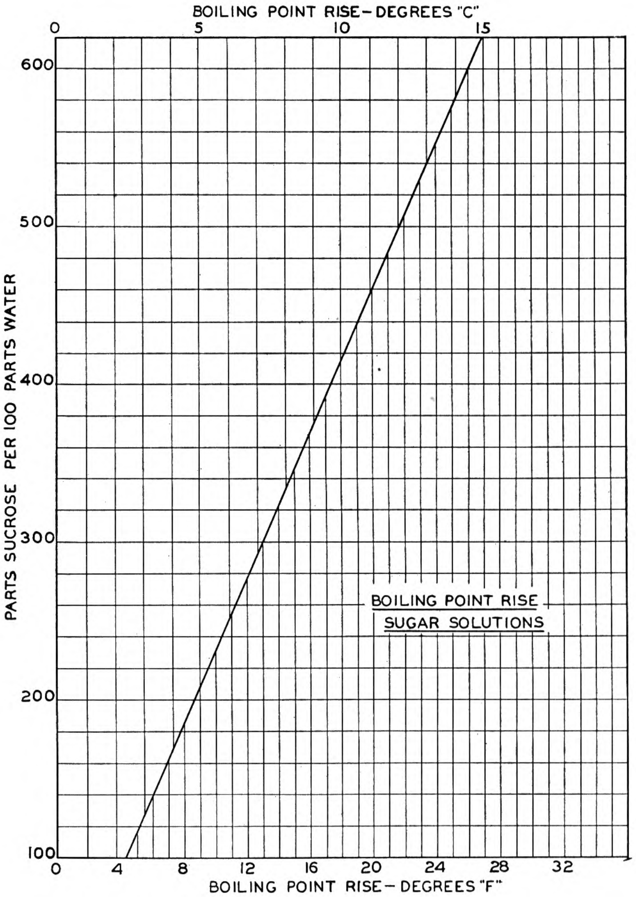


Fig. 6 Boiling-Point-Rise, Sugar Solutions

Unlike most soluble salts, sugar crystals do not form in the solution as soon as the saturation point is reached. Indeed, grain will not form until the concentration has been pushed quite a bit farther. Even after the crystals are formed they will not grow rapidly unless a certain amount of supersaturation is maintained. The manipulation of densities evidently requires skill and knowledge, for if too high concentrations are maintained, new small crystals will form and these will have to be destroyed by bringing the syrup below saturation, which involves not only loss of time, but also the heat expense of evaporating the water used for dilution. The growing densities and crystal-forming densities must be carefully controlled for satisfactory operation.

Saturation, Supersaturation, and Unsaturation

This is all delicate work, totally impossible in inexperienced hands, and must be carefully analyzed to be properly understood. The solubility of sucrose in water is the foundation. For this, tables by Herzfeld are used. Fig. 5 has been plotted from this table. In it ordinates represent the solubility of sucrose in parts per hundred parts of water. The abscissas give the temperatures within our range. The heavy line is the solubility or saturation. Above it are lighter lines showing the different levels of supersaturation, and below, similar lines of unsaturation. The effect of a change of temperature on a solution of any concentration can be easily and quickly read. The chart is for pure sucrose solutions, and would have to be modified if impurities were present in material proportions.

Boiling-Point Rise

Fig. 6 shows the rise in boiling points of sucrose solutions above the boiling points of water. This is usually called the "boiling-point rise," abbreviated B.P.R. The data were taken from Claassen.

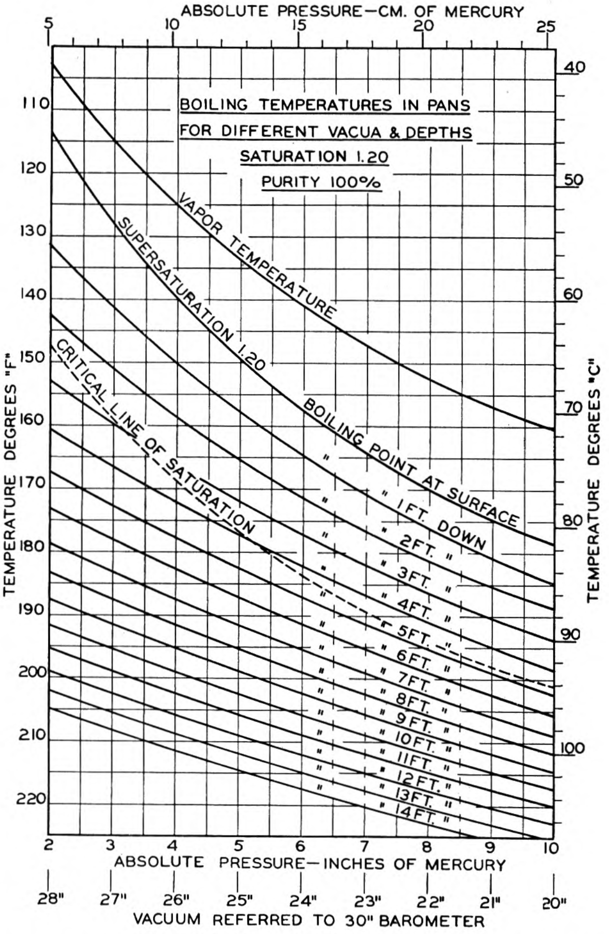


Fig. 7 Boiling Temperatures in Pans for Different Vacua and Depths—Saturation 1.20, Purity 100 Per Cent

Pan Temperatures

Figs. 5 and 6, supplemented by the steam tables, make it possible to plot the very interesting diagram of Fig. 7, showing the maximum temperatures that can be attained in the boiling masse-cuite in a vacuum pan while it is in operation, for any vacuum, and at any depth below the level of the liquid.

Fig. 7 is based on a supersaturation of 1.20, as recommended by both Claassen and Theime, who are recognized authorities on the subject. This 1.20 point is subject to some variations. It may drop as low as 1.15 for high-purity syrups while making fine granulated sugar. It may also reach 1.30 for low-grade crystallizer strikes. For the present, it is assumed that the 1.20 suffices as fairly representative of average operating conditions.

The ordinates represent temperatures, but in this instance they are plotted in the reverse order for convenience. The abscissas give the absolute pressures and vacua under which the pan is operating. The top line shows the vacuum temperature. Next comes the boiling temperature at the surface of the masse-cuite, which was obtained by adding the B.P.R. to the vapor temperature for a supersaturation of 1.20 at the particular temperature. It must be noted that the B.P.R. is not the same for different vacua, even though the supersaturation is constant, because the solubility of sucrose varies with the temperature and the same supersaturation at various temperatures involves different concentrations, and hence different B.P.R's.

The next line below shows the temperature required for ebullition at a depth of one foot below the surface. This is arrived at by correcting the vacuum in the pan for the superposed hydrostatic head, and then adding the same B.P.R. as before for the 1.20 supersaturation. The succeeding lines give this boiling point for depths of 2 ft, 3 ft, and so on, to 14 ft.

The dotted line is significant, showing the depth at which ebullition temperatures have brought the saturation down to unity. The modified Herzfeld chart makes it possible to plot this curve. Above this critical line is a condition of supersaturation in which the sugar crystals will grow, and below it, a condition of unsaturation in which the sugar crystals will dissolve. In the latter event, not only will the size of the crystals decrease, involving a destruction of work done, but at the same time the concentration of the syrup or molasses will increase, and this, if carried too far, can easily bring about the formation of "smear," false grain, or conglomerates when the masse reaches the boiling surface, as at this point the supersaturation will be suddenly increased beyond the safe limit. Very high strikes always involve this danger, as can be readily seen.

Vacuum Variations

Pan operators always complain vigorously when there are appreciable changes of vacuum during the operation. A study of Fig. 7 will show the reason for this. Assume, for example, a drop of vacuum from 26 in. to 24 in., and after a period of time, a return to the original 26 in. The boiling temperature chart, Fig. 7, shows that the boiling points at 1.20 supersaturation are 140.0 and 157.5 F. Going back now to the Herzfeld diagram, Fig. 5, the first change lowers the supersaturation from 1.20 to 1.075. Nothing happens except that the pan slows down a little until the standard supersaturation at the new vacuum is attained. The second change, however, when the vacuum is suddenly brought back to 26 in., boosts the supersaturation to 1.325 and, with this, the formation of false grain is inevitable. All necessary precautions should be provided to avoid vacuum variations during the making of strikes in vacuum pans. It will pay big dividends in improved quality of sugar, and in steam saving as well.

Summing Up the Data

The experimental and theoretical studies have shown up many weak points in no uncertain manner, and we are now ready to draw conclusions:

(1) The so-called good circulation was not so good after all. At best, it was poor, and at worst, it was stagnation.

(2) Local overheating attains unbelievable proportions that bring the syrup or molasses in the masse-cuite in the tubes much below saturation, permitting redissolution of crystals with destruction of work done. The consequent additional danger of color increment is also present. With the increased concentration of syrup above normal, there is also the imminent probability of false grain and conglomerates.

(3) The distribution of feed is also poor, and leaves much room for improvement.

(4) All of this makes for delicate and difficult control of an operation that should be simple.

MECHANICAL CIRCULATION

The solution to all these problems has been found in the proper application of mechanical circulation. The idea is old, and failed originally for several reasons among which may be mentioned improper design, inadequate size and capacity, and insufficient power.

It took several years of investigation and study to arrive at the apparatus shown in Fig. 8. Originally, it consisted of a large screw-pump element installed at the bottom of the downtake, driven through a wormgear reduction mounted at the top of the pan. It was necessary to find the proper speeds and the amount of power under different operating conditions, and in this connection it is important to remember that there is a vast difference between pumping water and pumping viscous masse-cuite.

THE FUNCTION OF THE AMMETER

For this reason, early during the experimental period, an ammeter was installed in one of the electric circuits on the motor drive, so that at all times the amount of power being used could be measured. It soon developed that this instrument was a valuable adjunct to the pan, for, since pumping was against a friction head only, the reading of the ammeter was almost directly proportional to the viscosity of the masse. The pan operator is guided by viscosity in regulating the amount of feed to the strike, and the ammeter gave him an excellent index for his work. Therefore, a recording instead of an indicating ammeter was used and it has now become part of the regular equipment.

ONE SCREW PUMP INADEQUATE

Certain difficulties were found with one screw pump in the downtake. As long as the strike was low, everything worked well, but when a level of 3 or 4 ft above the top tube sheet was passed, the temperature of the masse-cuite began to go to abnormal proportions, attaining an excess of as high as 30 to 40 deg at the end of the strike. Finally, it was realized that this was owing to the fact that all of the masse-cuite heated in the tubes of the calandria did not go up to the boiling level but shunted back into the circulator due to the draft of the screw pump.

SUPPLEMENTARY SCROLL

The next step was to put a large scroll on the shaft immediately above the upper tube sheet, extending almost to the top of the finished strike level. This helped somewhat, but there were still excessive temperatures as before. The conclusion was then reached that the material was so viscous that the scroll lost its true shape, and thus failed in proper displacement. The vanes of this scroll had a very thick layer of masse-cuite adhering to them during operation, and it appeared that the masse-cuite, instead of being pushed down, swirled with the mechanism. This produced a centrifugal tendency bringing about a radial flow away from the center and destroying the intended downward flow.

MULTIPLE ROTORS

One solution would have been to enclose the scroll in a tube. This could not be done, since the scroll would then be inoperative until the strike level passed the top of the enclosing tube. The arrangement finally adopted and now in use is shown in Fig. 8. Three more screw pumps were placed on the shaft above the top tube sheet. These pumps are surrounded by a framework of six angle irons fastened to the tube sheet at one end and to the dome at the other. Each runner is then enclosed by a ring that barely overlaps the blades. This absolutely stops radial flow away from the center. Then, between each runner and the next, a set of vertical rectifying vanes is interposed, rigidly secured to the angles, so that any swirling tendency imparted by the rotors is immediately converted into a downward motion, thus helping the pump instead of robbing its capacity.

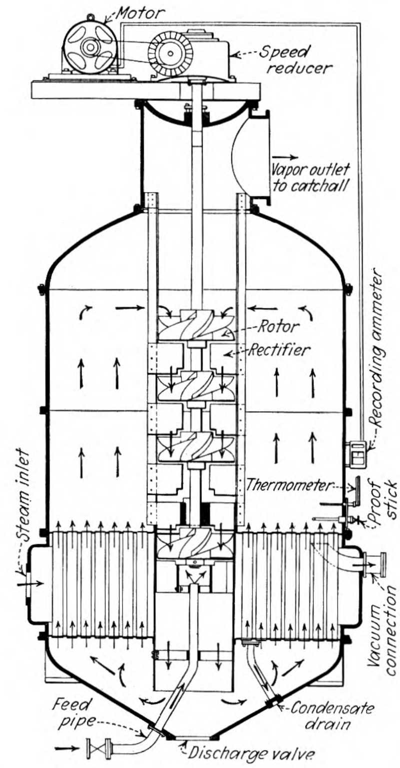


FIG. 8 VACUUM PAN PROVIDED WITH MECHANICAL CIRCULATION

With this design, no matter where the strike level may be, there is a positive direct flow of masse-cuite from the surface of ebullition, down the circulator, through the central downtake, into the bottom, up the tubes again, to the boiling surface, and down again, completing the circuit, all without cross flow or interference.

FEED DISTRIBUTION

Attention must now be turned to the matter of feed distribution. The screw pumps themselves are made of hollow drums open at the bottom. To these drums, the vanes or screw elements are bolted, and under each vane there are two 2-in. holes. The feed is admitted from below into the bottom of the lower drum, and flows out radially by centrifugal action through the 2-in. holes under the rapidly moving vanes, where an immediate mixture takes place.

TEMPERATURE CHART WITH MECHANICAL CIRCULATION

It is now time to examine a chart made on a "C" strike similar in all respects to the one submitted for the pan without mechanical circulation. The pan with mechanical circulation on which this test was made is an exact duplicate of the one without it, is located in the same plant, and is operating under precisely the same conditions and by the same operator. The test observations in Fig. 9 show the accomplishments effected by positive adequate circulation. The principal feature, of course, is the

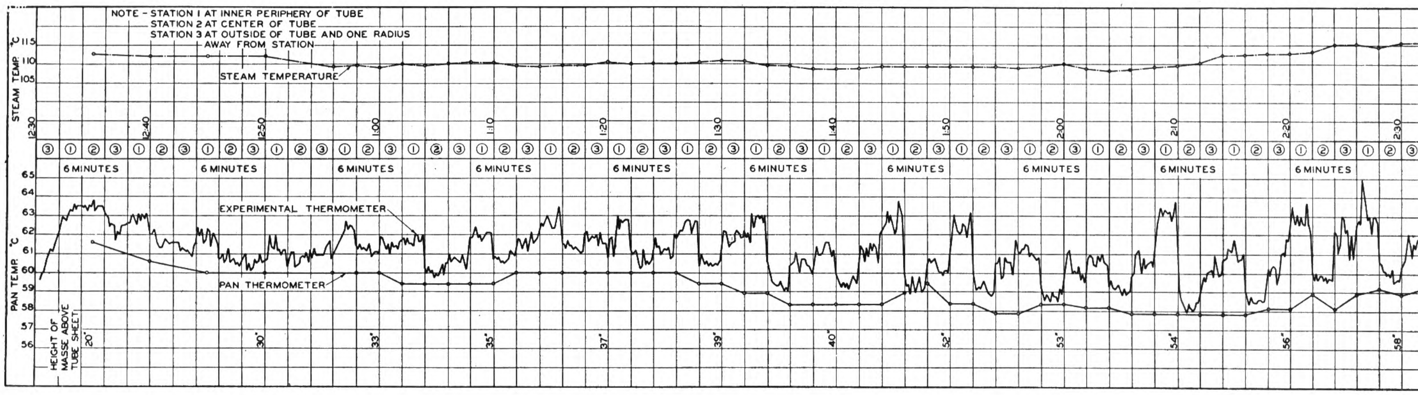


FIG. 9 TEMPERATURE OBSERVATIO

fact that the temperature changes noted by means of the experimental thermometer have been cut down to about one-fourth of their original intensity. It is too much to expect complete elimination of variations, which cannot be achieved except at abnormal expense altogether unjustified.

EVAPORATING RATES

At the beginning of the strike, when the level is low, evaporating rates, with and without mechanical circulation, are about the same, but as soon as the level passes 3 ft above the top tube sheet, there is a decided advantage in favor of the circulator. This advantage gradually increases as the strike goes up, until, toward the end of the operation, the rate of evaporation with the circulator is about five times as fast as without it. Another point worthy of comment is that these new pans, since the circulation is independent of the steam pressure, can operate at any height above the top tube sheet. Also they can run with much lower steam pressures than before. Actually, time and again, "C" strikes have been made with steam at 5 in. vacuum and the levels have been carried as high as 8 ft above the upper tube sheet. In some of the refineries the strike level has been carried 12 ft above the heating surface, with perfectly good results.

POWER REQUIREMENTS

The power required for driving the mechanical circulator is much more than that required by the former design, because it has greater capacity, but it does an incomparable job in terms of the old units. However, the power capacity is not at all excessive. The load is relatively small until final concentration takes place, at which there is quite a peak, the duration being perhaps 15 min for low grades and only about 3 min for refinery work.

The unit has to be designed for maximum conditions and hence it is of rugged construction. When the cooling of low grades is undertaken, the power increases greatly owing to the higher viscosity of the masse, and when such an operation is contemplated, either the power must be increased or the speed reduced.

BASIC CONDITIONS

In the making of a strike there are two factors, one being the concentration of the sucrose solution by evaporation and the other the absorption of this sucrose by the sugar crystals kept in suspension by the circulation within the pan. Evaporation will be as fast as the heating surface under the existing temperature conditions will permit, but must not be faster than the crystals will absorb the sucrose thus made available, otherwise the supersaturation will increase until it passes the critical limit and false grain will begin to appear.

The question then is, How fast will the crystals assimilate this sucrose? It has been established by investigators that with high-purity solutions, this rate is very fast indeed, probably faster than it is possible to evaporate. What factors affect the rate of sucrose absorption by the crystals?

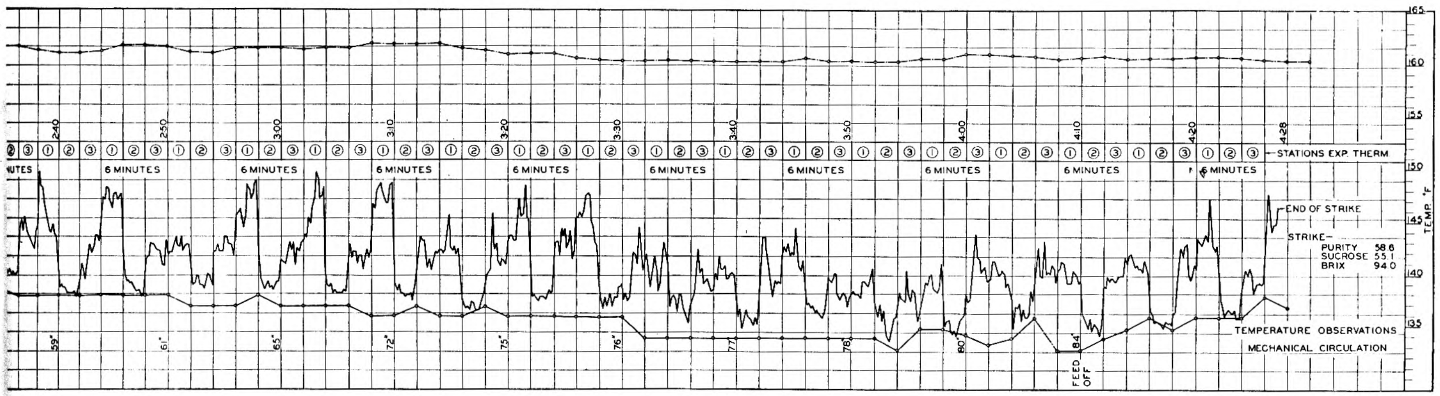
SPEED LIMITS OF CRYSTAL GROWTH

It is known that this rate is directly proportional to the sum of the surfaces of the crystals. For any solid structure of definite formation, it is a fact that the weight varies with the cube of its dimensions and the surface with the square of its dimensions. For a given weight of sugar crystals, therefore, the sucrose-absorbing surface will be indirectly proportional to their individual sizes, and this means that the smaller the crystals, the greater the rate at which they can absorb sucrose from a solution of a given concentration. In other words, the finer the grain formation, the faster the strike can be made without danger of bringing out false grain. False grain never is found in a fine granulated strike. If confectioner's "A" is being made, however, the problem is entirely different. Since the crystals are very large, the sum of their surfaces is very small, and the operation is difficult because of the inability of these crystals to absorb the sucrose from the syrup as fast as evaporation makes it available, even at slow rates. In the ordinary pan, under these conditions, evaporation would have to be slowed down so much that it would kill the circulation and the crystals would drop out of suspension. The situation must be remedied by feeding water to evaporate into the pan to maintain circulation fast enough to keep the big crystals moving. This is paid for in terms of the steam required to evaporate this water. With the mechanical circulation pans, since the circulation is independent of the rate of evaporation, it is believed that it may be possible to reduce the amount of this boiling water, if not eliminate it altogether.

CONDITIONS AT THE BEGINNING OF A STRIKE

An interesting phase of the same condition is the period at which grain is made in the pan, and the immediate subsequent operations. As has been said before, the problem consists in the making of a limited number of crystals and then causing them to increase in size and not in number.

It is not within the scope of this discussion to cover the entire technology of the making of strikes. It will suffice to state that the first step is to concentrate the syrup to a point of excessively high supersaturation, called the "graining point," at which crystals begin to form. This can be done in a number of ways, the simplest being to let the concentration proceed until small crystals begin to appear and to allow those to increase in number until a sufficient quantity is present. After this stage is reached, the formation of new crystals must be arrested. This is known



WITH MECHANICAL CIRCULATION

as "hardening the grain." Knowingly or not, this is accomplished by lowering the supersaturation from its grain forming 1.30–1.40 to 1.20 or less, at which new crystals will not form. Time must be allowed for the fine crystals to grow in size until they have sufficient surface to absorb sucrose as fast as it is released by evaporation, without crowding the supersaturation to the point where new crystals will again form.

At this point, mechanical circulation has been found to be valuable, for intense movement can be maintained without evaporation, and hence, the rapid growth of the infinitesimal crystals can be effected without additional concentration which might bring out new grain. It is a critical condition which requires very careful attention in the ordinary pan. As the size and, therefore, the sucrose-absorbing surface of these crystals, increases, the evaporation is speeded up correspondingly, until soon the danger is past, inasmuch as the possible rate of sucrose absorption is greater than the rate at which evaporation makes it available, and it is no longer possible to push the supersaturation to the point of spontaneous crystallization from the syrup. As the crystals increase in size, their sucrose-absorbing capacity becomes greater and greater, and all imminent danger has passed. This does not mean that it is not possible to bring out false grain by sudden temperature changes. This can always be done.

The sum of the crystal surfaces at the end of the strike is many times greater than it is at earlier stages, and this is what makes possible the rapid final excessive concentration without danger of bringing out false grain.

The reaction is a balance between the rate of evaporation and the speed of crystal growth, governed by the supersaturation, which adjusts itself to these two factors.

PURITY

Purity has a great influence on pan performance. If the purity is low, then it is necessary to change the film surrounding each crystal as fast as the available sucrose in this film is absorbed, so as to permit new richer molasses to come in contact with the grain. It is because of this effect that low-purity strikes have to be made more slowly than high-purity strikes. Nature helps here, for low-purity syrups are of higher viscosity and the evaporation is slower with the same steam-temperature conditions.

MOVEMENT

Evidently, to effect rapid changes of the molasses film surrounding the crystal, motion and agitation are required, and are obtained by good circulation. This is another factor in operations and probably the most important. With fast mechanical circulation, constantly maintained, irrespective of steam pressure, rate of evaporation, height of strike, purity of masse-cuite, or anything else, better results than before should be obtainable.

NECESSARY PRECAUTIONS

It would be incorrect to say that no precautions are necessary in the operation of mechanical-circulation pans. One in particular should be mentioned. It was stated previously that at the latter stages of the strike these pans are about five times as fast as pans without mechanical circulation. It has been observed that at the very end of low-grade strikes, when the usual final concentration is given, a smear sometimes appears. This is due to the fact that the increase of supersaturation is too fast for the proper absorption by the sugar crystals. Another factor usually aggravates this condition. When the final concentration is given, the rate of evaporation decreases due to the increased viscosity. If the pan has a fixed rate of injection on its individual condenser, and this injection is not reduced, the vacuum will rise perhaps one inch, which will reduce the temperature, thus increasing the supersaturation beyond normal. These two effects, namely, added concentration and simultaneous decrease of temperature, push the supersaturation beyond the critical limit, resulting in the smear. The remedy is obvious, and with a little intelligent attention, there should be no trouble from this source.

CRYSTALLIZER ELIMINATION

After the details of the mechanical-circulation pan had all been worked out, it developed that since the formation and growth of sugar crystals took place under radically altered conditions, it might be possible to do the work of the crystallizer in the new pan.

Obviously, for proper exhaustion of molasses in the low-grade strikes after the normal work of the pan has been accomplished, certain basic reactions are necessary. The masse-cuite must be cooled gradually and uniformly at a rate no faster than the sugar crystals can absorb the sucrose made available by the decreased solubility due to reduced temperature. The speed at which these crystals can absorb sucrose from the molasses in turn depends upon how fast and how thoroughly the exhausted film surrounding them is moved away, as mentioned previously, and that in turn depends upon the mechanical agitation of the masse, and the tenacity of the film, which is a function of its viscosity. It is known that the viscosity is greater as the temperature is reduced, but this temperature reduction squeezes out sucrose from molasses, since its solubility curve is direct, and results without cooling cannot be hoped for.

There are thus conflicting tendencies in the cooling of the masse-

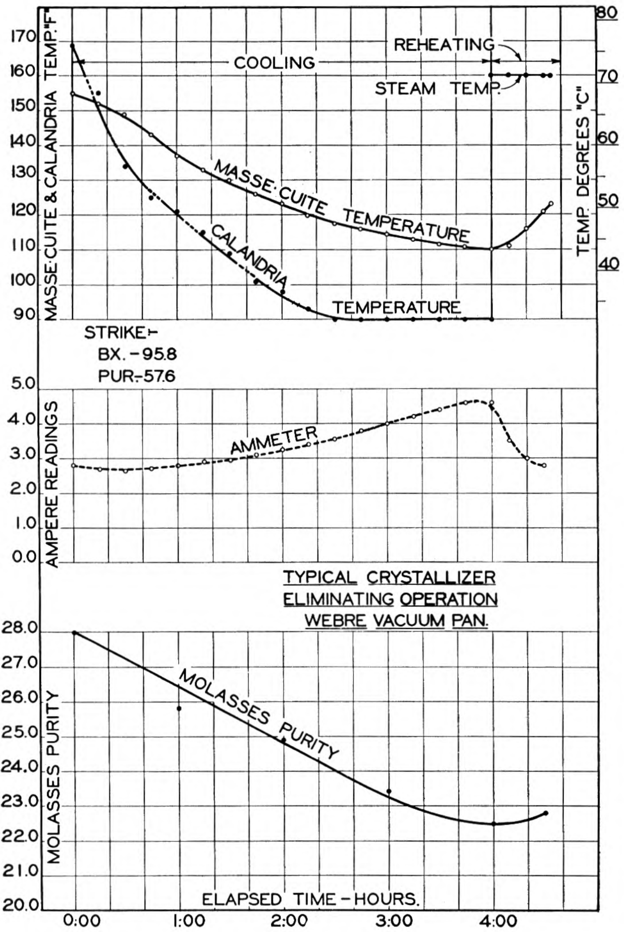


Fig. 10 Typical Crystallizer Eliminating Operation

cuite. One is to make more sucrose available for crystallization due to reduced solubility, and the other is to make it more difficult for the crystals to absorb the sucrose due to increased viscosity. A compromise point is necessary. In practise it is found that it does not pay to carry the cooling too far and many authorities agree that 100 to 110 F is about the economic limit.

The task then is to cool the masse-cuite from its normal temperature at the end of the strike down to 110 F, at the same time building up the liberated sucrose upon the surfaces of the existing sugar crystals. Three ways of doing this are available.

In the first place, cold water could be passed through the calandria of the pan with the circulator in motion. This is not very attractive, because it is impossible properly to distribute the cooling water throughout the calandria, and unequal cooling would result, too much at the water inlet and too little at the outlet. If there is unequal cooling, trouble would result immediately because cooling increases the viscosity of the masse, and the tubes having cool masse-cuite would stagnate, while the circulation would move rapidly through the tubes having no cooling. This, in turn, would bring about abrupt changes in local temperatures and inevitably false grain. This method has been tried with indifferent success and does not offer likely possibilities.

The other method is to cool by raising a high vacuum on the strike while being circulated, thus lowering the temperature by flashing. This, of course, would be perfectly uniform and gradual, and could be controlled by regulating the vacuum. The flashing involves evaporation and evaporation brings about increased concentration and, therefore, increased supersaturation. It is necessary to dilute the strike during this procedure both to avoid false grain and to keep down the horsepower required for the circulator drive. It has been found that there are too many adjustments involved and in the end the results wanted are not obtained.

However, flashing may be used in another way. It is understood that there must be no temperature shock in this cooling, which is necessarily gradual at a rate commensurate with the ability of the crystals to absorb the liberated sucrose. The method is to fill the calandria with hot water at a temperature approximating that of the strike, which involves no shock. Then, raising vacuum in the calandria only, the point is reached at which this water begins to boil. The heat of the masse-cuite circulating on the inside of the tubes is transmitted into the water, and is thus dissipated gradually, uniformly, and without shock, at a rate which can be controlled, since it is possible to regulate the vacuum. A 6-in. pipe was installed in the calandria extending up on the inside within 4 in. of the upper tube sheet and this pipe was connected to an auxiliary condenser. In the space of four hours, the cooling of the strike can be completed, and the final molasses made about the same as would be obtained in three days in the crystallizers.

Reheating

This operation was supplemented with one of reheating in the pan before dropping to the mixer. Water was dumped out of the calandria and steam was turned on at a vacuum of about 18 in. The temperature rose in about a half hour to 125 F. The purging of the low grades at this temperature is much quicker and more thorough due to the reduced viscosity of the molasses. There is no redissolution of sucrose, since the concentration of the molasses is not lowered below saturation. One raw-sugar mill has used this method exclusively for the last three or four years. Fig. 10 shows the record taken from this operation and indicates all the temperature changes, as well as the gradual exhaustion of the molasses. The recording ammeter gives the corresponding changes of viscosity brought about by these changes of temperature.

Final Conclusions

Mechanical circulation, properly designed and properly applied, is now an accomplished fact. Installations have been in operation long enough to establish the following possible performances:

(1) Thorough and uniform distribution of feed as it enters the circulating masse, avoiding local dilution or segregation by differences of gravity.

(2) Accurate control of operating densities made possible by the use of a recording ammeter giving the power required for the drive, and hence indicating the viscosity.

(3) Adequate rapid movement of the masse at all times depending only on controlled mechanical equipment.

(4) Minimum local variations of temperature.

(5) An effective and reliable method of cooling masse-cuite in the pans themselves, avoiding the necessity of crystallizers.

(6) All the consequential improvements brought about by these accomplishments.