WHERE SHOULD THE DOWNTAKE BE?

By DEON HULETT

The title of this paper poses a much argued question and requires some straight thinking in attempting to arrive at the correct answer.

Let us first list what are undisputed requirements of a first class vacuum pan for the boiling of sugar massecuites and then see how we are to go about achieving these requirements in the mechanical design of the pan.

1. Good circulation.
2. Low hydrostatic head.
3. Absence of "dead" zones.
4. Massecuite volume to the top of the calandria to be only $\frac{1}{3}$ of the total volume of the pan.
5. Sufficient heating surface.
6. Good entrainment separation.
7. Easy serviceability.
8. Efficient scavenging of incondensable gases from the steam space.

1. Good Circulation

Good circulation ensures that the massecuite maintains a higher velocity and a more even temperature throughout the pan. The higher velocity means more relative movement between crystals and this has the effect of one crystal rubbing the spent molasses film away from the surface of its neighbour, thereby allowing a fresh film of higher supersaturation to come in contact with the crystal. In this way the rate of crystallization is increased. The heat transfer rate between the tube and massecuite increases as the velocity increases and so higher velocity means increased heat transfer rate.

What causes the massecuite to circulate in the pan? Circulation is caused by the difference in density of a column of massecuite and steam bubbles rising through the tubes to the surface, from a column of massecuite descending in the downtake.

What is stopping the massecuite from circulating? Friction! Friction in the tubes, friction in the downtake and friction between the liquid and other surfaces of the pan.

From the above two facts it becomes obvious that to obtain maximum circulation in a pan two things are important. One is to maintain the largest difference in head between the two columns of liquid, and two, arrange the pan to offer the least resistance to flow due to friction.

Maintaining the largest difference in head between the rising column of bubbles and massecuite and the massecuite in the downtake requires that the downtake be remote from the rising column of bubbles so that bubbles can rise to the surface to separate from the massecuite and not short circuit and become entrained in the down stream.

Reducing the friction requires, since friction loss is proportional to the length of conduit and inversely, proportional to the fourth power of the diameter,* large diameters and short lengths for the flow passages. Friction being also proportional to velocity requires that this be reduced, but as high velocity is required for good heat transfer rate and fast crystallization, a compromise in this respect has to be reached.

A further compromise has to be reached with respect to the length of tubes since as the bubbles form in the tubes the density decreases, and for the same mass flow rate, the velocity and hence the heat transfer rate increases towards the top of the tube (as in film evaporators).

On increasing the diameter of the tubes the volume to surface area ratio increases, so in order to maintain sufficient heating surface a further compromise has to be made to keep the calandria volume to one third that of the pan.

The downtake should offer a small resistance to flow and occupy a minimum volume, and since friction is inversely proportioned to the fourth power of the diameter, it is important that the downtake have the maximum cross section area to equivalent diameter ratio for any section and this of course, is a circle.†

Now in deciding what the ratio of the downtake area to tube need be, let us consider Poiseuille's Law:

$$LW = 32\ \mu LV/g_c D^2 \rho$$

Consider a pan whose downtake area is 40% that of the tube area. The velocity in the downtake is at least two-and-a-half times that up the tube neglecting the bubbles in the tube.

Assuming the massecuite viscosity, density, etc., to be uniform throughout the pan the friction in the downtake is equal to a constant k times V_d/D_d^2 and the friction in the tube is the same constant $k x V_t/D_t^2$

where V_d = velocity in downtake
D_d = diameter of downtake
V_t = velocity in tube
D_t = diameter of tube

Now $V_t = 0.4\ V_d$, and
D_d in a 1,000 cu. ft. pan is of the order of
12 x D_t (in 4 in. tube and 4 ft. downtake).

This makes the friction in the tube equal

$$k \times 0.4 \frac{V_d/D_d^2}{144} = 57.6 \times V_d/D_d^2$$

or about 58 times the friction in the downtake.

Now, this means that the old pans with the small downtakes were not so bad after all as far as the downtakes were concerned. Since it is a fact that most of the resistance to flow is in the tubes, surely it is better to have as many tubes as possible and to have them as large a diameter as is practical, consistent with maintaining sufficient heating surface. Since the head lost in the downtake is small most of the pressure difference between the downflowing and rising columns will appear across the tube bank and so the more tubes, the greater the flow and hence the circulation of the pan.

It is interesting to note that a pan with a downtake in the form of an annulus occupying the same area as the circular downtake calculated above, would have an annulus only about 9 in. wide or an equivalent diameter of only 18 in. so the friction would be (4/1½) 4 times the friction in the circular downtake, i.e., 50 times. To obviate this increase in friction, the area would have to be increased to 100% that of the tube area at the expense of tubes which, as has already been shown, are the principal resistance to flow.

So, for good circulation, many large diameter tubes are required.

2. Low Hydrostatic Head

To ensure that a pan has not too much hydrostatic head at the heating surface is important, for at the vacuum existing in a pan a pressure of say 10 feet of massecuite means an elevation in the boiling point of about 50° F. This, of course, limits greatly the heat flux, the boiling, and hence the circulation. Also, of course, it is undesirable to have large changes in temperature throughout the pan as the high temperature can cause the solution to be unsaturated at one point in the pan and at the cold surface the massecuite may be supersaturated to the point of false grain formation.

3. Absence of "Dead" Zones

Unfortunately the squat pans required for low hydrostatic head design usually have a fairly slowly circulating zone of massecuite, particularly when the pan is full, above that outer portion of the pan which is outside the plan of the calandria. The rising column, of course, tends to move towards the downtake and so a volume of massecuite is left behind to circle on its own and not mix too readily with the main flow of massecuite.

4. Calandria Volume

In order to keep this within a one third of the strike volume, care must be taken not to waste space in the lower reaches of the pan. Sufficient space must be left, however, in order to facilitate the fitting and expanding of the tubes in the bottom tube plate. Tubes must be close together and the downtake not unnecessarily large.

5. Sufficient Heating Surface

The pan must of course, have sufficient heating surface and the size and number of tubes has been discussed in the section on circulation. "A" pans boil a higher purity material and for this reason the rate of crystallization is higher. So in order to evaporate the water fast enough to maintain the super saturation of the massecuite, more heating surface is required than for the low purity "C" boilings.

6 and 7. Good Entrainment Separation and Easy Serviceability

This goes without saying but a point to be borne in mind with saveалls is that if they can be made easy to maintain this should be incorporated. Webber has recommended an efficient design incorporating a change in direction of the vapours and a slowing down of the flow rate so that entrained droplets may settle out. The design recommended by Webber is of great interest particularly with respect to its simplicity and serviceability. It can be entered, examined and cleared from inside the pan without having to remove any cover other than the pan manhole door cover.

8. Efficient Scavenging of Incondensable Gases from the Steam Space

Many pans have multiple entry points of steam to the calandria and multiple draw-off points for the incondensable gases; others use baffles to direct the steam flow and incondensable vent points. It seems that the important thing is to know where the incondensables are going to collect and vent them off from that point with a minimum loss of steam.

The venting of incondensables is important for two reasons. One is the fact that some of the gas is corrosive to brass tubes and also steel tube plates, and secondly, the fact that incondensable gas blocks off some valuable heating surface.

Surely the logical thing to do is to blow the incondensables to some collecting point with the steam, and vent them from that point. Remember that air is heavier than steam and ammonia lighter so vents must draw off from near both the top and bottom tube plates.

Conclusion

The title of this paper is somewhat misleading as to the context but it was motivated by the great controversy existing last year with the re-introduction of the floating callandria pan to our industry.

From what has been pointed out in the paragraph on circulation, it should be clear that the tubes are the controlling factor in this respect and so the pan with the greater tube area and tube diameter will have the greater circulation. This of course must be a pan with a circular section downtake. However, in practice so much depends upon the technique of the various operators on how a pan performs and his influence will probably have more effect than the actual pan design provided the latter, of course, is not too incorrect.

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* **Poiseuille's Law.**

$LW = 32\,\mu\,LV/g_cD^2\rho = (128/\pi)\,\mu\,LW/g_cD^4\rho$
LW = friction loss, ft. lbs./lbs.
ρ = fluid density, lbs./ft.^{3}.
V = average velocity, ft./sec.
g_c = gravitational constant, ft./sec.^{2}
L = pipe length, ft.
D = pipe diameter, ft.
μ = fluid viscosity, lbs./ft. sec.
W = weight rate of flow, lbs./sec.

† The equivalent diameter of a secton $= \dfrac{\text{4 x cross sectional area}}{\text{Wetted perimeter}}$

Mr. Gunn (in the chair): The floating calandria pan has an annular downtake which according to your formula must have a higher resistance than the centre downtake. If the friction in the annulus is somewhat higher in the floating calandria pan this makes for a slight reduction of circulation, but it does give the massecuite a chance to be released from the vapour bubbles at the top of the pan and therefore a much denser material comes down the side of the pan.

A floating calandria pan does not have dead zones but it is a debatable point whether or not the absence of these zones counteracts the effects of increased friction.

Mr. Hulett: Two pans have been installed at Felixton, one with a central downtake and one with an annular one, but so far it cannot be said that one boils a better sugar than the other.

At Darnall a circulator has been installed, with a 60 horse-power motor, in a pan. This pan and one next to it boiled the same massecuite but when the sugars were analysed by the S.M.R.I. no significant difference was found.

Mr. Young: With the two pans at Darnall boiling the same massecuite, but one pan having a circulator, what is the ratio of boiling times?

Mr. Hulett: Despite the terrific increase in heat transfer in the pan with the circulator both are boiled for the same time — approximately five hours. But the time could be decreased in the circulator pan.

Mr. Young: I do not think a direct comparison in boiling time can be made unless the steam to the circulator pan is reduced.

Mr. Hulett: That is correct but we have not been able to reduce the steam as the pans are at present connected to a common condensate system.

A lot more experimental work has yet to be carried out on the circulator pan and some interesting results are expected.

Mr. Dick: Mr. Hulett says "Maintaining the largest difference in head between the rising column of bubbles and massecuite and the massecuite in the downtake requires that the downtake be remote from the rising column of bubbles so that bubbles can rise to the surface to separate from the massecuite and not short circuit and become entrained in the down stream".

In some pans several circular louvres are positioned above the downtake, apparently to deflect the rising massecuite from the tubes so that it will not be entrained in the manner mentioned by Mr. Hulett.

I gave this matter thought some years ago and came up with the idea of a "raisable" downtake so that as the massecuite was rising the downtake could be raised. The bubbles would then come up to the top and not be entrained in the centre part, and would flow over the top edge of the raised downtake.

Mr. van Hengel: We fitted a loose annular tube in the downtake of a pan at Illovo. When it was lowered the top and lower tube plate were level. For a diameter of five feet there was half an inch of play either side.

The tube was three feet long and the idea was that when it was extended it would increase the length of the central downtake to six feet.

The rising tube when extended would be three feet above the tube plate and when the pan was full the strike level was five feet, that is, two feet over the tube.

Some time before this the Australians published an article in which it was said that circulation patterns are quite normal up to two feet above the tube plate.

We hoped to maintain this two feet by raising the tube plate with the massecuite, keeping it two feet behind.

Temperature probes were fitted in the pan and many readings were taken and analysed. So far there is no clear indication of any improvement in the boiling.

Dr. Douwes Dekker: In the experiment at Illovo the boiling was very irregular. Temperatures varied far more than we expected, probably due to fluctuations in the vacuum. There was also variation in the boiling techniques of the pan boilers.

Therefore, although we have plenty of data, it is not possible at this stage to draw conclusions in respect of the sleeve in the downtake. The experiment will, however, be continued.

Mr. Jones: This paper makes a very important point when it says "However in practice so much depends upon the technique of the various operators on how a pan performs and his influence will probably have more effect that the actual pan design, provided the latter, of course, is not too incorrect".

It is virtually impossible to make any assessment of circulation in a pan until the effect of the pan boiler can be regularized, i.e. until a constant, standardized method of boiling is attained.

Mr. Boyes: Mr. Hulett has used Poiseuille's formula and drawn certain conclusions from it.

When studying the resistance of flow in a pipe it is usual to start with Poiseuille's Law and evolve a formula which incorporates a Reynold's number. This formula is particularly useful when the flow is turbulent.

With a liquid, like syrup, of high viscosity and streamlined flow it is usual to use another formula, using a Grashof number.

But neither formula can be used here because we have a liquid which incorporates a large quantity of crystal. Therefore no scientific formula has so far been evolved that can adequately measure the resistance of massecuite. We can only use empirical means such as the velocity of massecuite passing a certain point, etc.

I mention this because Mr. Hulett draws a conclusion in favour of a central downtake as opposed to a downtake on the circumference, using Poiseuille's Law, which I do not think is strictly applicable.

Mr. Hulett: I have assumed that the viscous fluid has a streamlined flow.

No matter what formula is used, it is quite certain that resistance to flow will be less in a circular pipe. The shape of a downtake is significant, but is its position in the pan also significant?

Mr. Elysee: Good circulation is important in a pan. Yield per cubic foot of sugar is the most essential thing in a sugar factory and I think it time that consideration again be given to coil pans instead of calandria pans.

Mr. Bentley: A lot of work has been done in Queensland on the design of calandria pans. I wish to refer to a paper presented at the 26th Conference of the Q.S.S.C.T. by Allan and Saranin. They say that one of the main reasons for moving the downtake away from the centre is the effect a central downtake has on decreasing the circulation of the pan. "In the top layer of the massecuite there must be a horizontal flow towards the downtake. With the conventional type of calandria this horizontal velocity increases as the downtake is approached and the smaller the diameter of the downtake the more this condition is aggravated. It follows that with viscous material some bubbles will be carried over to a position vertically above the downtake. This will decrease the head on the down-going column thus hindering circulation. Some bubbles will be carried down, thus aggravating the loss of head, and a further effect is that, with the increase of hydrostatic head, they will collapse, raising the temperature and decreasing the supersaturation of the down-going stream, both undesirable features."

Because of this, and after making a lengthy study of pan boiling, they decided it was far better to allow the circulation to take its natural course out to the circumference and thus have the downtake on the circumference of the pan.

In connection with stirrers they say "It has been established that stirring, of the intensity used in vacuum pans, does not increase the rate of crystallization. It does help by improving mixing, and, in the absence of short-circuiting of the zone where vapour formation and disengagement take place, it may also improve heat transfer." In other words, if the pan design is bad and the circulation is bad a stirrer will help, but where the circulation is already good a stirrer makes no difference.

Mr. Hulett: I have some pictures of massecuites, with and without circulators, boiled in the pan patented by Allan and Saranin and by comparison sugar made at Darnall, in central downtake pans without circulators, is far better.

Mr. van Hengel: I prefer the coil pan to the calandria pan. The arrangement of the heating surface in a coil pan in itself is of course important. However, the heating surface is positioned better with regards to the hydrostatic head. This will make a good coil pan a better proposition than a calandria pan, if cost is disregarded.

Dr. Douwes Dekker: It is quite true that improved circulation does not necessarily improve rate of crystallization. In crystallization we have to take into account two speeds, that is, the speed at which molecules are supplied to the growing crystals and the speed at which the molecules are laid on the crystal, this last one being completely independent of viscosity.

In a boiling massecuite, the rate of crystallization is governed either by the rate at which the molecules are supplied to the crystal surface or by the rate at which they are laid on to the surface. In Germany, for pure sucrose solutions, it was found that at a certain temperature one of the two speeds was more important and under that temperature the other was more important.

Regarding friction in tubes, Hugot read a paper at an International Congress and discussed the matter exhaustively.

Mr. Gunn: The British Sugar Corporation tried stirrers in pans for refinery sugars but effected little improvement until the pan boiler improved his technique. They found they did not need movement water in the pan and movement was supplied by electrical power.