ENTRAINMENT FROM PANS AND FROM INTERMEDIATE EVAPORATOR VESSELS

By G. R. E. LIONNET

Sugar Milling Research Institute

Abstract

Experimental methods for the measurement of entrainment from pans and intermediate evaporator vessels are given. Entrainment under steady operations correlated with vapour velocity and did not result in high sugar losses. High losses were however measured under unsteady operation.

Introduction

In 1981 the SMRI started a project aimed at generating design data for entrainment separators. The intention was to vary operational conditions in pans and evaporators over a range wide enough to reach the points where the separators stopped operating efficiently. It was soon found, however, that this approach was not feasible on the factory scale. The operational conditions could be varied only over relatively narrow ranges and, in some cases, unsteady behaviours seemed to persist over long periods of time after operational conditions had been changed. The investigation was therefore concentrated on the development of experimental methods for the measurement of entrainment from pans and intermediate evaporators.

Under steady evaporator operations, namely without splashing or direct spouting, the levels of entrainment will depend on such factors as evaporation rates, absolute pressures, liquid and vapour densities, viscosities and surface tension. Since the vacuum profoundly affects the specific volume of vapour, the interacting effect of evaporation rate and vacuum is best considered together by using vapour velocities. Vapour velocity has been shown as one of the main factors controlling entrainment.[1-5] A number of authors show entrainment to be a function of vapour velocity through relations of the form:

$$\text{Entrainment} = a.(\text{Vapour velocity})^b$$

Re-entrainment[1,2] occurs when the vapour velocity in the separator becomes high enough to cause the collected liquid to be picked up again and swept out, that is when drainage breaks down. Entrainment then reaches very high levels. With hindered drainage the liquid hold-up increases thus reducing the area for vapour flow. This increases vapour velocities and re-entrainment occurs either by collecting liquid as just described or by the shattering of the liquid surfaces forming smaller droplets, which are then swept out.[3]

Experimental Procedure

Direct vapour sampling

Vapour sampling on the factory scale has been investigated by Beale and Stewart[5] and by Claire.[6] The technique presents a number of problems and was not considered applicable here.

Intermediate evaporator vessels

Li^+ was added at a known rate to the feed stream of the vessel, and the stream was sampled after the addition point. Evaporation rate was then calculated by using the Li^+ pumping rate, the concentration of Li^+ in the feed and the brix analyses of feed and outlet syrups. Vapour velocity was then calculated using the specific volume, the evaporation rate and the relevant diameter.

The condensed vapours, from the calandria of the following vessel, were sampled continuously, preserved and analysed for sugar as described by Schäffler.[7]

Vacuum pans

Condensate flow was measured continuously using a proportional head weir. Flashing was prevented by the use of steam traps and surging did not generally cause problems. Jigger steam flow, where applicable, was measured by using an orifice plate. Evaporation rate was assumed to be equal to the condensate flow plus jigger steam flow.

Vapour velocity was calculated as described above. Condenser inlet and outlet water samples were analysed for sugar in ppm. Outlet samples were obtained by using a positive displacement pump and the sampling was continuous. Temperature measurements are required to calculate inlet and outlet flows by heat balances. They were obtained at regular intervals using precalibrated mercury in glass thermometers. Vapour temperatures were calculated from absolute pressures.

An additional step involving the use of lithium was also used. A quantity of lithium chloride was introduced in the pan, together with the footing, and allowed to mix with it. The amount of LiCl added was calculated to give a concentration of Li^+ of between 100 and 200 mg Li^+/kg massecuite at the start of the boil. Li^+ was then monitored in the tail-pipe water. Samples of massecuite were also taken at regular intervals from the pan and analysed for pol and Li^+, which yielded Li^+/pol ratios.

If it is assumed that the material entrained consists of the whole massecuite, this ratio and the Li^+ concentration in the tail-pipe water may be used to obtain the quantity of sugar entrained.

Li^+ levels in the condenser inlet water are also required to correct for background levels.

Experimental approach

The investigation was designed to measure entrainment levels under various operational conditions, for centrifugal and angle-iron separators in the factory.

Vapour velocity was selected as the most important variable to be considered. Attempts to change vapour velocities in evaporator vessels, to cover as wide a range of operations as possible in the same vessel, were made by changing both steam and juice flows. In vacuum pans, it was expected that a wide enough range would be available by investigating both massecuite and seed boilings.

Usually some 3 to 4 runs were carried out with a given separator. A run consisted of sets of measurements, each set covering a period of 10 to 15 minutes.

Results

Intermediate evaporator vessel

A first vessel located immediately after the Kestners at DL was investigated. The vessel was fitted with a cyclonic type separator. Entrainment has been plotted against the maximum vapour velocity in the cyclone as shown in Figure 1, where the results which appear to be outliers are shown by the squares.

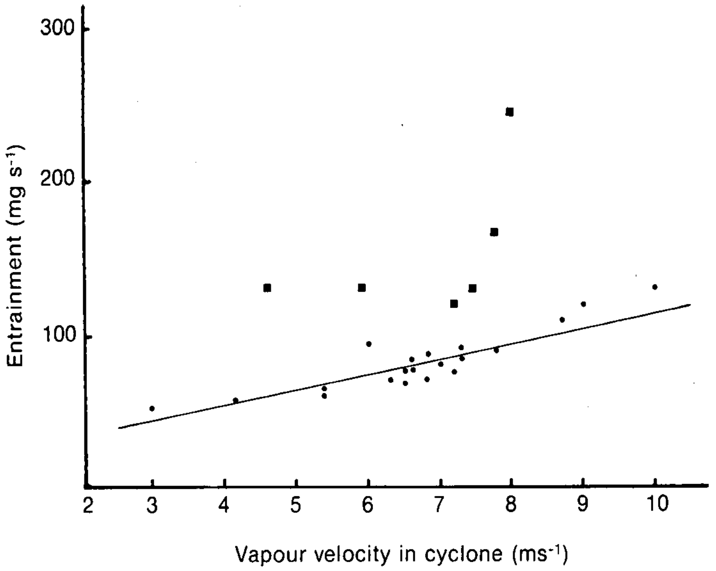

FIGURE 1 Entrainment in mg of sugar per second against vapour velocity for a cyclone separator

The regression equation

Entrainment = 19,8 × (Vapour velocity)^{0,8}

with a correlation coefficient of 0,82 for 21 pairs of observations, fits the data (excluding the apparent outliers) fairly well.

These results show that the performance of the cyclone is good over the range of vapour velocities from 2 to 10 $m.s^{-1}$, with less than 100 mg of sugar being lost per second. This would represent less than 50 kg of sugar per week.

It is also evident that higher levels of entrainment, which do not correlate with vapour velocity, do take place in the vessel. A possible explanation for these points would be that spouting occurs at times in the vessel and that severe entrainment results from this. This highlights the importance of steady operational conditions, since intermittent spouting probably results from abrupt changes in vacuum, juice flow, steam flow and pressure.

The results also show that under factory operation, it was not possible to change conditions to the extent required to reach the point when re-entrainment occurs.

Tests on another vessel with an angle-iron separator yielded results qualitatively similar to those shown in Figure 1, but showing a much larger scatter. Vapour velocities through the separator ranged from 2 to 6 $m.s^{-1}$ with entrainment between 100 and 200 mg per second except for a number of high values not correlating with vapour velocity.

It is interesting to compare the results obtained here to those quoted by Humm,[3] who gives operating vapour velocities of about 10 to 40 $m.s^{-1}$ for cyclones, with re-entrainment occuring at the higher limit. The range measured here is thus restricted to the lower region quoted by Humm. The operating range for louvres or zig-zag baffles is given as 3 to 13 $m.s^{-1}$. Again, the louvre investigated here operated at the lower end of this range. According to Humm, re-entrainment is not liable to occur in those two separators. Entrainment problems are therefore more likely to be caused by direct spouting of liquid into the separator.

Pans

A number of runs were done in an A-pan fitted with a cyclone separator. The results include both grain and massecuite boilings. Since the condenser inlet water showed sugar levels around 40 ppm, only the lithium based results were considered satisfactory. Again entrainment is plotted against vapour velocity in Figure 2, where high levels not related to vapour velocity have been shown by the large circles.

Four of the outliers occurred at start-up or during cutting-over. It was also observed that vacuum changes occurred during the boilings, which may explain the remaining outliers.

The other points fit the following equation poorly, with a correlation coefficient of only 0,71 for 5 pairs:

Entrainment = 0,05 × (Vapour velocity)^{2,4}

These results are qualitatively similar to those obtained previously for cyclones, with some operational evidence for the high entrainment outliers.

Tests were done on two C-pans at EM; one with a top-hat separator and the other with a cyclone. Apart from the separators, the two pans were of similar design. Relatively sugar free inlet water (about 10 ppm) was made available for the tests, which allowed comparisons between the lithium based and sugar ppm based results.

The pan with the top-hat started by boiling C-seed and cut over half its content 4 hours later. The footing was boiled up and a C-massecuite dropped after a further 5 hours.

Although the level of sugar in inlet water was relatively low, some negative values for entrainment were obtained. Excluding these negative values, there was a fairly good agreement between the sugar based and lithium based results.

Entrainment calculated by the lithium based method has been plotted against vapour velocity in Figure 3.

These results fit the following equation fairly well with a correlation coefficient of 0,82 for 20 pairs.

Entrainment = 2,2 × (Vapour velocity)^{1,1}

The range of vapour velocities is fairly large, but the highest value (35 $m.s^{-1}$) is still below the upper limit (41 $m.s^{-1}$) quoted by Humm.[3]

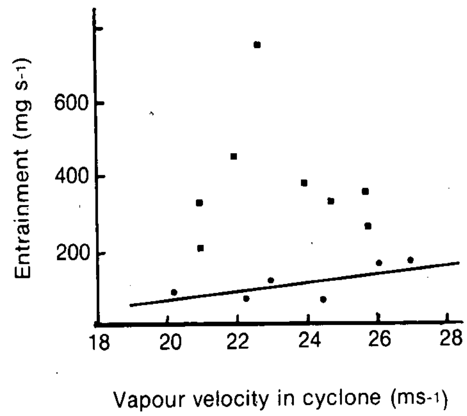

FIGURE 2 Entrainment in an A-pan

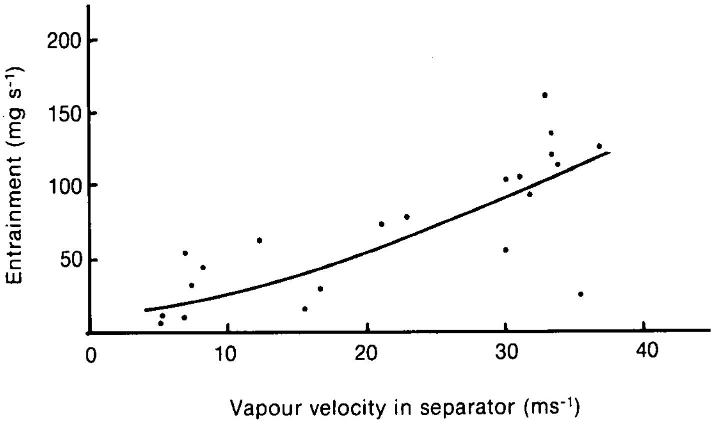

FIGURE 3 Entrainment from a C-pan with a top-hat separator

The results from the other pan with the cyclone separator were qualitatively similar. Scatter was however larger and high entrainment values, not related to the vapour velocity, occurred during cut-overs and at start-up, as shown in Table 1.

TABLE 1

Entrainment and vapour velocities at start-up and cutting over

Vapour velocity ($m.s^{-1}$)	Entrainment ($mg.s^{-1}$) based on lithium tracer	Remarks
22,8	1 010	Vacuum fluctuations
24,9	2 684	Vacuum fluctuations
17,4	3 068	Cut-over
17,9	1 023	Cut-over
36,6	9 660	Start-up
36,6	1 240	Start-up
11,1	613	Vacuum fluctuations

These results confirm the influence of operational considerations on entrainment from pans.

Reasons for the difference in the effect of start-up or cutting-over on entrainment between the two pans are not readily evident. Local process staff was aware of this difference, and all attempts to reduce entrainment levels during cutting-over or starting-up had been unsucessful.

Conclusion

The results obtained for the evaporators consist of two distinct parts. Firstly, most of the entrainment measured correlates fairly well with vapour velocity, the relation being of the form:

$$\text{Entrainment} = a.(\text{Vapour velocity})^b$$

with a and b averaging 18,5 and 1,2 respectively. Secondly, all tests have shown the apparently random occurrence of high entrainment levels, not correlating with vapour velocity. These levels could range up to 200 to 300 ppm of sugar in tail-pipe wate or condensate.

While the first type of entrainment would account for losses of sugar, ranging from 50 kg/week to about 200 kg/week, the second type, although not occurring continuously, could account for much higher losses. These high levels are most probably due to juice being thrown directly into the separator by sudden changes in operational conditions, such as vacuum, juice and steam flows. These results therefore highlight the need for steady operations.

The range of vapour velocities occurring in pans was wider than that found in the evaporators, but did not exceed the 40 $m.s^{-1}$ limit given by Humm.[3] The fact that no evidence of re-entrainment was found agrees with Humm's results. The results obtained again fitted a relation of the type shown for the evaporators with $a = 3$ and $b = 1,1$. The tests done with sugar-free water show that entrainment may be measured by using a Li^+ tracer, which is necessary when sugar levels in condenser inlet water are high. The Li^+ based approach is more precise, but also more costly, than the usual one since large quantities of lithium hydroxide, which is an expensive and not readily available material, are required. High levels of entrainment, not related to vapour velocity, were found again. In some cases, these entrainment peaks could be related to operational changes such as vacuum fluctuations, start-up and cutting-over procedures.

These results show that entrainment from pans operating under steady operations does not result in heavy losses of sugar. High sugar losses were, however, measured under unsteady operational conditions such as vacuum fluctuations, changes in flows, start-up and cutting-over.

Inefficient drainage of separators, because of partially blocked return pipes, was often found to be a major cause of entrainment from pans. Figure 4 is a schematic arrangement which is proposed to solve this problem. It was designed[8] for an SMRI separator followed by a wire mesh demister but the draining and steaming out arrangements may be easily modified to suit other separators.

The drains should be made of 75 mm pipe into a 100 mm main. A sight glass is useful for checking that material is flowing and should be provided. The left leg of the U-seal returns all the separated material into the pan above the maximum level of massecuite. This helps reduce blockages due to massecuite. The drains must be steamed out regularly.

The steaming out arrangement consists of a 150 mm main, feeding vapour one into the system. Branches of 50 mm would be adequate. Flanges should be provided, as indicated, to allow regular dismantling and cleaning of pipes. Steaming out of drains and separators should be carried out after each strike together with the pan steaming.

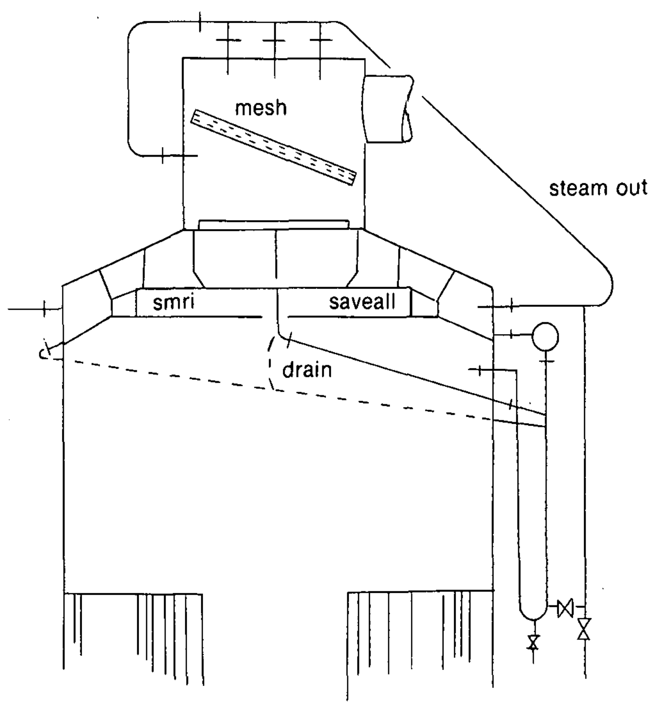

FIGURE 4 Proposed arrangement for draining and steaming out the pan separator

Acknowledgements

The author would like to thank the management and staff of the factories where the experiments were done, for their co-operation. He is also indebted to the Analytical Services and Chemical Divisions of the SMRI, who carried out all the analytical work and to the Workshop staff for their help with the instrumentation.

REFERENCES

1. Buchanan, E. J. (1962). An investigation of entrainment and entrainment separation in evaporators with particular references to the sugar industry. M.Sc. thesis. University of Natal.
2. Frew, R. (1971). Entrainment prevention in sugar mill evaporation plant. *Proc int Soc Sug Cane Technol* 14: 1499–1503.
3. Humm, D. M. (1979). Entrainment separators for vacuum pans and evaporators. 39th Meeting Sug. Ind. Tech. 190–215.
4. Perry, R. H. and Chilton, C. H. (*ed.*) (1973). *Chemical Engineers Handbook*. 5th Ed. McGraw-Hill, New York. p. 5–61.
5. Beale, R. F. and Stewart, P. N. (1962). Entrainment investigations. *Queensland Soc Sug Cane Technol* 29: 95–107.
6. Claire, A. G. (1965). A method for detecting and measuring entrainment. *Proc int Soc Sug Cane Technol* 12: 1725–1732.
7. Schäffler, K. J. (1978). Sugar entrainment monitoring. *Proc S Afr Sug Technol Ass* 52: 123–124.
8. Allan, G. N. SMRI, Private Communication.