THE OPERATION AND PERFORMANCE OF CONTINUOUS C-CENTRIFUGALS

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Abstract

A series of factory investigations, initially based on a statistical approach, was carried out to determine the effect of various operational parameters on the performance of continuous C-centrifugals. The relationship between C-sugar purity and C-molasses purity is given. The influence of steam and water additions and water temperature on the centrifugal performance is reviewed. The importance of the crystal size distribution of the C-massecuite is discussed relative to its effect on final molasses purity.

Introduction

The first continuous C-centrifugals were introduced in the South African sugar industry in the late fifties. In about fifteen years they had, because of their many advantages, completely replaced the batch-type centrifugals on B- and C-massecuites. During this period many local technologists have investigated the performance of the centrifugals and the findings of Carter,[1] de Robillard,[2] McEvoy and Archibald,[3] among others, have greatly contributed to a general improvement in their operation. However, attempts to determine accurately their optimum mode of operation have not been conclusive. This is not surprising, considering the large number of operational variables which are combined in running a centrifugal and the constantly changing characteristics of the massecuite.

In Australia, Kirby et al[4, 5, 6] and Swindells et al[7] have carried out extensive investigations into the performance of continuous centrifugals and have made a series of interesting findings which, however, may not necessarily apply under the different local conditions.

In this investigation, carried out over a two season period, a fresh attempt was made to determine the combination of operating conditions which would optimise centrifugal performance.

Experimental Approach

All the tests were carried out in various factories using C-massecuites as normally supplied to the centrifugal station. The massecuite purity ranged from 47° to 56° at a brix varying between 91° and 95°. The curing temperature varied between 58° C and 63° C with viscosities ranging from 500 to 2 600 Pa.s at the curing temperature.

The investigation was conducted in four main parts:—

(*a*) A series of factorially-designed experiments[8] run at factories No. 1, 2 and 3 during the 1980/81 season. The operational variables under investigation were the massecuite throughput, water addition and temperature and steam addition.

(*b*) Six factorially-designed experiments, two each at factories No. 3, 4 and 5, held in June and July 1981.

These experiments differed from Part (*a*) in that they were each carried out in ± 6 hours instead of over several days; in addition C-sugar purity replaced the massecuite throughput as a set variable.

(*c*) A series of comparative tests to investigate the influence of a change in only one operational variable on the centrifugal performance at factories No. 3, 4 and 5.

(*d*) A survey undertaken in co-operation with a major sugar group at its five mills (No. 4, 6, 7, 8 and 9). The objective was to determine the purity rise in molasses across the centrifugals under normal operating conditions, and the effect of crystal losses through the screen perforations on the purity rise.

Experimental Procedure

All the tests were carried out on factory centrifugals, namely BMA K 850 at factories No. 1, 3 and 4 and Western States CC 5 and CC 4 at factories No. 2 and 5 respectively. New screens of 0,06 mm were fitted at the start of each experiment. At the beginning of every run all the operational variables were set at their desired levels, and the centrifugal run under steady conditions for a minimum of 20 minutes. The C-sugar and C-molasses were then sampled at regular intervals over a 5 minute period following which the molasses was collected over a timed period and its mass and temperature were recorded. During the run a sample of massecuite was taken and the Nutsch molasses extracted using an SMRI Nutsch bomb.[9] The apparent purity of the C-massecuites, nutsch and final molasses, and C-sugars was determined and the viscosity of the massecuites was measured with a Brookfield viscometer. The C-massecuite throughput for each run was calculated by the following equation:

$$Q_m = \frac{P_s (Q_f - Q_w) - (Q_f \cdot P_f)}{P_s - P_m}$$

All symbols are defined in the Nomenclature.

Results and Discussion

Factorial Experiments

The data from Part (*a*) showed no significant correlation between the operational variables and the centrifugal performance at all three factories. However, when the data from each factory was analysed separately on a daily basis highly significant correlations between the C-molasses purity rise ΔP and the C-sugar purity were found. (See Table 1). The reason for the lack of significance when the data was analysed as a whole can be explained by the wide variations in ΔP recorded from day to day at the same factory, and which appeared to be caused by the presence of a large and varying number of small sugar crystals in the molasses.

These crystals are not always visible under normal operating conditions because they dissolve in the hot dilute molasses. They are seen by a microscopic examination of the "undiluted" C-molasses obtained by running the centrifugal without steam and water.

It became obvious that a change in the crystal size distribution of the massecuite was sufficient to obscure the effect the operational changes had on the molasses purity. To eliminate this problem, each full experiment in Part (*b*) was completed within 6 hours to ensure that the massecuite characteristics did not change. In all six experiments good correlations were found for the final molasses purity and the C-sugar purity, as shown in Table 1, to confirm that there is a rise of approximately 0,1° in molasses purity for each unit increase in C-sugar purity.

TABLE 1
Regression Equations between C-Molasses Purity and C-Sugar Purity

Factory No.	C-Sugar Purity Range	Regression Equations*	Significance
1	74 - 86	$\Delta P = 0{,}07U_s - 1{,}80$	99
2	66 - 90	$= 0{,}12U_s - 4{,}35$	99
3	67 - 84	$= 0{,}06U_s - 2{,}43$	99
3	69 - 86	$U_f = 0{,}08U_s + 31{,}03$	99
3	71 - 88	$= 0{,}09U_s + 29{,}84$	99
4	69 - 88	$= 0{,}10U_s + 26{,}57$	99
4	73 - 87	$= 0{,}16U_s + 19{,}99$	99
5	73 - 85	$= 0{,}06U_s + 33{,}60$	95
5	70 - 88	$= 0{,}06U_s + 33{,}01$	99

Note: ΔP was used instead of molasses purity in the first factorial experiments because of the change in massecuite characteristics during the experiment.

* Symbols have the meaning given in the Nomenclature.

A plot of C-molasses purity versus C-sugar purity for factory No. 4 is shown in Figure 1.

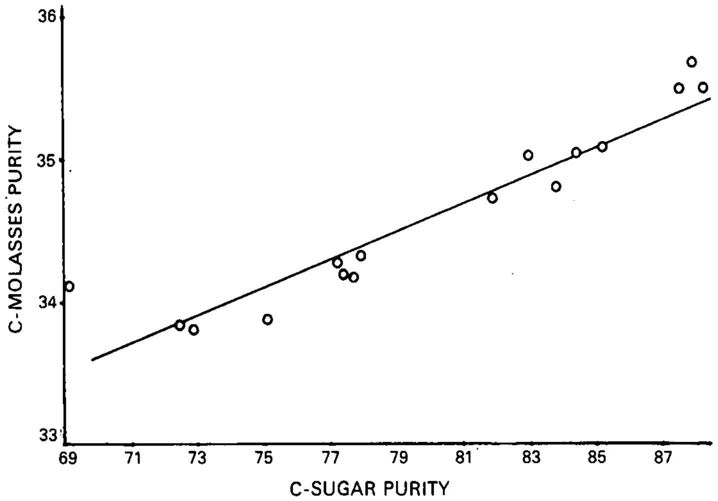

FIGURE 1 C-molasses purity versus C-sugar purity (Factory No. 4).

To investigate the effect of the operational variables on the centrifugal performance, the experimental data was subjected to a multi-linear regression analysis through the SPSS (Statistical Package for the Social Sciences) Package available on the Natal University Univac 1100. This package allows a forward multi-linear regression to be carried out, and selects only those independent variables which are significant at a specified significance level (5% in this case) to be included in the regression equation. The equations for C-molasses and C-sugar purities in terms of the operational variables for some of the tests are given in Table 2.

As indicated by the correlation coefficients the fit is generally good. The equations show that in most cases those factors that affected the C-sugar purity also affected the C-molasses purity in the same direction and that a unit change in C-sugar purity was accompanied by approximately 0,1° change in C-molasses purity. The massecuite throughput did not follow the same trend and caused a decrease in the sugar purity but no accompanying reduction in molasses purity. The fact that the steam effect was only evident in one test must not be taken as an indication that steam addition has a negligible effect on the centrifugal performance. The absence of significance is probably due to the narrow range of steam addition during the tests.

Comparative Tests (See also addendum)

These tests were carried out with the objective of detecting more precisely any effect which may have been hidden in the more complex factorially designed experiments. The operational variables which were directly investigated were the wash water temperature, the steam and water additions and the molasses temperature. All the comparative tests were carried out on the same centrifugal at the same C-sugar purity and completed within 6 hours to eliminate the crystal loss effect.

TABLE 2
Equations for C-Sugar and C-Molasses Purities in Terms of the Operational Variables

Factory No.	Test No.	C-Molasses Purity	C-Sugar Purity
3	2	$U_f = 35{,}2 + 0{,}13\ W_r$ $(r = 0{,}70)$	$U_s = 74{,}3 + 1{,}01\ W_r$ $- 0{,}005Q_m$ $(r = 0{,}86)$
4	1	$U_f = 32{,}3 + 0{,}12\ W_r$ $+ 0{,}01T_w$ $(r = 0{,}98)$	$U_s = 60{,}2 + 1{,}07\ W_r$ $+ 0{,}09T_w$ $(r = 0{,}95)$
	2	$U_f = 31{,}2 + 0{,}17\ W_r$ $+ 0{,}01S_p$ $(r = 0{,}91)$	$U_s = 83{,}8 + 0{,}09\ S_p$ $- 0{,}004Q_m$ $(r = 0{,}91)$
5	2	$U_f = 35{,}7 + 0{,}29\ W_r$ $(r = 0{,}77)$	$U_s = 61{,}3 + 3{,}76\ W_r$ $- 0{,}006Q_m$ $(r = 0{,}91)$

* Symbols have the meaning given in the Nomenclature.

(*a*) Wash Water Temperature

Thirty tests were carried out at factories No. 3 and 4. The water and steam additions were adjusted at normal factory level and the water temperature changed from 80°C to 50°C at every alternate run. The massecuite throughput was manually adjusted to obtain the desired sugar purity. The results are summarised in Table 3.

TABLE 3
The Effect of Water Temperature on Centrifugal Performance
(Average of 16 tests at factory No. 3 and 14 tests at factory No. 4)

Factory No.	Water Temperature (°C)	Massecuite Flow rate (kg h^{-1})	Water % Massecuite	C-Sugar Purity	Final Molasses Purity
3	81,5	1 710	13,2	85,0	42,20
	55,0	1 470	15,5	84,6	41,79
4	83,4	1 660	9,4	84,6	38,61
	53,3	1 550	10,0	85,1	38,16

In both tests the molasses purity dropped by about 0,4° at the lower water temperature accompanied by a reduction in throughput of 14% and 7% at factories No. 3 and 4 respectively.

(*b*) Steam Addition

The effect of steam on the centrifugal performance was investigated at factories No. 3 (18 tests) and No. 5 (10 tests). The tests were run by keeping the quantity and temperature of the wash water at their normal factory level and changing the steam admission from a high to a low level at every alternate run. The results for factory No. 3 are shown in Table 4.

At factory No. 3 the use of extra steam increased the capacity by 34% and 46% accompanied by an increase in molasses purity of 0,64° and 0,40° for the two experiments. At factory No. 5 there was a 20% increase in throughput and an average increase of 0,60° in the molasses purity.

(*c*) Molasses Temperature

The centrifugals were set to produce alternately runs at high and low molasses temperatures by using a combination of high steam admission and high water temperature

TABLE 4
The Effect of Additional Steam on Centrifugal Performance at Factory No. 3
(Each test is the average of 9 runs)

Test No.	Steam Addition	Massecuite Flow rate (kg h^{-1})	C-Sugar Purity	Final Molasses		
				Temp (°C)	Brix	Purity
1	Normal	1 680	81,9	58,4	79,2	40,00
	High	2 250	83,1	67,4	81,4	40,64
2	Normal	1 800	79,4	61,1	81,0	38,90
	High	2 620	80,5	68,0	83,5	39,30

(80°C) for the hot runs and low steam admission and low water temperature (50°C) for the cold runs. The results of tests at factory No. 4 are given in Table 5 and show that the 20% increase in capacity at high molasses temperature was accompanied by an increase in molasses purity. The same tests repeated at factory No. 3 yielded a 30% increase in capacity at high molasses temperature with an increase of 1,7° in molasses purity.

TABLE 5
The Effect of Molasses Temperature on the Centrifugal Performance at Factory No. 4
(Average of 8 runs and 6 runs for tests No. 1 and 2 respectively)

Test No.	Molasses Temperature (°C)	Massecuite Flow rate (kg h^{-1})	C-Sugar Purity	Final Molasses	
				° Brix	Purity
1	66,9	1 890	82,0	84,0	37,99
	59,6	1 510	80,8	80,8	37,34
2	65,1	1 590	79,1	86,8	36,99
	56,3	1 355	78,9	82,6	36,67

TABLE 6
The Replacement of Steam by Additional Water at Factory No. 3
(Average of 15 runs)

Steam Addition	Water % Massecuite	Massecuite Flow rate (kg h^{-1})	C-Sugar Purity	Final Molasses	
				° Brix	Purity
Open	7,6	1 993	82,6	80,4	41,67
Closed	10,5	1 915	83,0	78,2	41,80

(*d*) Interchangeability of steam and water

In this series of tests at factory No. 3, the steam admission valve which is normally run fully open, was closed at every alternate run, and the addition of water at 80°C increased so that the capacity remained the same at the same C-sugar purity. The results are given in Table 6 and indicate that the replacement of steam by 38% additional water did not cause, for all practical purposes, any change in C-molasses purity.

Molasses Purity Rise Survey

The purity rises in final molasses across the C-centrifugals, measured during the two seasons the investigation was proceeding, are given in Table 7.

During the survey carried out in the five mills of a sugar group the purity of the "dry run" molasses, obtained by running the centrifugal without water and steam addition, was determined and compared with the nutsch and final molasses purities. The purity rise due to crystals in the molasses ("physical loss") was taken as "dry run" purity minus Nutsch purity and the purity rise due to water and steam addition ("operational loss") was taken as final molasses purity minus "dry run" purity. The average results for the 5 mills were:

TABLE 7
The Molasses Purity Rise across Continuous C-Centrifugals at a C-Sugar Purity of ± 80°

Factory No.	Purity Rise	Date
1	3,8	July 1980
2	5,8	Sept. 1980
3	2,6 5,4 2,3 2,5 1,5 3,6	Nov. 1980 May 1981 June 1981 Oct. 1981 Oct. 1981 Nov. 1981
4	3,3 3,3 5,2	July 1981 July 1981 Jan. 1981
5	4,6 3,5 4,1	June 1981 July 1981 Jan. 1982
6	7,4	Aug. 1981
7	3,9	Aug. 1981
8	3,5	Aug. 1981
9	3,0	Aug. 1981
Average	3,9	Seasons 80/81 and 81/82

"Total" purity rise	4,4°
"Physical" loss	2,7°
"Operational" loss	1,7°

It is felt, based on the above results and the data in Table 7, that an "operational loss" of 1,5° would be a fair value to use as an industrial average and would represent the total purity rise were it not for the "physical loss" factor.

Conclusion

The investigation showed that the molasses purity rise across the continuous C-centrifugals in the industry was high (see Table 7). A large part of this loss was found to be due to the passage of small sugar crystals through the centrifugal screen slots into the final molasses. It is worth mentioning that, since all the tests were carried out with new screens, the average industrial losses could be even larger than reported here. With the available evidence, it can be confidently stated that the physical loss of crystals accounts for more than two points of molasses purity in the industry in general. Although part of the physical loss was, at times, observed to come from false grain formation, most of it came from the smaller range of the crystal size distribution of the C-massecuite.

The purity rise across the centrifugal was found to be dependent on the C-sugar purity. Highly significant correlations (Table 1 and Figure 1) were found between final molasses purity and C-sugar purity and it was found that under local conditions every one point increase in C-sugar purity (in the range 75° to 85°) would result in approximately 0,1° rise in molasses purity. By and large it was found that the molasses purity rise remained practically the same, no matter what combination of operational parameters was used to obtain an identical C-sugar purity. Consequently at a fixed sugar purity, only small improvements in molasses purity can be expected through an optimisation of the operational technique. It is considered that an operational loss of 1,5° could be an achievable "total purity rise" target, were it not for the crystal loss. This is borne out by the fact that factory No. 3 had a total purity rise of only 1,5° in October 1981 (see Table 7).

Contrary to general belief, it was found that when the centrifugals were "pushed" to run at a higher capacity there was a resultant rise in the purity of the molasses at the same sugar purity. All the different methods used to obtain additional throughput, such as increasing the wash water temperature and/or the water addition and/or the steam addition, yielded the same pattern. The approximately 10% capacity increase achieved by the use of water at 80°C instead of 50°C was accompanied by a rise of about 0,4° in molasses purity (see Table 3). Similarly the capacity improvements of up to nearly 50%, obtained through additional steam usage, were always associated with higher molasses purities (ranging from 0,3° to 0,9° rise). The operation of the centrifugals at high molasses temperature also yielded higher capacities with increased C-molasses purities (see Table 5). It is worth noting that in all the comparative tests the lower purity molasses was always at a lower brix or, to put it differently, the combination of low throughput - low molasses temperature - low molasses brix yielded lower molasses purities than the "high" combination.

During the investigation the molasses temperature was found to vary widely both between and within factories. For example, factory No. 4 produced molasses at 68°C from a massecuite at 60°C, while at factory No. 5 the massecuite was at 62°C and the molasses at 43°C. At factory No. 3, six centrifugals placed alongside each other, and curing a massecuite at 60°C were producing molasses varying in temperature between 49°C and 62°C. Because of its influence on the centrifugal performance, the molasses temperature is certainly one operational factor which ought to receive closer attention from the processing staff. It was found that the centrifugals acted as very efficient heat exchangers, and it is evident that in many cases a reduction in their intake of cold air by mechanical means would reduce the molasses cooling effect and make it possible to reheat the C-massecuite to a lower temperature with a reduction in purity loss. The main practical conclusions that can be drawn from this investigation are summarised below:

(*a*) The purity rise across the C-centrifugals in the South African industry is high at about 4 points. A large part of this rise is due to the presence of sugar crystals in the molasses, which can only be reduced by improving the crystal size distribution of the massecuite.

(*b*) There is an increase of approximately 0,1° in molasses purity for each unit increase in C-sugar purity. Consequently to reduce the purity rise, the C-sugar purity must be kept as low as possible.

(*c*) There is a rise in molasses purity when the centrifugals are "pushed" to perform at a higher capacity. The commonly adopted practice of running only part of the centrifugals in a station in order that they can be "pushed" is detrimental to the molasses purity. It appears that within practical limits a drop of 10–20 per cent in capacity (at identical C-sugar purity) will reduce the molasses purity by approximately 0,5°.

(*d*) At identical throughput and C-sugar purity any combination of the operational variables will yield the same C-molasses purity. This does not hold when the molasses is at a much higher temperature than the massecuite and/or the molasses brix drops to below the 76° level.

(*e*) The molasses temperature has an important influence on the centrifugal performance. The temperature of the molasses from each centrifugal in a station ought to be regularly monitored and adjusted to ensure that there is uniform and optimum operation at the station.

(*f*) It is recommended that each factory carries out a "dry run" test on a daily basis to assess the magnitude of the "physical" loss. The result would assist in taking the necessary remedial action at the pan floor.

Nomenclature

Q_m = Massecuite flow rate (kg h^{-1})
Q_f = Molasses flow rate (kg h^{-1})
Q_w = Water flow rate (kg h^{-1})
P_s = Pol % C-sugar
P_m = Pol % C-massecuite
P_f = Pol % molasses
U_f = Molasses purity
U_s = C-sugar purity
W_r = Water % massecuite
T_w = Water temperature (°C)
S_p = Steam pressure (kPa)
r = Multi linear correlation
ΔP = Molasses purity rise

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ADDENDUM

Wash Water Addition

A series of tests was carried out at factories No. 4 and 5 with the wash water addition adjusted at two different levels at every alternate run. The wash water temperature and steam addition were kept at normal operating conditions. The performance results are summarised in Table 8.

TABLE 8

The Effect of Wash Water Addition on Centrifugal Performance
(Average of 8 tests at factory No. 4 and 14 tests at factory No. 5).

Factory No.	Water Addition (kg h^{-1})	Massecuite Flow rate (kg h^{-1})	C-Sugar Purity	Final Molasses	
				°Brix	Purity
4	90 123	1695 2035	83,7 83,4	86,9 85,9	35,04 35,40
5	77 129	890 1012	82,0 82,3	83,6 80,0	33,61 33,85

In both tests the increase in capacity of 20% and 14% obtained at higher water addition was accompanied by about 0,3° rise in final molasses purity.

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