REVIEW PAPER

A REVIEW OF THE PHYSICAL PROPERTIES OF A-MASSECUITE THAT AFFECT BATCH CENTRIFUGAL OPERATIONS

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Abstract

The function of the centrifugal is to efficiently separate the sugar crystals and molasses from the A-massecuite. Small quantities of steam and water are used to wash the remaining molasses from the surface of the crystal and to improve the Polarization (Pol) of sugar. There is a linear inverse relationship between the sugar Pol and colour. In the washing process, a degree of crystal dissolution and loss in exhaustion takes place. A-exhaustion plays an important role in sugar recovery and colour recirculation in the factory. At some factories, up to 20% of the exhaustion gained in the vacuum pan is lost in the batch centrifugal.

The two important physical properties of A-massecuite that affect the batch centrifugal operations are the viscosity of the mother liquor and the Coefficient of Variance (CV) of the crystals. The viscosity of the mother liquor is a function of its non-sucrose content, the total dissolved solids (brix) and the temperature. Small crystals and bagacillo affect purging by blocking the voids in the bed of crystals inside the centrifugal basket. The centrifugal will experience high vibration if the molasses cannot drain rapidly during the spinning cycle. The vibration can lead to damage and sometimes to the catastrophic failure of the centrifugal, which poses a risk to the operator.

The effect of the mother liquor viscosity is more pronounced when producing a high Pol, low colour sugar. Since the refining process is essentially a colour-removal process, back-end refineries, without the affination stage, can benefit from the low sugar colour.

The type and concentration of the non-sucrose is not in the hands of the factory personnel. Factories can improve the operation of the batch centrifugal by producing good quality crystals and by optimizing the fugalling characteristics of the massecuite, by adjusting the brix and temperature throughout the season, as the type and concentration of the non-sucrose changes.

Keywords: A-massecuite viscosity, batch centrifugal performance, sugar quality, mother liquor viscosity, loss across batch centrifugal, fugalling behaviour

Introduction

In this paper, 'mother liquor' refers to the liquid fraction of massecuite, and 'molasses' refers to the mother liquor after it has been diluted with steam and hot water in the centrifugal. A sample of the mother liquor is extracted for analysis purposes by using a Nutsch pressure filter. The sugar colour is measured by using the ICUMSA 420 method and it will be referred to as 'colour'. Pol refers to the polarization of sugar measured as °Z, and it will be referred to as 'Pol'. Brix refers to the total dissolved solids measured as °Brix. The Mean Aperture (MA), Coefficient of Variance (CV) and % fines of the crystals are calculated as per the official methods (SASTA Laboratory Manual). The difference in purity between the massecuite and the mother liquor is a convenient way of measuring the exhaustion at each stage in the crystallisation process. 'Centrifugal' refers to the batch centrifugal.

The South African export requirement of 99.35 Pol and 1500 colour is generally easy to meet, for most of the crushing season. The introduction of Very High Pol (VHP) sugar has resulted in South African refineries dispensing with the affination process as the first step in colour removal. These refineries can benefit from high-Pol, low-colour sugar.

VHP and affinated sugar colours

The batch centrifugal is used to produce both raw and affinated sugars. When the molasses coating from the crystal surface is completely stripped way, the sugar is referred to as 'affinated sugar'. If affination is done correctly, about 85% of the impurities can be removed from the raw sugar (Watson & Nicol, 1975). El-Syiad *et al.* (2020) compared the impurity levels of raw and affinated sugars in the Egyptian sugar industry. Their results showed that the dextran, ash and reducing sugars decreased by 55%, 83% and 47% respectively by increasing the sugar Pol from 99.45 to 99.62. However, there was no removal of starch, which indicated that the starch was occluded inside the crystal. Davis *et al*. (2013) presented the VHP and affinated sugar colours for South African raw sugar for the period 2003 to 2013. This trend is shown in Figure 1.

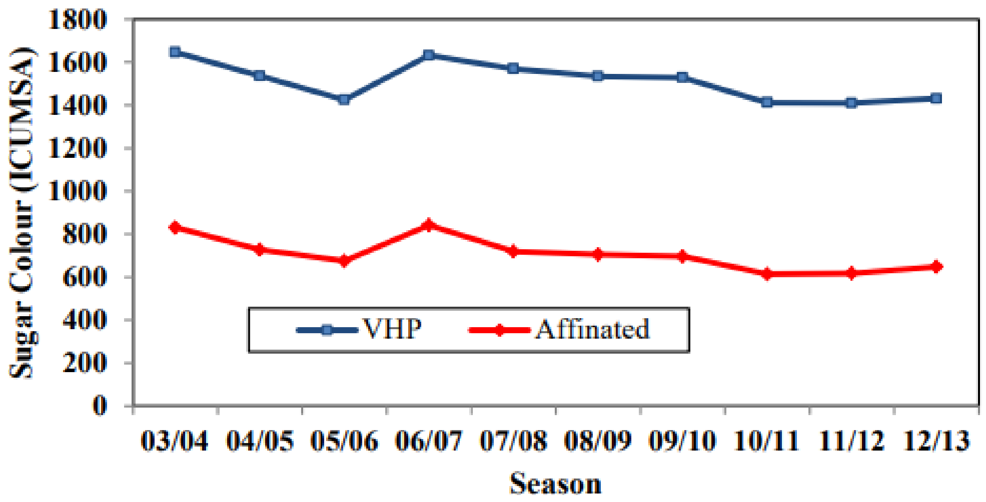

Figure 1. VHP and affinated sugar colours for the period 2003 to 2013 (Davis *et al.*, 2013)

By eliminating affination as the first step in colour removal, South African refineries have increased the impurity/colour loading on the other colour removal processes.

Sugar Pol and colour

The Pol and the colour reflect the purity of the sugar. There is a linear inverse relationship between sugar Pol and colour. The data shown in Figure 2 were collected from several sugar factories in southern Africa in the 2022/23/24 seasons, as well as from various publications across the global sugar industry, and they include data from refined, mill white and Australian very low colour sugars.

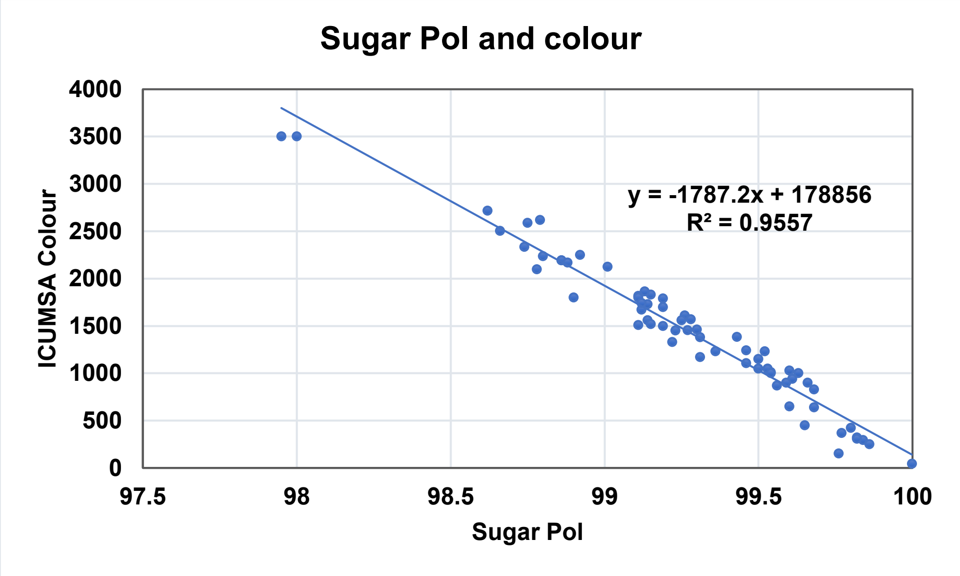

Figure 2. The relationship between Pol and colour

Irrespective of the type of colour removal process that is employed, there is a linear relationship between the Pol and colour. Jullienne (1983) found a similar relationship: "the level of impurities in A-sugar was found to decline linearly with the sugar purity". The South African affinated sugar colour of around 700 can be achieved with a sugar Pol of around 99,68.

A-exhaustion

Ninela and Rajoo (2006) demonstrated the importance of A-exhaustion in improving factory sugar recovery. Booysen and Davis (2019) and Naidoo *et al.* (2024) showed the importance of high A-exhaustion in reducing colour recirculation in a sugar factory. Data on A-station exhaustion, expressed as 'purity drop/rise', is shown in Table 2. The vacuum pan is the biggest contributor to A-exhaustion and the centrifugal is the biggest 'thief' of exhaustion, with about 20% of pan exhaustion being lost in the centrifugal.

Table 1. The purity drop/rise across the vacuum pans and crystallisers, and the purity rise across the centrifugals

Purity drop/rise across:	Nielson (1992) *	2023/24 season**
A-Pan	-20.34	-19.98
A-Crystalliser	-2.85	-1.73
A-Centrifugal	4.22	4.23

*Average of 5 season **average of 6 factories in South Africa

Some technologist, believe that producing a higher Pol sugar will result in a lower A-exhaustion, as extra 'washing' is required in the centrifugal. However, this does not have to be the case if the physical properties of A-massecuite are such that the molasses and crystals separate easily in the batch centrifugal with the minimum of wash water. Naidoo *et al.* (2024) showed that a factory can produce a VHP of 967 colour and still achieve 69.75% exhaustion, if good sugar technology principles are followed in the factory. Naidoo *et al.* (2024) focused on low boiling temperatures to minimise the Maillard reaction.

Molasses flow in a batch centrifugal

The separation process in a batch centrifugal is essentially a filtration process through a packed bed of sugar crystals, assisted by the inertial effects of the rotation motion, which is commonly referred to as the 'centrifugal force'. The mother liquor has a difficult flow path in the centrifugal and must move through the crystal bed of about 150 mm wide, as well as the working screen and the backing screen, and then through small drainage holes in the basket. According to Grimwood *et al*. (2003), the resistance to flow is dominated by the crystal bed. It is important to note that the crystal bed in a batch centrifugal is stationary, relative to the screen, whereas in a continuous centrifugal, a thin bed of crystals is moving up the screen.

Hedley (1937) found "that when the temperature of the centrifuged massecuite is high, a much higher purity of sugar is obtained, as a result of the better elimination of the molasses that results from the reduction of its viscosity"

Broadfoot and Miller (1996) investigated the fugalling behaviour of high-grade massecuites in Australia. They found that of all the variables that influence the fugalling performance, the mother liquor viscosity had the strongest influence on the composition of the purged sugar. The influence of the molasses viscosity on the fugalling performance is more pronounced when producing higher polarization sugar. The viscosity of the mother liquor has a significant effect on the drainage time of the liquid in the centrifugal. Of the granulometric properties determined by the usual sieving procedures, the Coefficient of Variation (CV) of the size distribution was the variable with the strongest influence. The above authors recommend the following actions to reduce mother liquor viscosity:

- Increase the A-massecuite temperature by decreasing the vacuum just before striking the pan
- Reheating or diluting the massecuite before centrifugalling.

The Australian sugar industry does not use cooling crystallisers on A-massecuite because the industry prefers to centrifugal the massecuite while it is hot.

A collaboration study was conducted by researchers from various Universities (viz. the UK, Australia and RSA) and the South African Sugar Industry. The Industry was represented by Richard Loubser and Steve Davis, in response to difficulties that the industry was experiencing at the centrifugal station. The study was entitled 'Liquid flow in a sugar centrifugal', and it modelled the behaviour of molasses in a batch centrifugal (Please *et al.*, 2012). Since the drainage time is a function of the viscosity of the mother liquor, researchers used hot water, hydrogen peroxide and steam in their trial to decrease the viscosity. They found that "by far, a better way to remove the remaining molasses is to heat the molasses by spraying with steam. Spraying with steam can reduce, by half, the volume of the molasses remaining on the crystals". The practical implication of this finding is that steam addition will increase the centrifugal capacity for a given sugar quality, or the sugar quality can be improved for a given cycle time.

Massecuite and molasses viscosity

Honig (1959) stated that: "The dominant factor in crystallisation technology is viscosity... Since viscosity varies extensively with the composition of the non-sucrose constituents, optimum operating procedures are attained by adjusting the principal variables, temperature and solids content, in order to reach the desired viscosity ranges. No closely-defined specifications can be set up due to the uncontrollable variations in composition of the molasses. Each factory, therefore, must investigate its own situation with regard to the effect of the variables, temperature, supersaturation and viscosity".

Shah *et al.* (2017) referenced the work of several researchers and showed that the viscosity of massecuite was highly-dependent on the viscosity of the mother liquor. Mother liquor viscosity is dependent on dry substance and temperature, as shown by Rouillard and Koenig (1980). Love (2002) proposed the following correlation between Dry Solids (DS), brix and pol.

$$DS = Brix\left(1 - 0.00066\,(Brix - Pol)\right) \ \ . . . \ \ (1)$$

The biggest effect on dry solids is the brix, and increasing the brix will increase the viscosity of the mother liquor. Jullienne (1994) found a linear relationship between the brix of A-massecuite and the brix of the mother liquor. Increasing the A-massecuite brix, for example, from 91° to 93° Brix, will increase the mother liquor from 81° to 83° Brix. A good 'rule of thumb' is that the mother liquor brix is 10 units lower than the A-massecuite brix.

Genotelle (1978) produced the following equation for the viscosity of a pure sucrose solution:

$$\log_{10}\mu_{solution} = 22.46N - 0.114 + \ (30 - T) \times \frac{(1.1 + 43.1N^{1.25})}{91 + T} \ \ . . . \ \ (2)$$

$$Where \qquad N = \frac{B}{1900 - 18B} \ \ . . . (3)$$

$$\mu = dynamic\ viscosity\ in\ mPa.s \ ; \ B = \ brix\ as\ \% \ ; \ and\ T = \ temperature\ as\ ℃$$

It must be noted that the above equation is for pure sucrose solutions, and that the viscosity will increase as impurities are introduced into the solution. The viscosity will increase further by the Maillard reaction, if gases are introduced into the massecuite. Impurities, like dextran, will also increase the viscosity. South African massecuites are known to have high levels of dextran and other polysaccharides in the rainy season.

The above equation was used to model the effect of brix and temperature on the mother liquor viscosity. The effect of temperature and mother liquor brix is shown in Figures 3 and 4.

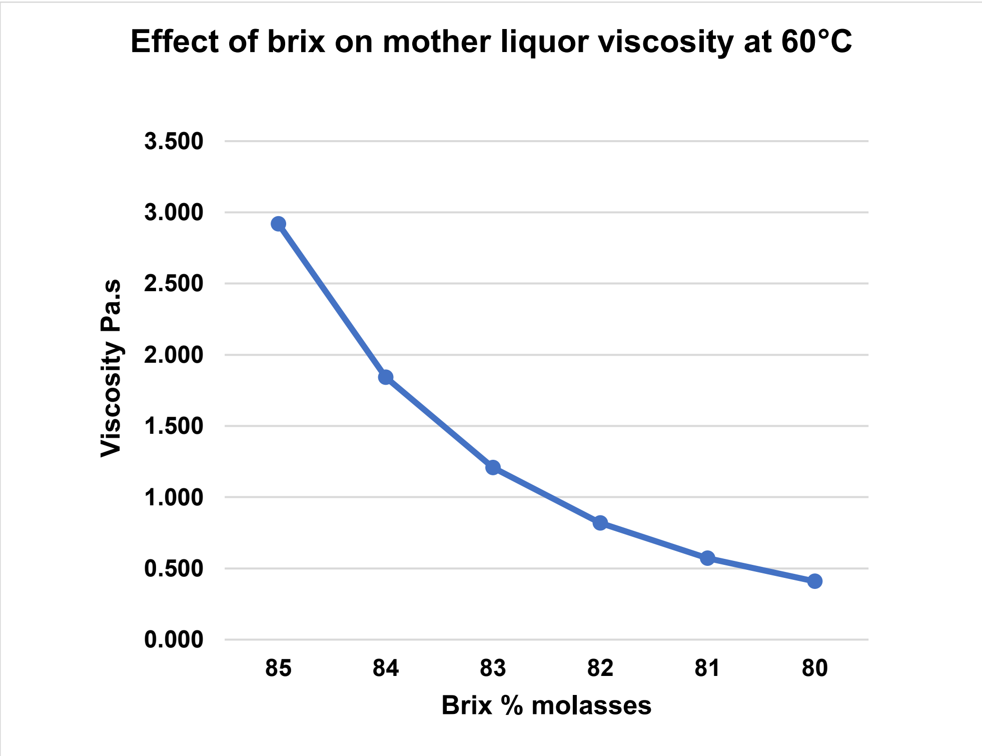

Figure 3. Effect of brix on mother liquor viscosity

In Figure 3, the temperature of the mother liquor was kept constant at 60°C. The mother liquor brix, in typical South African A-massecuite, ranges between 80° and 82°Brix. Decreasing the brix from 82° to 80°Brix decreases the viscosity from 0.818 to 0.409 Pa·s, a reduction of 50%.

Honig (1959) states that the viscosity of factory molasses almost doubles, for each increase of 0.8% in the total solids.

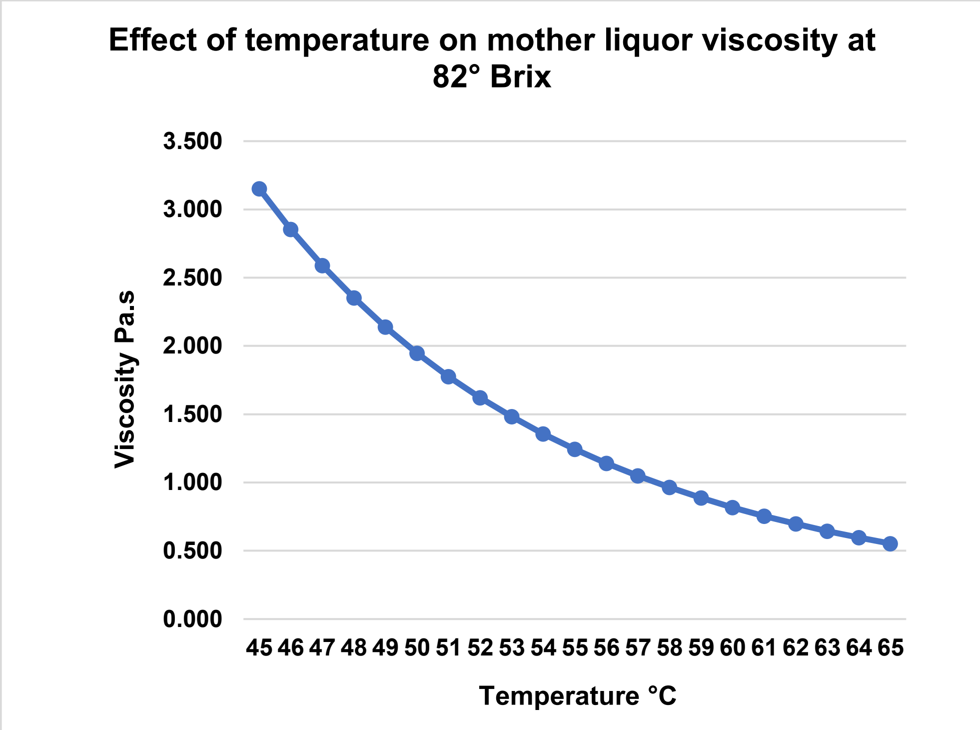

Figure 4. Effect of temperature on the mother liquor viscosity

In Figure 4, the mother liquor Brix was kept constant at 82°Brix. Increasing the mother liquor temperature from 50° to 60°C, decreases the viscosity from 1.948 to 0.818 Pa·s, which is a decrease of 42%. Rein (2007) referenced the work of several researchers and proposed a two-fold change in massecuite and molasses viscosity with a temperature difference of 9°C.

The data presented in Figures 3 and 4 show that both the Brix and temperature have a strong influence on the viscosity of the mother liquor for pure sucrose solutions. Although the viscosity will be higher for factory molasses, it is assumed that the shape of the graph will be the same. As the viscosity of the mother liquor decreases, the drainage time in the crystal bed will also decrease, which means that a shorter time will be required to spin off the molasses in the centrifugal basket.

The effect of the crystal content on massecuite viscosity has been discussed by Honig (1959) and Rouillard and Konig (1980). According to Honig (1959), as the crystal content approaches 45%, the mobility of the massecuite is severely restricted. Some South African factories achieve high crystal contents of up to 54% in the vacuum pan. However, this might not be the crystal content that enters the centrifugal, due to dilution in the crystallisers. Robertson *et al.* (1979) proposed pre-curing as a method of decreasing the viscosity, by decreasing the crystal content of the massecuite in the A-crystallisers. By pre-curing a part of the strike massecuite without water or steam addition, the undiluted A-molasses was returned to the A-crystalliser to decrease the crystal content. This method allowed a higher pan brix without the inhibiting effect of crystal content on the massecuite viscosity and damage to the crystalliser stirrers (and to the centrifugal). The proposal was not adopted on a large scale due to the fact that 25%-30% of the massecuite was pre-cured and resulted in a sugar with a low Pol and high a colour.

Crystal quality and bagacillo

Although smaller crystals increase the rate of crystallisation in the pan, the limiting factor towards smaller crystal size is the ability of the centrifugal to remove the molasses (Honig, 1959). Watson and Nicol (1975) highlighted the importance of the Specific Grain Size (SGS) on the affination process. A mixture of grain sizes negatively affects the affination process. This is the reason that South African export sugar needs to conform to certain granular properties like MA, CV and percentage fines.

Watson and Nicol (1975) also found that dust (bagacillo) behaved like fine crystals. Smith *et al.* (2000) found that a syrup flotation clarifier removed up to 88% of the bagacillo from the syrup. Although there has been anecdotal evidence that syrup clarifiers improve A-exhaustion, the science is not clear. The blockage of voids in the packed sugar bed by bagacillio explains how bagacillo can affect A-exhaustion. Blom and Munsamy (1994) found that certain juice flocculants had a higher affinity for bagacillo than others. Again, there was anecdotal evidence that some flocculant types improved A-exhaustion. It is therefore important that flocculant trials should include bagacillio removal as one of the selection criteria. Bagacillo in clear juice will find its way into the A-massecuite, in the absence of syrup clarification. Wind-borne bagacillo and other foreign matter will also enter the A-crystalliser if it is not covered.

Some factories believe that 'slurry graining' the A-massecuite will improve the crystal quality. Bux and Munsamy (1989) conducted trials at a sugar factory and assessed several sugar quality parameters. They found no significant difference between 'slurry graining' and 'B-magma footing' with the MA, the CV, percentage fines and affinated colour of the two methods. However, a smaller grain size produced a higher percentage of fines in both methods. It is important that factories stay within the export specification of ≤35% fines.

Grimwood *et al*. (2003) state that the typical open area between the crystals in a sugar cake in a batch centrifugal is around 42% of the total volume of the cake. Unlike those in a continuous centrifugal, not all the fine crystals are lost in a batch centrifugal. Fine crystals, which are commonly referred to as false grain, are trapped in the crystal bed, thus decreasing the open area in the cake bed. If the occurrence of false grain is severe, the factory operations can come to a halt, as the A-massecuite will not purge. The build-up of molasses in the crystal bed can cause severe vibrations and put the centrifugal out of balance. If the centrifugal is not protected with vibration/gyration switches, the unit can be damaged and cause injury to the operator. Grimwood *et al.* (2002) stated that a 1.2 m diameter basket spinning at 1200 rpm generates energy equivalent to a family car travelling at 280 km/h. Centrifugal basket diameters have increased to a 2.0 m diameter, with 1200 rpm speeds resulting in higher energy generation. Good general maintenance and regular checking of the safety devices are essential for the safe operation of centrifugals. The structure supporting the centrifugal must be strong and rigid, and the regular inspection of the structure should be part of the planned maintenance.

Dissolution of sugar during washing in the centrifugal

Small quantities of steam and water are used in the centrifugal to produce the different grades of sugar. Jullienne (1983) studied the dissolution of sugar in batch A-centrifugals at two factories in South Africa. His test data are shown in Table 2.

Table 2. Crystal dissolution and A-molasses purity rise at different A-sugar purities (Jullienne, 1983)

A-sugar purity	% crystal dissolution		Molasses purity rise	
	Darnall	Umzimkulu	Darnall	Umzimkulu
98.9%	0.7	1.6	0.4	0.7
99.4%	2.3	4.2	1.2	2.3

99.6%	3.7	6.0	2.0	3.2

The average CV for both the Darnall and Umzimkulu sugar was 37 and the average massecuite temperatures were 62°C and 55°C, respectively. The effect of washing time on sugar purity is shown in Figure 5.

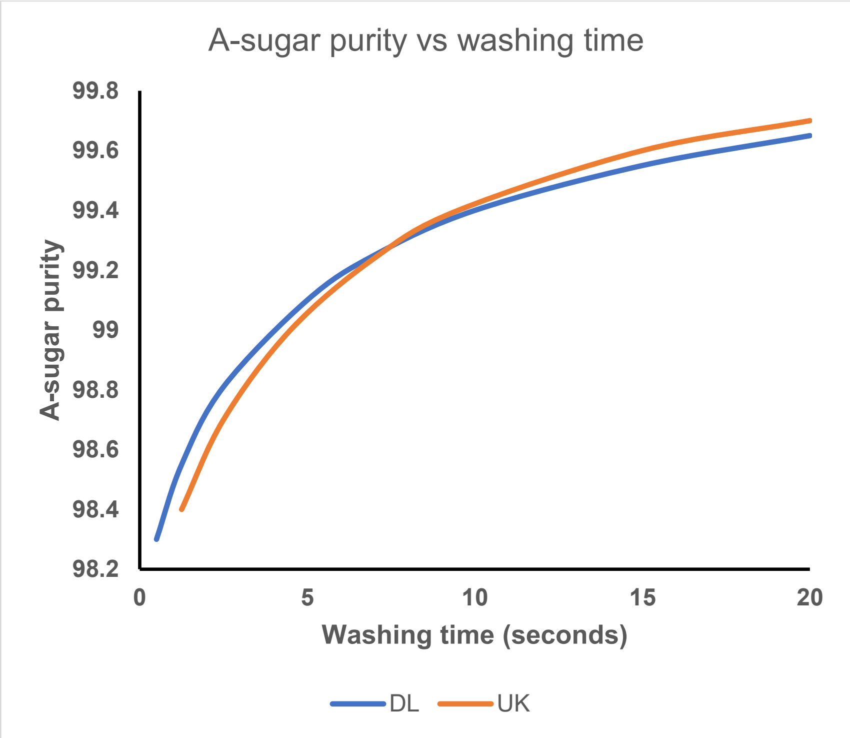

Figure 5. The effect of washing time on A-sugar purity (Jullienne,1983)

Figure 5 shows that the South African export specification of 99,35 Pol sugar can be obtained with 10 seconds of washing.

Handling massecuites of high viscosity in batch centrifugals

At certain times in the crushing season, the juice is contaminated with dextran and other polysaccharides, due to long burn-to-crush delays. These contaminants increase the viscosity of the massecuite to a point where it does not cure easily, or not at all, in the batch centrifugal. Until the introduction of the continuous centrifugal, A, B and C-massecuites were cured in batch centrifugals. The low-grade massecuites were 'conditioned' by reheat and/or dilution before centrifugalling. Beckett and Munsamy (1994) adopted this methodology when faced with drought-affected viscous A-massecuite that was difficult to purge and that caused excessive vibration in the centrifugal. The A-massecuite temperature before purging was increased to 55°C by bypassing 50% of the crystallisers and introducing hot water in the cooling coils. In addition, the massecuite brix was lowered to around 90°Brix. The batch centrifugal was loaded to about 75%, to decrease the flow path in the crystal bed. These interventions resulted in the centrifugal operating 'quietly' without vibration. In addition, defoamers (vegetable oil and commercial defoamers) and sodium hydrosulphite (Blankit) was used to improve the evaporation in the pan. Although there was anecdotal evidence that these additions improved pan boiling and purging in the centrifugal, no qualitative evidence was available for A-massecuite. In summary, when faced with massecuites of high viscosity, factory personnel can try the following:

- Increase the temperature of the massecuite
- Decrease the brix of the massecuite in the pan
- Dilute the massecuite before centrifugalling

The factory massecuite piping is configured for end-of-season liquidation, so the facility to bypass the crystallisers and increase the temperature already exists.

Summary and Recommendations

The centrifugal requires a massecuite from which crystals and molasses will separate easily.

- The viscosity of the mother liquor is the single parameter that has the greatest influence on the final sugar purity and the wash-time required to reach the required purity. Since the viscosity also varies with the composition of non-sugars, it is difficult to prescribe the optimum brix and temperature for a factory. The A-massecuite should have sufficient fluidity to fill the centrifugal basket in about 10 seconds. If this target is not met, then the massecuite temperature and brix will need to be adjusted. A word of caution; massecuites that are too fluid can overfill the centrifugal basket, which is dangerous.
- The massecuite brix, which is very important for crystallisation in the pan, must also meet other operational requirements. Factories that produce A-massecuite in continuous vacuum pans must select a brix that will minimise encrustation and fouling inside the pan. For batch pans, a predetermined striking time should determine the brix of the massecuite (Jullienne,1984). The striking time is a good indication of the viscosity (fluidity) of the massecuite. A rapid rate of brixing will increase the crystal colour. Jullienne (1984) found that about 40% of the crystal colour was occluded in the final 30 minutes of the brixing stage, when the crystallisation rate was rapid. Lionnet (1998) found that the impurity transfer rate was totally dependent on the rate of sucrose crystallisation and the concentration of impurity in the feed liquor. Therefore, from a colour perspective, a very high brix in the pan and consequent dilution of the massecuite for mobility, is counterproductive. A rapid rate of brixing will also increases the chance of false grain formation, which has a negative effect on the purging efficiency of the centrifugal.
- The steam cycle should commence early, to heat the mother liquor and lower its viscosity, and the hot water should be around 80°C. The top covers of the centrifugal must be closed to avoid ambient air from entering the basket and cooling the massecuite.
- Even if raw sugar factories supply their own refineries, the granular quality of the crystals is very important for centrifugal operations. A sieve analysis must be conducted regularly and pan boiling techniques must be adjusted to produce a low CV and percentage fines below 30%. Action must be taken to lower the bagacillo content of A-massecuite.
- It is important that there is good communication between the centrifugal operator and the pan-boiler, and that the pan-boiler adjusts the massecuite properties to meet the target settings in the centrifugal, and not *vice versa*.
- A high level of 'equipment sympathy' is required to protect this expensive and critical equipment from vibration and damage. A long spin cycle must not be used to compensate for poor dryer performance. The long spin time will harden the sugar cake and make it difficult to plough the sugar. The dryer performance should be investigated and rectified.

References

Beckett J and Munsamy SS (1994). Experiences with processing very low purity cane. *Proc S Afr Sugar Technol Ass* 68: 101-104.

Booysen KC and Davis SB (2019). Colourant behaviour during sugarcane processing. *Proc S Afr Sugar Technol Ass* 92: 358-371.

Broadfoot R and Miller KF (1996). Fugalling characteristics of high-grade massecuites. *Proc Aust Soc Sugar Cane Technologists*: 350-360.

Genotelle J (1978). Expression de la viscosité des solutions sucrées. *Ind Aliment Agric* 95: 747-755.

Hedley EP (1937). The crystallisation of massecuites. *Proc S Afr Sugar Technol Ass* 11: 68-81.

Honig P (1959). Principles of Sugar Technology, Volume 2: Crystallisation. *Elsevier Publishing Company, Amsterdam.*

Grimwood C, Thewlis J and Thompson P (2002). Observations on centrifugal operations – Part 1. *International Sugar Journal* 104: 1248.

Grimwood C, Thewlis J and Thompson P (2003). Observations on centrifugal operations – Part 2. *International Sugar Journal* 105: 1253

Jullienne LMSA (1983). Washing sugar in batch A-centrifugals. *Proc S Afr Sugar Technol Ass* 56: 42-45.

Jullienne LMSA (1984). Exhaustion and colour investigations in A-massecuite. *Proc S Afr Sugar Technol Ass* 57: 42-46.

Lionnet GRE (1998). Impurity transfer rates during the crystallisation of sucrose. *Proc S Afr Sugar Technol Ass* 72: 261-268.

Naidoo S, Mncube F, Ndlovu V and Ninela M (2024). Improvements in sugar colour and boiling house recovery at the Maidstone mill. *Proc S Afr Sugar Technol Ass* 96: 264-271.

Ninela M and Rajoo N (2006). Practical steps taken at Tongaat-Hulett sugar factories to achieve low target purity difference. *Proc S Afr Sugar Technol Ass* 80: 448-461.

Please CP, Fowkes DP, Mason DP, Khalique CM, Hutchinson A and Rademeyer MC (2012). Liquid flow in a sugar centrifugal. *Report on Mathematics in Industry Study Group, South Africa Meeting, Africa Institute of Mathematical Studies, Muizenberg, January 2012.*

Rein P (2007). Cane Sugar Engineering. *Berlin. Vertrag Dr Albert Bartens KG:* 406-407

Rouillard EEA and Koenig (1980). The viscosity of molasses and massecuite. *Proc S Afr Sugar Technol Assoc* 54: 89-92.

Smith GT, Davis SB, Madho S and Achary M (2013). Eighty-eight reviews of the milling season in southern Africa (2012-13). *Proc S Afr Sugar Technol Ass* 86: 339-365.

Smith IA, Schumann GT and Walthew DC (2000). Some developments in floatation clarification. *Proc S Afr Sugar Technol Ass.*70: 263-266.

Shah S, Lokhat D and Peacock SD (2017). An investigation into the viscosity of C-massecuite using a pipeline viscometer. *Proc S Afr Sugar Technol Ass* 90: 339-365.

Watson JA and Nicol WM (1975). Raw cane sugar quality in relation to refining requirements. *Sugar Technol Rev* 3: 69-126.