THE IMPLEMENTATION AND OPTIMISATION OF MUD RECYCLE AT MAIDSTONE MILL

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Abstract

Mud Recycle is a process option for cane diffuser factories; it eliminates the need for a filter station by using the bed of shredded cane in the diffuser to separate out mud solids from the juice. This paper describes the Mud Recycle system at Maidstone mill and presents the results of a Mud Recycle trial that was carried out during the 1998 season. Maidstone switched to Mud Recycle on a permanent basis at the start of the 1999 season. The experiences with Mud Recycle during both periods are discussed and steps taken to optimise and automate Mud Recycle are presented. Possible changes to the current methods for mud analysis are discussed, and a simplified method for calculating the mill balance is proposed for those mills that operate Mud Recycle. Finally, the cost savings for Maidstone during the 1999 season, as a result of Mud Recycle, are presented.

Introduction

The bed of shredded cane in a diffuser acts as a filter, separating out much of the suspended material which, with a milling tandem, would pass into the draft juice. Therefore, the suspended solids % mixed juice is significantly lower from a diffuser factory than from a factory with a milling tandem. The basic premise for recycling clarifier mud to the diffuser is to use the "inherent" filtration capabililty, offered by the bed of shredded cane in the diffuser, to separate suspended solids from the mud. (Instead of using the traditional rotary vacuum-filters.) The suspended solids are carried along with the bagasse to the boilers where the combustible portions are incinerated and the non-combustible portions become boiler ash.

The idea of using shredded cane to filter suspended solids from sugar juices is not a new concept. In Java during the 1930's clarifier muds were sucessfully recycled to a milling tandem. However, juice clarification became more difficult and the sucrose content of the bagasse increased (Tromp, 1936). However, eliminating the loss of sucrose in filtercake compensated for the lower extractions. Lamusse (1980) attempted to perform the entire clarification operation in a diffuser, which would eliminate the need for both clarifiers and filters. However, problems with increased colour formation, when clarifiying at high temperatures, and with post-precipitation, when clarifying at lower temperatures, resulted in the practice being discontinued. Clarifier-mud recycle avoids these problems by only replacing the filtration step.

The implementation of Mud Recycle at a diffuser factory is relatively simple, but the benefits of this process change are significant:

- Reduced capital, maintenance and operational costs by eliminating the filter station and all ancillary equipment (bagacillo separation and conveying system, filtercake conveyer belt and storage facility).
- Reduced physical and chemical sucrose losses. At a typical diffuser factory about 0.2% of the sucrose entering the factory leaves the factory in the filtercake. Mud recycle eliminates this physical loss of sucrose. Furthermore the chemical (bacteriological) losses associated with filter station operation are also eliminated. (Bacteriological losses under Mud Recycle are neglible as mud temperatures close to 100°C can be maintained.)
- Reduced evaporation requirements as the water used for washing the filtercake is eliminated.
- Reduced solid waste disposal costs with the elimination of filtercake.

Increased supply of fuel to the boilers

The potential for implementing mud-recycle has existed in the South African industry since the installation of the first diffuser in 1965. However, it was some decades later that the first mud-recycle trials were carried out at a cane diffuser factory (Meadows *et al.* 1998). The trials were carried out a Maidstone mill and lasted for three weeks in total.

The cane payment system in the South Africa is based on tons of sucrose contained in the juice leaving the diffuser (measured) and in the bagasse going to the boilers (calculated by mill balance). Recycling mud back to the diffuser, without modifying the mill balance calculation, would result in double-payment for all the sucrose contained in the mud. During the first Mud Recycle trial, it was agreed that, for cane payment purposes, the average Pol Factor (for the weeks before and after the trial) would be applied to the Direct Analysis of Cane results. Before further Mud Recycle trials could be carried out, it was necessary to obtain approval from the South African Sugar Association (SASA). In September 1998, SASA gave the approval for further Mud Recycle trials to be carried out, and published official methods for mud weighing, sampling and analysis; and for the incorporation of the mud results into the mill balance calculation (Brokensha, 1998). In October 1998 a second Mud Recycle trial commenced at Maidstone and continued for some three months until the end of the crushing season. On the basis of this and other successful Mud Recycle trials at Malelane and Komati mills, SASA approved the implementation of Mud Recycle at South African mills in April 1999 (Brokensha, 1999). Maidstone immediately switched to Mud Recycle on a permanent basis.

This paper describes the Mud Recycle system at Maidstone and discusses the experiences with Mud recycle during the 1998 trial and during the 1999 season. Laboratory results are presented for both periods, and steps taken to optimise and automate Mud Recycle are discussed. Finally, changes in the method for mud analysis are proposed and a simplified method for calculating the mill balance is presented.

Maidstone Mud Recycle System

Figure 1 shows a process flow diagram of the Mud Recycle system at Maidstone. Maidstone has two diffusers: a Tongaat-Hulett design diffuser which is rated at 300 tons cane per hour (shown in Figure 1), and a BMA design diffuser which is rated at 200 tons cane per hour. After weighing separately, the two draft juice streams are combined and pumped through the mixed juice heaters to a flash tank. Lime is added prior to flashing and juice flows by gravity from the flash tank to two Dorr-type clarifiers, each of which has four mud offtakes. The mud withdrawal system is automated, with mud being withdrawn from each of the mud compartments in sequence, to a common standpipe. The standpipe is fitted with a level transmitter to ensure that a constant volume of mud is withdrawn from each compartment. (Once the mud level reaches the high-level set-point the mud-valve from that compartment closes. As the mud continues to be pumped from the standpipe the mud level drops, and on reaching the low-level set-point mud is then withdrawn from the next mud compartment in the sequence.) The mud is pumped from the standpipe to the mud scale where it is weighed and sampled.

After weighing, the mud is recycled to either the Tongaat-Hulett or the BMA diffuser. In order to distribute the mud evenly across the bed of cane, the mud is pumped directly into the suction side of one of the diffuser recirculation pumps, thereby avoiding the need to install a mud distribution system in the diffuser. As discussed by Meadows *et al*. (1998), the position where the mud is return to the diffuser is important:

- Firstly, to minimise the impact on the juice concentration gradient in the diffuser, the mud should be returned as close to the draft juice trough as possible. (The brix of the juice in the mud is the same as that in draft juice.)
- To ensure good filtration, the mud should be added where the bed is well established.
- To prevent the mud blinding the bed, which would reduce juice percolation through the bed and possibly result in flooding of the diffuser, the mud should be added where the bed is not too heavily compacted (*e.g.* near a set of lifting screws).

The location best satisfying these criteria, as shown in Figure 1, is the recirculation pump that delivers juice to the sprays positioned immediately before the first set of lifting screws.

The Pol Factor is defined as the tons of pol in cane, calculated by the mill balance, divided by the tons of pol as determined by Direct Analysis on Cane (DAC). This factor, which should equal 1, provides a means of cross-checking the accuracy of the cane and mixed-juice analyses. It is also a means of indentifying any sucrose destruction in the diffuser. Double tandem factories are fitted with two juice scales to allow the Pol Factor to be calculated separately for each tandem. Under Mud Recycle, the mill balance calculation is based on the adjusted tons of mixed juice (calculated by subtracting the mud from the measured quantity of mixed juice). Therefore, in order to calculate the Pol Factor for each tandem, the tons of Mud Recycled needs to be measured separately for both diffusers.

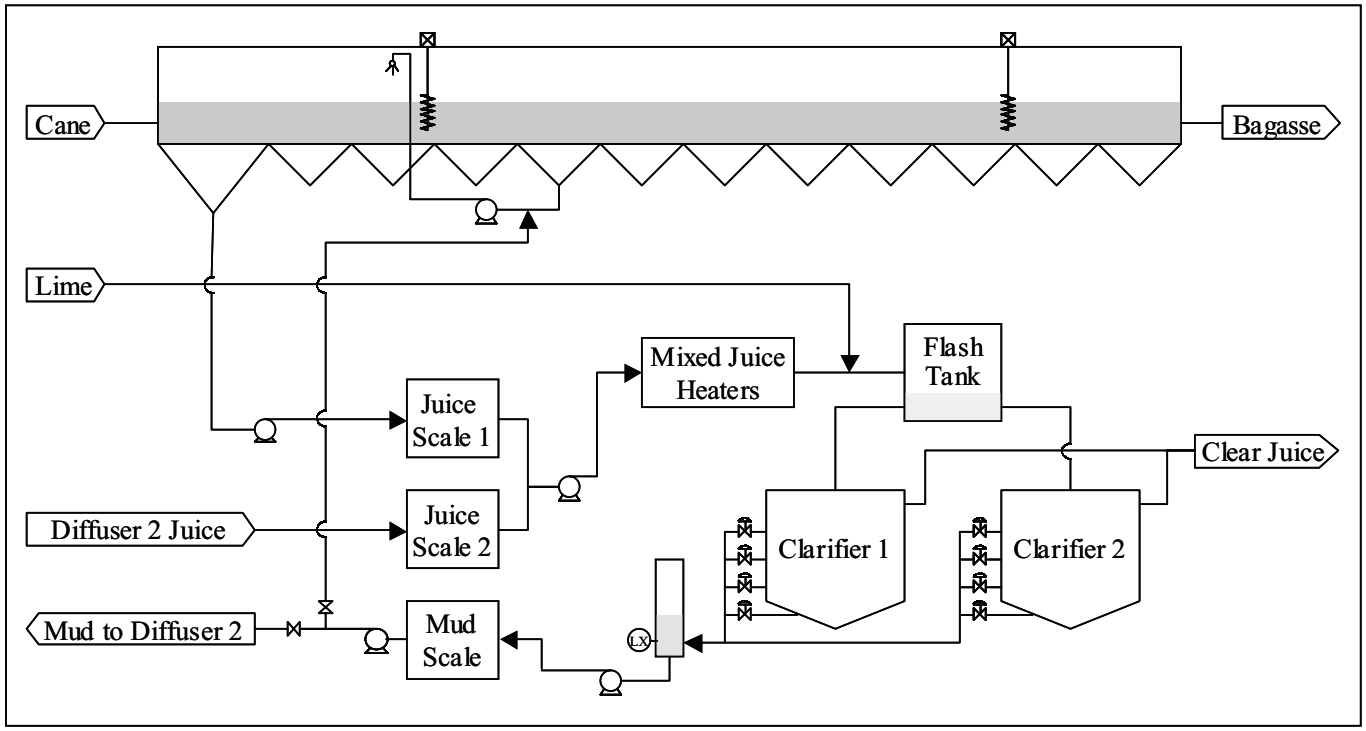

Figure 1. Maidstone Mud-Recycle System.

This is achieved by recycling the mud to only one of the two diffusers at any given time.

However, from a processing point of view, the mud stream should theoretically be split between the two diffusers in proportion to the cane throughput on each tandem. This would ensure an approximately equal mud load each diffuser bed, thereby minimising the impact of Mud Recycle on juice percolation in the diffusers. However, the experience at Maidstone is that a single diffuser has sufficient filtration capacity to cope with all the mud from both tandems. Therefore it is unlikely whether the additional cost of weighing the mud separately to each diffuser would be justified in terms of increased extraction.

The pumps used for recycling the mud are centrifugal pumps, with a non-choking open impellor design. Mud is highly corrosive/erosive and both the pump impellor and the Mud Recycle pipework have been replaced with stainless steel since the first trial in 1997. The Mud Recycle pumps were sized to pump a maximum of approximately 30 tons of mud per hour. The average mud flow rate during the 1998 trial was 15 tons per hour. Therefore the Mud Recycle system has sufficient excess capacity to reduce the clarifier mud levels, even at maximum crush rates.

Section 1: 1998 Mud Recycle Trials

The aim of the first Mud Recycle trial at Maidstone was to assess whether Mud Recycle was a viable sugar-processing alternative to the filter station. The aims of the second Mud Recycle trial were firstly, to assess Mud Recycle over a longer trial period, and secondly, to determine the accuracy of the analytical procedures drafted by SASA for mud analysis. A thorough assessment of these procedures was required before Mud Recycle could be approved on a permanent basis. This section discusses the sampling and analytical methods tested during the trial, while the operational aspects of Mud Recycle are discussed in Section 2.

Mud Sampling and Sub-Sampling

In order to calculate the tons of sucrose recycled to the diffuser, catch samples of mud were collected every hour, and the scale reading at the time of sampling was recorded. The non-homogeneous nature of clarifier-mud makes sampling difficult. Furthermore, to minimise microbiological deterioration after sampling, the mud should be chilled and chemically preserved. Therefore, in the absence of a suitable on-line instrument for sampling and chilling the mud, a manual catch sampling method was employed.

During the initial stages of the trial, various methods of sampling the mud were compared. Firstly mud samples were collected as the mud discharged from the scale tank to the bottom tank. However, the time taken for the mud to fill the scale tank allowed the mud-solids to settle. As a result the consistency of the mud sample depended on how quickly the sample was taken once the scale began discharging. Secondly, mud samples were collected from the bottom tank immediately after the scale-tank had finished discharging. (The mud was reasonably well mixed at this point.) However, the vapour released during the discharge of the scale tank made this sampling method unsafe. The third method was to collect mud samples from the delivery of the mud pump just after the scale had completed discharging. This method, gave results that were consistent with the second method, and was the primary method used during the trial.

Similar difficulties had to be overcome when collecting sub-samples from the original mud-sample, either for analysis or for compositing. During the sub-sampling process, the original sample was stirred vigorously, whilst "spooning" out the correct mass of sub-sample. Stirring and then pouring out the sub-sample did not give a representative sub-sample.

Insoluble Solids Balance

Under the following conditions the mass of insoluble solids contained in mixed juice should equal the mass of solids recycled in the clarifier mud:

- No carryover of solids in the clear juice.
- The mass of the precipitate formed during liming is small.
- No physical loss of mud from the clarifier by dumping.

For the period of the trial, SASA selected the Insoluble Solids Recovery, (defined as the mass of suspended solids in the mud, divided by, the mass of suspended solids in mixed juice), as a means of checking the methods employed for weighing, sampling and analysing the mud.

Figure 2 shows a plot of the Insoluble Solids Recovery on a weekly basis during the Maidstone trial. The low insoluble solids recoveries early on in the trial prompted a joint investigation by the Cane Testing Services (CTS) and the Sugar Milling Research Institute (SMRI) into both mud-solids sampling and analysis, and the mixed juice solids analysis. Various adjustments were made in week 6, the most significant being the change in the mud-sample point to after the pump, and immediately a step change in the insoluble solids recovery was observed. The insoluble solids recoveries for the remainder of the trial, although scattered, averaged approximately 100%. The scatter in the data is not unexpected, as both the insoluble solids % mud and the solids % mixed juice analyses are very sensitive to sampling and analytical technique. However, the important conclusion from Figure 2 is that is possible to achieve

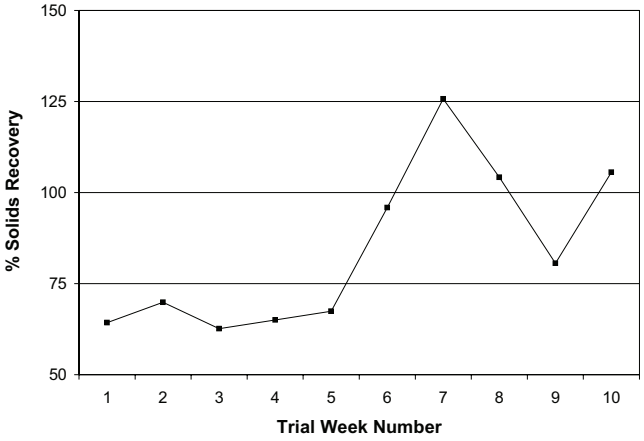

Figure 2. Insoluble Solids Recovery during 1998 trial.

100% insoluble solids recovery using the prescribed methods for massing, sampling and analysing the mud.

The official method for insoluble solids analysis on mud is both complex and time consuming (Brokensha, 1998). It is based on filtering off the mud under a low vacuum, rinsing the remaining mud (without washing any mud-solids through the filter paper), and finally drying the solids. As a check on this procedure, an indirect method of determining insoluble solids was also used. This method involves measuring the total mud-solids by evaporation, and then subtracting the dissolved solids (or Brix) to determine the insoluble solids. Figure 3 compares the two methods. As the results were in reasonable agreement, after 25 November only the direct method was used. Towards the beginning of the trial thick muds were recycled to the diffuser (mud solids around 8%); then during the main portion of the trial the mud solids were between 4% and 8%; and finally towards the end of the trial the muds solids averaged about 4%, dropping on occasions to 2%. Figure 4 shows a plot of Mud % Mixed Juice during the trial. At the beginning of the trial the Mud % Mixed Juice was less than 3%. This figure gradually increased during the trial, reaching an average of more than 4% by then end of the trial. The trend of recycling thinner and thinner muds, as shown in figures 3 and 4, are evidence of steps taken to minimise possible sucrose degradation in the clarifier-mud.

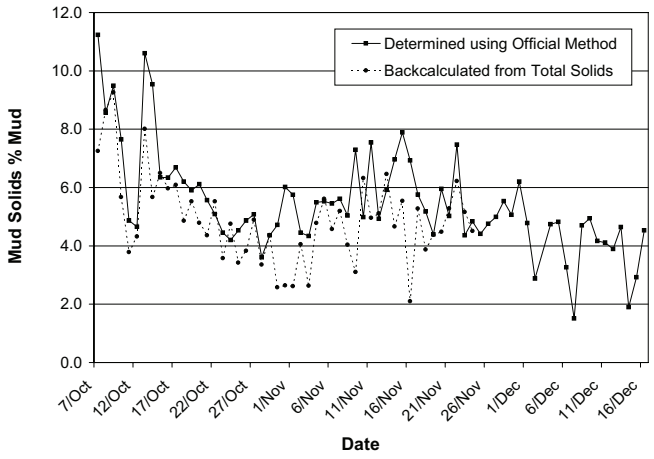

Figure 3. Comparison of methods for Mud-Solids Analysis.

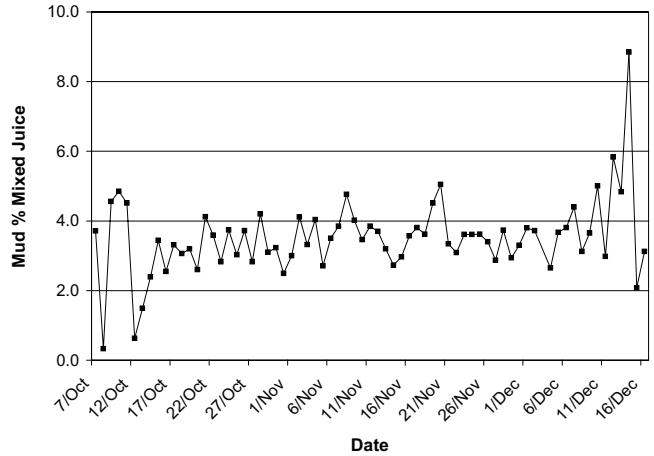

Figure 4. Mud % Mixed Juice during 1998 trial.

Mud Purity

Prior to implementing Mud Recycle, Maidstone consistently experienced problems with degradation of mud in the clarifiers and at the filter station. Immediately before the Mud Recycle trial, the filtrate purity was approximately 4 units lower than the mixed juice purity. This was primarily caused by poor filter station throughput, resulting in high mud levels and long mud retention times in the clarifiers. Figure 5 shows the trend of daily mud purity versus mixed juice purity during the period of the trial. For the duration of the trial, the trends of the mixed juice and mud purities are similar, with the mud purity approximately 2.5 units lower on average.

However, the 2.5 unit purity drop was higher than expected, and as shown in figures 3 and 4, thinner and thinner muds were recycled in an effort to reduce the purity difference between mixed juice and mud. However, as shown in figure 6, the mixed juice minus mud purity difference actually increased towards the end of the trial as the mud retention times were decreased. The primary reason for the higher-than-expected mixed juice minus mud purity difference was found to be analytical.

In the official method for brix % mud (Brokensha, 1998), the measured brix is multiplied by a correction factor, which takes into account the presence of insoluble solids. (This correction is similar to the suspended solids correction that is applied to mixed juice pol and brix.) However, the official method for pol % mud (Brokensha, 1998) does not include a correction for insoluble solids. The analysis assumes a constant insoluble solids % mud, which is accounted for by using 25.5g of mud sample (instead of the normal 26g) per 100 ml of solution. As the pol % mud is independent of the insoluble solids, the mud purity (given by mud pol divided by mud brix) according to the official methods becomes a function of the insoluble solids % mud.

In an effort to eliminate the effect of varying mud solids on the mud purity, samples of mud were diluted with water and then filtered in the laboratory. The purity of the filtrate was found typically to be between 1 and 2 units higher than the mud purity as determined by the official methods. This observation was also made independently at Malelane mill (Lionnet, 1999). Therefore the "actual" average Mixed Juice minus Mud purity difference for the 1998 trial can confidently be taken as being at

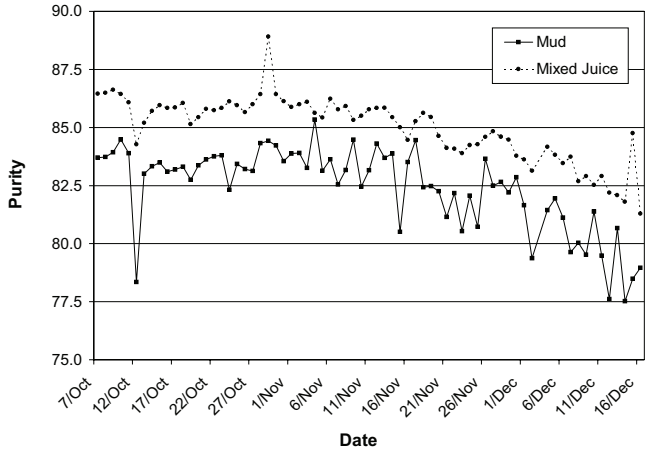

Figure 5. Comparison of Mud and Mixed Juice Purity during 1998 trial.

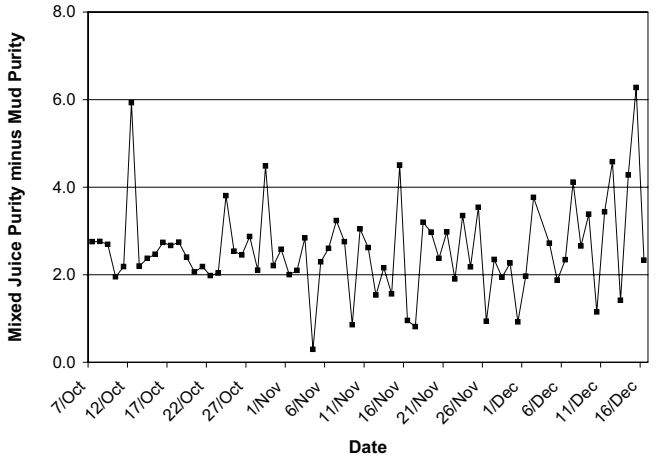

Figure 6. Mixed Juice minus Mud Purity during 1998 trial.

least 1 unit less than the 2.5 units shown in figure 6. However, as shown in Appendix A, the shortcomings of the pol analysis that are identified here, had a neglible impact on the mill balance calculation and therefore on cane payment.

Hourly versus Composite Sample Analysis

As instructed by SASA, Maidstone analysed all hourly mud samples for pol and brix. This represented a significant increase to the mill-laboratory workload, and to an extent, negated some of the other (operational) labour savings that were achieved with Mud Recycle. A lower frequency of mud analysis is desirable, to avoid the need to employ additional laboratory staff specifically for Mud Recycle.

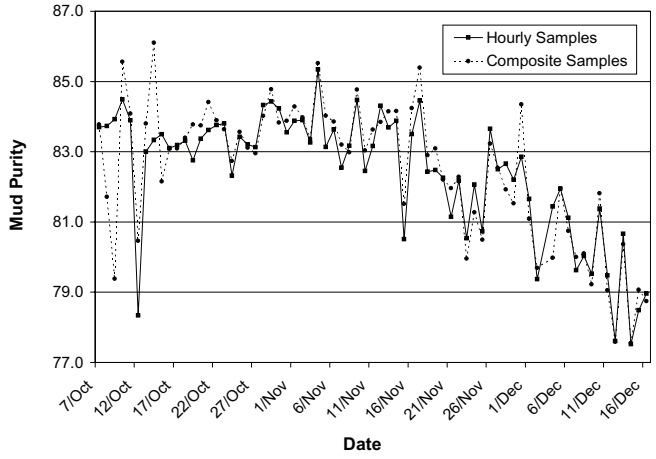

Figure 7. Comparison of Mud Purity results from hourly and 8-hourly composite sample analysis.

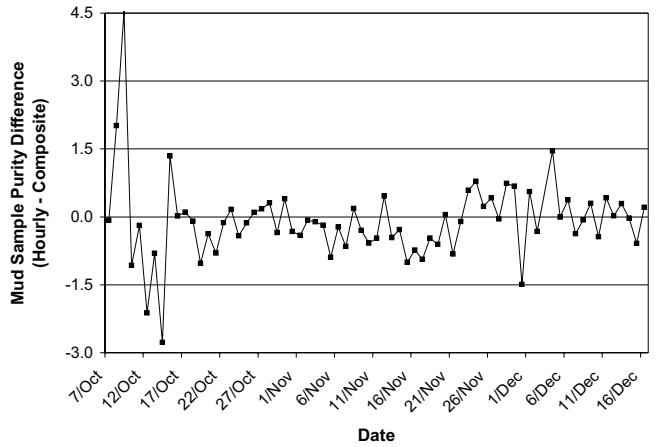

Figure 8. Difference in Mud Purity between hourly and 8-hourly composite samples.

In order to assess the impact of analysing only composite samples, the 8-hour composite samples, which were collected for the insoluble solids analysis, were also analysed for pol and brix. Figure 7 compares a weighted daily-average of the composite results with the weighted daily-average of the hourly results, and shows excellent agreement between the two methods. Figure 8, which plots the difference in purity between the two methods, shows that after the initial problems with the compositing procedure were corrected, all results were within 1.5 units of purity of eachother. The composite samples were preserved with Mercuric Chloride and then stored at in a refrigerator at 3°C. These results prove that composite sample analysis is definitely a viable means of reducing the analytical load associated with Mud Recycle, without introducing significant errors.

General

In addition to the data presented in this paper, CTS monitored the Pol Factor, the undetermined loss, and the mixed juice minus DAC purity difference, before and during the trial. As with the 1997 trial, there was no evidence of bias, introduced by Mud Recycle, to any of these factors. In April 1999, on the basis of these results and other data Malelane and Komati mills, SASA granted the approval for the implementation of Mud Recycle on a permanent basis (Brokensha, 1999). The official procedures for massing, sampling and the analysis of recycled clarifier muds were revised to include the assumption of 100% solids recovery and introduced the use of composite mud samples (Brokensha, 1999). The assumption of 100% solids recovery allows the insoluble solids % mud to be calculated from the suspended solids % mixed juice, thereby eliminating the need to measure insoluble solids % mud. On the basis of the results in figures 7 and 8, the mud analysis frequency was reduced from hourly to 4-hourly, provided that regular checks are conducted to confirm the ongoing reliability of the composite sampling.

Section 2: Mud Recycle – 1999 Season

Results and Discussion

Figure 9 shows the mud solids % mud for the 1999 season, calculated on the basis of 100% solids recovery from mixed

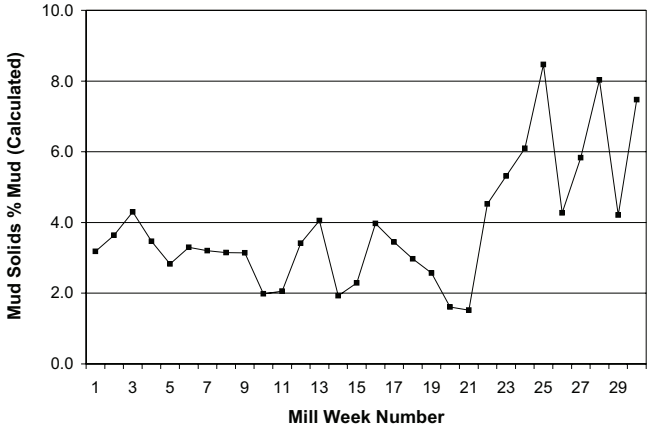

Figure 9. Calulated Mud Solids % Mud during the 1999 season.

juice. For the majority of the season the mud solids % ran at ± 3% (about one unit lower than the 1998 trial). However, in week 21, there is a sharp increase to between 6 and 7 mud solids %. This increase coincides with the implementation of an automated mud-consistency control-system, which is discussed below. Figure 10 shows the mud % mixed juice for the 1999 season. The mud % mixed juice was > 4% for the majority of the season. This is further evidence that the muds were thinner than those during the 1998 trial. Weeks 12 and 13 also show a sudden drop in the mud % mixed juice. A long factory stop occurred in week 12, and the clarifier muds became very thick. The thick muds reduced the capacity of the Mud Recycle system so significantly that the mud pump "struggled" to drop the mud-levels in the clarifiers. The second dip in the mud % mixed, in week 21, coincides with the implementation of the mud-consistency control system.

Mud Consistency Control

The ease with which mud may be withdrawn from the clarifier under Mud Recycle introduced a new problem at Maidstone: "juice recycle" to the diffusers. The pumping capacity the Mud Recycle system increases as the muds become thin. Therefore, once a compartment of has been emptied of mud, juice will continue to be recycled from that compartment at a high flow rate. Juice recycle has the following problems:

- Distorts the diffuser brix profile, and hence affects extraction.
- Results in higher mixed juice flows, and hence increases the load on the clarifiers.

To minimise juice recycle, operators would take a compartment out of sequence when the muds became too thin. They would then check the mud consistency in that compartment at regular intervals, and switch the compartment back into sequence once the mud had thickened again. Operating in this fashion required a high level of operator involvement and judgement, and resulted in both juice recycle, when a compartment was kept in sequence for too long, and mud deterioration, when a compartment was left out of sequence for too long.

In order to eliminate the need for operator intervention (to ensure that the muds do not become too thin) an on-line measurement of mud consistency was required. M. Gooch (1994) developed a flow-through method for measuring the consistency of clarifier muds. The method is based on the principle that, at a constant head and temperature, the mud flowrate through a venturi depends on the mud consistency. Tests carried out at Mt. Edgcombe Mill proved this method to be suitable for on-line mud consistency measurement. At Maidstone it was observed that the time taken for mud from each compartment to fill the mud standpipe depended on the consistency of the mud in that compartment. Measuring the time to fill the mud standpipe produced repeatable results for muds of similar consistency. (This is effectively an indirect method of measuring the mud flowrate.) By sampling the mud it was possible to determine the relationship between the mud withdrawal-time and the actual mud consistency for each compartment. This method of mud consistency measurement forms the basis of the automatic consistency control system implemented at Maidstone during the 1999 season. In addition to eliminating the need for operator involvement, the control system solved both the problem of mud deterioration in the clarifiers and that of juice recycle. It enabled the mud solids % mud to be controlled, whilst maintaining mud temperatures > 98C and mud levels at zero.

Figure 11 plots the difference between the mixed juice purity and the mud purity for the 1999 season. With the implementation of mud consistency contol in week 21, there was a sudden decline in the purity difference between mixed juice and mud from greater than two units to zero. For the remainder of the season the purity difference was actually negative. Although, as discussed earlier, this is partly a consequence of the analytical problems with the pol analysis, it is evidence of reduced sugar losses in the clarifier muds. Figure 11 also shows that in week 13, where problems were experienced with thick muds, that the mud purity was 5 units lower than the mixed juice purity due to mud degradation in the clarifiers.

Section 3: Mud Recycle and the Mill Balance

Brokenshaw (1998) revised the mill balance equations to cater for the recycle of clarifier mud to the diffuser. The primary change to the mill balance equations is that an adjusted, or "nett", tons of pol in mixed juice is used as the basis for payment of sucrose in cane. The nett tons pol in mixed juice, Pol_{MJ}(nett), is calculated by subtracting the tons of pol recycled with the mud, from the tons of pol measured in the mixed juice:

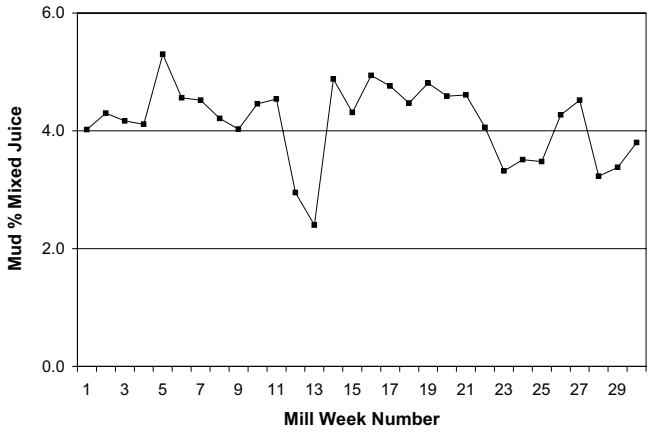

Figure 10. Mud % Mixed Juice during the 1999 season.

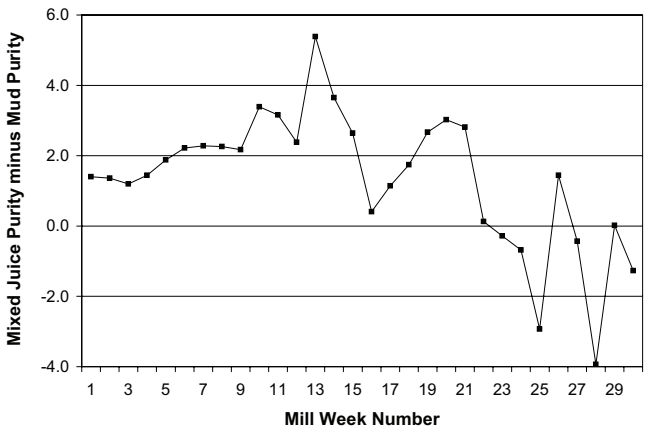

Figure 11. Mixed Juice minus Mud Purity during 1999 season.

$$Pol_{MJ}(\text{nett}) = Tons_{MJ} \times Pol\%_{MJ} - Tons_{Mud} \times Pol\%_{Mud} \quad (1)$$

where $Tons_{MJ}$ and $Tons_{Mud}$ are the tons of mixed juice and mud respectively, while $Pol\%_{MJ}$ and $Pol\%_{Mud}$ are the pol % mixed juice and mud respectively. The $Tons_{MJ}$ and $Tons_{Mud}$ are weighed using servo-balances, while the $Pol\%_{MJ}$ and $Pol\%_{Mud}$ are determined by sampling and analysis.

The pol % mixed juice, $Pol\%_{MJ}$, is calculated in two stages. An automatic sampling device samples the mixed juice each time the scale discharges. Once per hour this composite sample is filtered and analysed for pol (and brix). In addition an hourly catch sample of mixed juice is collected and composited over eight hours. The eight hour composite sample is analysed for suspended solids. This value of suspended solids is used to correct the hourly pol results as follows:

$$Pol\%_{MJ} = Pol\%_{FilteredMJ} \times (1 - SS\%_{MJ}) \quad (2)$$

where $Pol\%_{FilteredMJ}$ is the pol % mixed juice, ignoring the presence of solids, and $SS\%_{MJ}$ is the suspended solids % mixed juice. ($Pol\%_{MJ}$ cannot be calculated directly as the automatic sampling device does not collect a representative sample of the suspended solids in the mixed juice.)

The official method for calculating the pol % mud does not include a correction for insoluble solids in the mud. An alternative approach is to calculate the $Pol\%_{Mud}$ using a similar method to that of the $Pol\%_{MJ}$. Using this method the $Pol\%_{Mud}$ may be determined as follows:

$$Pol\%_{Mud} = Pol\%_{FilteredMud} \times (1 - SS\%_{Mud}) \quad (3)$$

where $Pol\%_{FilteredMud}$ is the pol % mud, ignoring the presence of solids, and $SS\%_{Mud}$ is the insoluble solids % mud.

The assumption of 100% solids recovery, allows the calculation of $SS\%_{Mud}$ from the $SS\%_{MJ}$ as follows:

$$SS = Tons_{MJ} \times SS\%_{MJ} = Tons_{Mud} \times SS\%_{Mud}. \quad (4)$$

Where SS is the tons of suspended solids passing through the mixed juice scales and therefore returning with the mud.

Substituting equations (2) and (3) into equation (1) allows the nett tons pol in mixed juice to be written in terms of the uncorrected pol % mixed juice and pol % mud data:

$$Pol_{MJ}(\text{nett}) = Tons_{MJ} \times Pol\%_{FilteredMJ} - Tons_{Mud} \times Pol\%_{FilteredMud} - Tons_{MJ} \times SS\%_{MJ} \times Pol\%_{FilteredMJ} + Tons_{Mud} \times SS\%_{Mud} \times Pol\%_{FilteredMud} \quad (5)$$

Substituting the assumption of 100% solids recovery, equation (4), allows equation (5) to be rerwritten as:

$$Pol_{MJ}(\text{nett}) = Tons_{MJ} \times Pol\%_{FilteredMJ} - Tons_{Mud} \times Pol\%_{FilteredMud} - SS \times (Pol\%_{FilteredMJ} - Pol\%_{FilteredMud}) \quad (6)$$

The first term in equation (6), $Tons_{MJ} \times Pol\%_{FilteredMJ}$, is the measured tons of pol in mixed juice, without adjusting for suspended solids. Similarly, $Tons_{Mud} \times Pol\%_{FilteredMud}$ is the measured tons of pol in mud, without adjusting for mud solids. The third term in equation (6), $SS \times (Pol\%_{FilteredMJ} - Pol\%_{FilteredMud})$, is the adjustment to the nett tons pol in mixed juice to account for the presence of suspended solids in mixed juice and mud. The third term may also be viewed as giving the error that would be introduced by ignoring the presence of solids in the first two terms.

The relative magnitudes of the three terms in equation (6) may be compared by substituting typical values for the mud % mixed juice and the suspended solids % mixed juice into the equation. Assuming the mud % mixed juice is 3% and that the suspended solids % mixed juice is 0.2%, then for 100 tons of mixed juice, equation (6) may be rewritten as:

$$Pol_{MJ}(\text{nett}) = 100 \times Pol\%_{FilteredMJ} - 3 \times Pol\%_{FilteredMud} - 0.2 \times (Pol\%_{FilteredMJ} - Pol\%_{FilteredMud}) \quad (6a)$$

Equation (6a) clearly shows the relative contribution to the tons pol in mixed juice of each of the terms in equation (6). However, $Pol\%_{FilteredMud}$ is essentially the pol % clear juice, which is very similar (if not identical to) the $Pol\%_{FilteredMJ}$. Therefore, under normal operating conditions, $Pol\%_{FilteredMJ} - Pol\%_{FilteredMud} \sim 0$. Therefore the contribution of the third term in equation (6) is very much smaller than the first two terms.

The important conclusion from equation (6) is that, under Mud Recycle, the corrections for solids in mixed juice and mud essentially cancel each other out when calculating the nett tons of pol in mixed juice. This statement is also intuitative. A clarifier is essentially a large suspended solids collector, returning all the solids passing through the mixed juice scales back to the diffuser via the mud scale. Therefore the tons pol in clear juice (which equals the nett tons pol in mixed juice, assuming no degradation of pol) is given by a simple subtraction of the pol in mixed juice and the pol in mud, without needing to account for solids.

In situations where $Pol\%_{FilteredMJ}$ exactly equals $Pol\%_{FilteredMud}$ equation (6) simplifies to:

$$Pol_{MJ}(\text{nett}) = Tons_{MJ} \times Pol\%_{FilteredMJ} - Tons_{Mud} \times Pol\%_{FilteredMud} \quad (7)$$

In this case presence of suspended solids in both the mud and mixed juice streams has no impact on the Pol_{MJ}(nett).

Finally, consider the situation where there is some degradation of sucrose in the clarifer, causing the mud purity to be lower than the mixed juice purity. If $Pol\%_{FilteredMud} < Pol\%_{FilteredMJ}$ then Pol_{MJ}(nett) as calculated by equation (7) will be greater than Pol_{MJ}(nett) as calculated by equation (6). This means that if the presence of suspended solids were ignored and equation (7) used as the basis for cane payments, degradation in the clarifier would result in Pol_{MJ}(nett) being slightly overstated. In effect this would penalise the miller. However, to put the magnitude of this error in perspective, consider the 1999 season at Maidstone where approximately 2 000 000 tons of cane were crushed and 191 000 tons of sugar produced. If equation (7) had been used (instead of equation (1)) to calculate the tons pol in mixed juice, and if there had been a 2 unit drop in purity between mud and mixed juice, Maidstone would have paid for approximately 10 additional tons of pol over the entire season. This is a small additional cost to the miller in comparison to the cost of measuring the solids in mixed juice and mud. If the purity drop were greater than 2 units (poor clarifier operations) the magnitude of this error would increase accordingly.

Conclusions

This paper presented in detail an assessment of the assumptions and analytical methods used to determine the impact of Mud Recycle on the mill balance. The 1998 trial showed that 100% insoluble solids recovery could be achieved using the prescribed methods for massing, sampling and analysis of the mud. It was also shown that the official method for mud solids analysis was consistent with the results of the total solids analysis. Composite sample analysis was presented as a viable means of reducing the analytical load associated with Mud Recycle, without introducing significant errors. Although problems were identified with the official method for mud pol analysis, the magnitude of the errors were not significant with respect to the mill balance. Nevertheless, the error does result in misleading mud purities and needs to be addressed.

In this paper Mud Recycle is shown to be more than just a viable process alternative to the filter station. Indeed the benefits of Mud Recycle over traditional filters are significant. It is likely that, within a few years, all diffuser factories in South Africa would have moved to Mud Recycle. In an attempt to quantify the benefits of Mud Recycle to a typical sugar mill estimates of the costs savings at Maidstone during the 1999 season are included:

Item	Cost Saving
Reduced Maintenance Costs	R120 000 p.a.
Reduced Operational Costs	R120 000 p.a.
Reduced Physical Losses (using industry figures for sugar losses in filtercake for the 1999 season)	R500 000 p.a.
Reduced Chemical Losses (assuming a 0.02% undetermined loss in a typical filter station)	R60 000 p.a.
Reduced Solids Waste Disposal Costs	R430 000 p.a.
Reduced Losses in Bagasse (through approximately a 5% increase in imbibition)	R100 000 p.a.
Total:	R1 330 000 p.a.

In addition to quantifying the benefits of Mud Recycle to Maidstone, this paper has identified some further benefits associated with Mud Recycle. The first of these benefits is the ease with which clarifier mud withdrawal can be automated under Mud Recycle. Minimal operator involvement is required to maintain optimal mud levels in the clarifier and hence mud deterioration is reduced. The second benefit is that Mud Recycle has the potential for simplifying the critical mixed juice analysis by eliminating the need to measure suspended solids in mixed juice. This would allow the analytical workload carried by CTS to be reduced without affecting cane payments. Finally, eliminating the need to measure mud solids would also simplify the mud sampling and analysis procedures.

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Acknowledgements

R Lionett for advice during the trials and with the writing of this paper; S Bhorat for his input in programming the consistency control philosophy; Maidstone laboratory staff for carrying the additional analytical workload; and Maidstone operational staff for making the process change happen.

APPENDIX A

The mill balance equation gives the nett tons of pol in mixed juice, Pol_{MJ}(nett):

$$Pol_{MJ}(\text{nett}) = Tons_{MJ} \times Pol\%_{MJ} - Tons_{Mud} \times Pol\%_{Mud} \quad (1)$$

Substituting the mud % mixed juice, *Mud%MJ*, into equation (1) gives,

$$Pol_{MJ}(\text{nett}) = Tons_{MJ} \times (Pol\%_{MJ} - Mud\%MJ \times Pol\%_{Mud}) \quad (8)$$

The accuracy of the $Tons_{MJ}$ and the $Tons_{Mud}$ is affected by the precision of the weighing equipment used. (In South Africa assized scales are used to weigh the mixed juice and the mud.) For the purpose of this discussion weighing errors are assumed to be negligible. The accuracy of the $Pol\%_{MJ}$ and the $Pol\%_{Mud}$ is affected by: how representative the samples of the actual streams are, the accuracy of the analytical method for pol determination, and the precision of the instrument used to measure the pol. The fact that the $Pol\%_{MJ}$ and the $Pol\%_{Mud}$ are accurate to some finite tolerance may be written mathematically as:

$$Pol\%_{MJ} = Pol\%_{MJ}^{meas} \pm err_{MJ} \quad (9)$$

$$Pol\%_{Mud} = Pol\%_{Mud}^{meas} \pm err_{Mud} \quad (10)$$

where $Pol\%_{MJ}^{meas}$ and $Pol\%_{Mud}^{meas}$ are the measured values of the pol in mixed juice and mud respectively while $Pol\%_{MJ}$ and $Pol\%_{Mud}$ are the actual values of the pol in mixed juice and mud.

The tolerance of the mixed juice and mud analysis written as $\pm err_{MJ}$ and $\pm err_{Mud}$ respectively. Substituting equations (9) and (10) into equation (8) and gives:

$$Pol_{MJ}(\text{nett}) = Tons_{MJ} \times (Pol\%_{MJ}^{meas} - Mud\%MJ \times Pol\%_{Mud}^{meas} \pm \text{err}_{Comb}) \quad (11)$$

where err_{Comb} is the combined tolerance as a result of err_{MJ} and err_{Mud}:

$$err_{Comb} = err_{MJ} - Mud\%MJ \times err_{Mud} \quad (12)$$

Substituting the average value of the *Mud%MJ* for the 1998 trial, *i.e.* 3%, into equation (12) gives:

$$err_{Comb} = err_{MJ} - 0.03 \times err_{Mud} \quad (13)$$

Therefore order for the mud error to fall within the tolerance of the mixed juice analysis, the error in the mud analysis err_{Mud} must be less than $err_{MJ}/0.03$. Assuming that no errors are introduced through the juice sampling method and the analytical procedure, err_{MJ} is given by the precision of the measuring instrument (*e.g.* for a saccharimeter this is typically 0.005). Taking the minimum value of err_{MJ} as 0.005, the error in the mud pol analysis will only be significant if err_{Mud} is greater than 0.167. Therefore, although the inaccuracies in the mud pol analysis have been shown to introduce errors of up to 2.5 units of purity, these errors fall "easily" within the minimum tolerance of the mixed juice analysis.