RAW JUICE FLOW CONTROL, SCREENING, HEATING AND LIMING

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Abstract

In preparation for defecation clarification of raw or mixed juice, the juice is screened, heated, limed and flashed, while the flowrate of juice to the clarification process is carefully controlled. Despite the potential for enhancement or optimisation in each of these pre-treatment areas, the past 50 years of South African Sugar Technologists' Association (SASTA) proceedings offer only six papers dealing specifically with aspects of pre-treatment. This paper reviews some of their findings in the light of current practice, discusses present installations in the South African sugar industry and considers probable future directions.

Keywords: juice flow, control, screening, heating, liming

Introduction

Four pre-treatment processes are undertaken prior to the defecation clarification of mixed juice. These are:

- coarse particulate removal by screening
- heating
- pH adjustment by controlled addition of lime
- dissolved gas removal and temperature stabilisation by flashing.

In addition, the flowrate of juice into the clarification process is controlled to assist pH control and facilitate good clarifier operation. Tables 1 to 5 summarise the current pre-treatment installations in the sixteen South African sugar factories [1](where a factory's name does not appear under a particular category, the relevant information was not available at the time of compilation).

Screening

It is common practice in South African factories to screen the juice coming from the extraction plant to remove coarse particulates such as bagasse/bagacillo fibres and, as far as possible, sand. Two types of screening devices are used:

- DSM screens are by far the most common, fitted typically with wedge-wire screens with 0,75 mm apertures, although larger apertures are encountered and ordinary mesh is used in some cases.
- 'Contra-Shear' cylindrical screens are gaining popularity. These are inclined, rotating screens on which screening is supposed to be enhanced by the formation of a 'bed' of solids in the bottom of the cylinder.

A linear belt filter was used for a period at MS but was discontinued when the milling plant was substituted by diffusion.

Several diffuser factories have no screening as it is believed to be superfluous, the diffuser bed itself acting as a screen. Low values of suspended solids in juice from diffuser factories support this. However, without exception, those factories without screening report problems such as carry-over of bagacillo in clear juice, sand erosion in juice heaters or blockages in heaters. Some of the factories using DSM screens report similar problems (at times due to screen wear increasing aperture sizes), but the Contra-Shear screens appear to prevent such occurrences (provided the screen is washed regularly). However, NB installed Contra-Shear with the intention of reducing suspended solids % mixed juice, but recorded no such decrease. DL experiences severe sand build-up in the DSM troughs and mixed juice tank, and is investigating the possible use of a hydrocyclone this season.

Table 1

Juice screening installations

No screening	FX, GH (diffuser), MS, ML
DSM screens	AK, DL, EN, ES, GD, NB, PG, SZ, UC, UF, UK
Contra-Shear rotating screens	GH (mill), KM, NB

Heating

Heating of the juice to above 100°C to allow flashing is standard practice throughout the industry. In most cases, this is achieved by primary heating using V2 followed by secondary heating using V1, although V1 only or V2, V1 and exhaust in combination are also used.

Table 2

Juice heating installations

Heater type:	
Shell-and-tube	AK, DL, EN, ES, FX, GH, MS, ML, NB, PG, SZ, UF, UK
Plate	GD, UC
Platular	KM
Standby heaters:	
None	EN
One	DL, ES, FX, GH, KM, MS, NB, PG, UF
Two	ML, SZ, UK, UC
Heating medium:	
V2 & V1	AK, EN, FX, GH, KM, NB, SZ, UF, UC
V1	DL, MS
V1 & exhaust	UK
V2, V1 & exhaust	GD, ML
Cleaning method:	
Skato-Skalo	AK, DL, EN, ES, FX, MS, ML, NB, PG
Caustic	GH, GD, KM, UF (brushed), UC
Baking/air blast	SZ, UK

The position of the stalwart of juice heating, the shell-and-tube exchanger, is being challenged by the use of plate-type

[1] South African sugar factories: AK = Amatikulu, DL = Darnall, EN = Entumeni, ES = Eston, FX = Felixton, GD = Glendale, GH = Gledhow, KM = Komati, ML = Malelane, MS = Maidstone, NB = Noodsberg, PG = Pongola, SZ = Sezela, UC = Union Co-op, UF = Umfolozi, UK = Umzimkulu

exchangers. Plate heaters used in the sugar industry are of the 'wide-gap' type, ie the plate gap on the juice side is typically 12 mm instead of the normal 4 to 6 mm (steam side). MS ran a pilot trial with a plate heater in 1990, but had serious problems with port blockages and did not achieve the anticipated Overall Heat Transfer Coefficients (OHTC).

Munsamy (1982) and Currie (1986) reported on the successful use of plate heaters on mixed juice at UC, each claiming OHTC of at least twice that typically obtained with shell-and-tube heaters, lower pressure drops and lower capital costs. However, UC now reports problems with the units, such as plate cracks and frequent and expensive gasket replacements.

A newcomer to the South African industry is the platular, all-welded (gasketless) exchanger with an 18 mm juice side gap. The factory using these units (KM) is extremely satisfied with the results.

Heater cleaning is usually done either mechanically (Skato-Skalo) or by cleaning-in-place using a caustic solution. An innovation at SZ and UK is the cleaning of shell-and-tube heaters with air. This is done by 'baking' the scale for a period and then blasting it off using nozzles supplied with air at 6 bar. Shell-and-tube heaters are cleaned weekly, whereas the plate units are cleaned chemically every three to four days. For this reason, all of the plate heater installations incorporate standby units to allow cleaning on the run.

pH adjustment

Lime preparation

The standard method of milk-of-lime preparation is the slaking of rock lime (calcium oxide) with water to form calcium hydroxide. Some factories, however, operate their own lime kilns. MacNaughton (1995) reported on the successful replacement of a rock lime slaking plant with a powdered lime plant. The powdered lime process is cheaper (in overall operating costs – powdered lime itself is a little more expensive), less labour intensive, better automated and cleaner. While it has therefore become the preferred process for new factories, it is difficult to justify the replacement of an existing plant with a powdered lime system.

Lime Baume varies from factory to factory, being influenced by plant constraints, staff preference and whether the lime is also to be used for diffuser liming. The range in South African factories is from 4 to 12°Be. Accurate control of Baume is problematic, and DL is considering installing a nuclear density meter for this purpose.

Liming strategy

Carter (1966) investigated cold, hot and intermediate liming (as well as other combinations) and found intermediate (heat, lime, heat) liming to yield the best clear juice clarity (with hot liming the worst). However, hot liming returned a far higher settling rate, possibly due to the occurrence of floc breakage in the heaters when using cold or intermediate lime addition.

To maximise settling rate and minimise the risk of alkaline colour formation during heating, the vast majority of South African factories liming with milk-of-lime practise hot liming.

Saccharate liming (liming with a solution of lime in evaporator syrup, typically in a 1:7 ratio) is practised at GH (which uses both cold and saccharate liming) and the facility is available at some others. At GH, a fixed quantity of lime is added to the juice with each scale tip and then lime saccharate at pH 11,5 is added by means of a Mono pump before finally heating the juice.

Table 3

Liming and pH control installations

Liming strategy:	
Cold/intermediate	GH*, UF
Saccharate	GH
Hot	AK, DL, EN, ES, FX, GH*, GD, KM, MS, ML, NB, PG, SZ, UK,
Mixing:	
Perry tank	GD, ML, UF, UK, UC
U-tube static mixer	ES, GH, KM, NB, PG, SZ
Other static mixer	AK, DL, EN, FX, MS
Lime dosing:	
Splitter box	GD, ML, UF, UK, UC
Peristaltic pump	AK, DL, EN, FX, KM, MS, NB
Mono pump	ES, GH, PG, SZ
Powdered lime plant	KM, MS
Juice sample:	
Before flash tank	ES, FX, GH, KM
From flash tank	AK
After flash tank	DL, EN, GD, MS, ML, NB, UF, UK, UC
Probe in flash tank	PG, SZ
Juice flow bias on pH control	FX
Second (reference) electrode	KM, ML#, PG, SZ#
Electrode requirements:	
Cooled sample	AK, DL, ES, GD, KM, UK
Cleaned per shift	FX, KM, NB (water), UC
Cleaned per day	ES, GH, PG, UF, UK
Cleaned per few days	DL, EN, MS
Cleaned per week	AK, NB (acid), SZ

* GH has facility for cold, hot and saccharate liming – cold and saccharate are normally used.
\# Being installed for the 1996-97 season.

North-Coombes *et al.* (1981) and Scott (1988) described experiences with saccharate liming and agreed that the process produces clear juice of superior clarity at the expense of higher mud volumes. North-Coombes *et al.* (1981) claimed additionally that saccharate liming provided steadier pH control, improved mud filterability and filtrate quality and easier lime handling. Scott (1988) countered that the improved clear juice clarity resulted in only slight improvements in sugar colour under poor cane quality conditions, and no improvement when crushing better cane, and that the additional complexity of saccharate was therefore difficult to justify.

None of the South African factories has had any experience with alternatives to lime, such as magnesium oxide, which is more soluble but more expensive than lime. However, the experience some process staff gained in other countries was that magnesium reduces evaporator scaling and therefore cleaning frequency, but that scale forms instead in the A-pans. This scale is, however, of a softer composition than normal evaporator scale. The question has been raised (but not yet answered) of whether it might be possible to use lime for phosphate precipitation and an alternative such as caustic for the remainder of the juice neutralisation.

Phosphoric acid addition is practised at some factories when natural phosphate concentrations in the juice fall below a minimum level. Carter (1966) found the optimum phosphate concentration to be 330 ppm P_2O_5, and it is generally believed that clarification is extremely difficult at phosphate concentrations below 150 ppm.

Lime addition

The traditional method of lime addition has been via an automatically adjusted splitter box into a Perry tank (a tank fitted with a stirrer in a draft tube) after the flash tank. Factories are now moving to static mixers installed in the juice line upstream of the flash tank, with the lime pumped into the line.

The most common static mixer design is the double-screw 'U-tube' shown in Figure 1, although various other designs are used. Lime addition is usually via a peristaltic pump fitted with a variable speed drive, although some factories are using Mono pumps. The pumped option has the inherent disadvantage that the variable speed drives cannot drop below a minimum speed, which can cause overliming at very low juice flowrates. Some factories address this by reducing their lime concentration when low flows are expected (values as low as 2°Be are used at KM), while others add water directly into the pump suction.

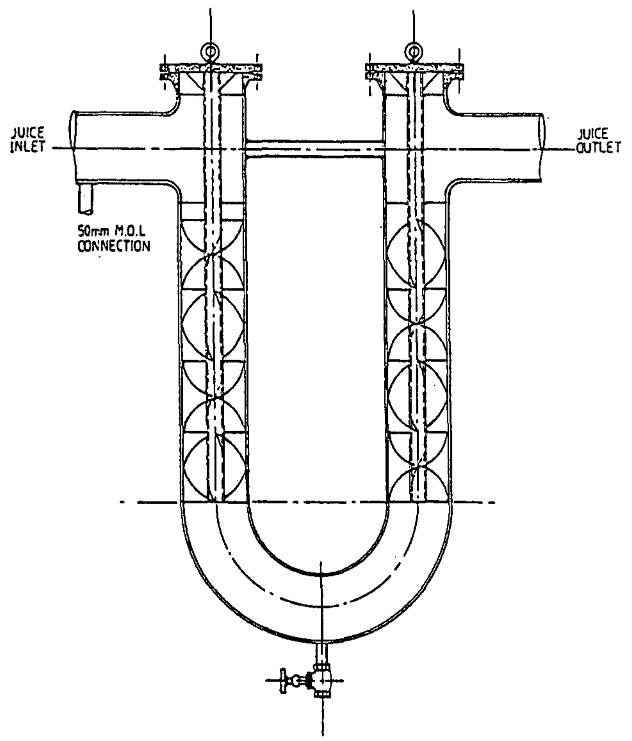

FIGURE 1: Popular in-line static mixer design

Control of pH

Measurement of pH is done by taking a continuous sample of juice and passing it through a chamber containing a pH electrode. These are of various makes (Polymetron, TBI, Yokogawa, Endress and Hauser) and types (antimony-ring seems to be the preferred type) and, until recently, required that the sample was cooled or mixed with cold water to lower the measurement temperature. However, many mills now take advantage of electrodes designed to work at elevated temperatures, and do not cool their sample. PG and SZ do not remove a sample at all, but insert their probes directly into their flash tanks, which, due to their elevation relative to the clarifiers, contain juice levels. EN tried inserting the probe directly into the juice line, but stopped due to electrode damage by suspended material in the juice. They are, however, changing to a recessed bulb pH electrode with a possible view to repeating this trial. Juice sample lines should be kept short to minimise lime deposition in the line. At AK this is taken so much for granted that the flanged sample line is replaced with a standby each week and cleaned.

Electrodes are cleaned at frequencies varying from once per shift to once per week. KM has an electrode sensitivity check built into its supervisory control system, which can be implemented at any time to check whether the probe needs cleaning. KM and PG use second electrodes as references so that the pH measurement may be obtained by comparing the two probe outputs, and two further factories are following this route.

Those factories using Perry tanks remove their sample from the tank outlet. However, the precise location of a suitable sample point is not as simple for the factories using static mixers, as the juice must be allowed a reasonable reaction time, but a sample point too far away from lime addition introduces too great a lag into the control loop. Most factories simply take their sample 'a few metres after' the static mixer or immediately after the flash tank and, it appears, hope for the best. It is claimed by some process staff that a 20 second reaction time is necessary for proper reaction and good control.

Control of pH is almost universally achieved by means of a standard control loop. The only exception is at FX where the control action is biased according to mixed juice flowrate, to provide a quicker response in lime addition to juice flowrate changes (UK is also planning to install this option). The most common problem with pH control is in fact an inability to cope with juice flow fluctuations arising from poor flow control.

Flashing

Flash tanks in the South African sugar industry are one of two simple designs:

- An empty cylindrical tank with the juice entering tangentially and leaving from the centre of the tank floor, while the vapour exits at top centre.
- A cylindrical tank containing a large impingement plate (splash plate) close to the tank floor. The juice is directed on to the centre of the plate and exits centrally below it, while the vapour exits at top centre. A feature of some flash tanks of this design is that they are installed at a low elevation relative to the clarifier(s), so that they always contain a level of juice.

An exception to these standard designs exists at MS only, where a tangential-entry flash tank contains a central draft tube which extends from the tank roof to below the juice inlet, via which the vapour exits the tank. UF also has an overflow line on their flash tank in case the outlet blocks.

Table 4
Flash tank installations

Tangential entry – type	AK, DL, EN, MS, ML, NB, UF, UK, UC
Impingement plate – type	ES, FX, GH, GD, KM, PG, SZ

Flow control

The control of mixed juice flowrate to provide a steady feed rate to the clarification process is done in a range of different ways in South African factories. The main methods are:

Manual control. Here only the flow is measured and adjustments are made manually to ensure the desired flow and maintain acceptable tank levels. UK, the only factory where this is used, is planning to change to level control.

Flow control (Figure 2a). The juice flow is controlled to a particular setpoint. The mixed juice tank level is manually controlled, either by adjusting the flow controller setpoint when the tank level is too low or high, or (for diffuser factories) by controlling the draft juice flow into the mixed juice tank on the basis of mixed juice tank level. This latter option uses the diffuser as a surge tank.

Level control (Figure 2b). The juice flow is controlled on the basis of the mixed juice tank level, usually via a heavily damped control loop to prevent the flow cycling with juice scale tips. This is a simple and robust system, but has the disadvantage that the clarification process is not protected against sudden changes in juice flow if the tank level rises or falls sharply. A variation on this system at SZ bases mixed juice flow on the clear juice tank level, and uses mixed juice tank level to control draft juice flow.

'Gap action' control (Figure 2c). The juice flow is controlled as in ordinary flow control. However, the setpoint is adjusted automatically, based on the mixed juice tank level. This may be via an algorithm relating level to flow setpoint, or via a 'look-up' table of levels and their corresponding flow values. This has the disadvantage of requiring considerable process knowledge to configure (accurate prediction of the expected range of juice flowrates is essential) and, depending on the capabilities of the controller, may result in frequent step-changes in flow as the level moves up and down.

Cascade control (Figure 2d). This system uses two complete control loops. A flow control loop controls the flow to a remote setpoint, which is the output of a level control loop, controlling the mixed juice tank level to a particular value. ML varies this by using a draft juice tank level control loop to provide the remote setpoint for mixed juice flow, with the mixed juice tank level controlling the draft juice flow into it. Cascade control offers the best combination of smooth changes in flowrate with acceptable tank levels, but is notoriously difficult to tune properly and, although available at many factories, is therefore infrequently used.

Other systems. Other, more complex, systems are in use or are planned. FX plans to use their supervisory control system to combine draft juice and mixed juice flows and mixed juice tank level in a multivariable control system. MS is replacing their gap action control this season with a system that allows mixed juice tank level and flowrate to vary to a certain extent, but functions to minimise the rate of change of mixed juice flow, ie. it smooths any changes in the flowrate.

Table 5

Juice flow control installations

Manual control	UK
Flow control	FX, GD, KM, PG, UF (secondary)
Level control:	
On mixed juice tank level	DL, EN, GH, UF (primary)
On clear juice tank level	SZ
Gap action control	MS, NB
Cascade control:	
On draft juice tank level	ML
On mixed juice tank level	AK, ES, U
Other elements:	
Draft juice flow control	AK, MS, UF
Mixed juice tank level/draft juice flow	KM, ML, PG, SZ
Control valve:	EN, ES, GH (primary), ML, NB, PG, SZ, UC, UF, UK
Variable speed pump:	DL, FX, GH (secondary), KM, MS

Process staff are unanimous in identifying juice flow control as fundamental to good pH control and successful clarification. Yet only seven of the sixteen South African factories reported reasonable levels of satisfaction with their current flow control systems. Even more remarkable, given the importance of this part of the process and the apparent lack of success in solving its associated problems, is the fact that

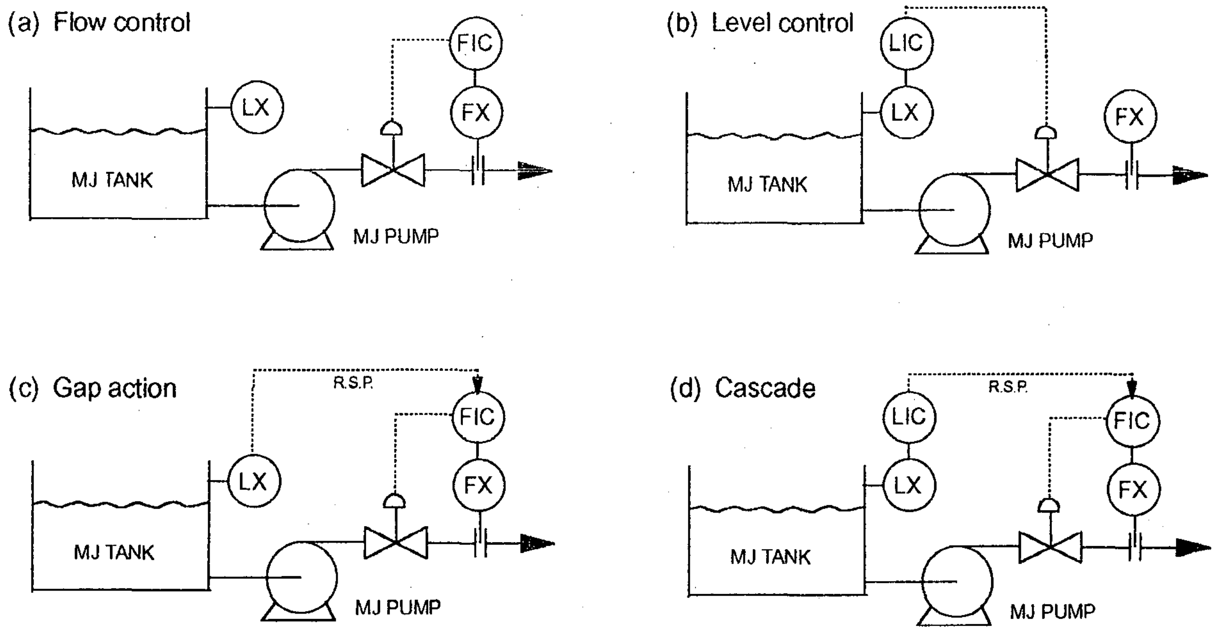

FIGURE 2: Standard mixed juice flow control schemes

nothing has been presented at SASTA congresses on the subject in the past 50 years! There is clearly a need for effort to be focussed in this area, as the benefits to the industry as a whole could be very significant.

The way ahead

It is projected that technological progress in the pre-treatment phase of the clarification process will take place along three main avenues:

(a) The optimisation of mixed juice flow and pH control, as the capabilities of modern control hardware and software allow an integrated approach, employing techniques such as multivariable control.

(b) Further investigation into alternatives to lime or at least alternative methods of its use, with a view to reducing scaling in the evaporators.

(c) The use of alternative separation technologies such as crossflow microfiltration for the removal of suspended material from the juice prior to a final clarification step.

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