SUGAR MILLING
RESEARCH INSTITUTE NPC

SUGARCANE TECHNOLOGY ENABLING
PROGRAMME FOR SUGAR FACTORY 4.0
(STEP-SF4)

Industry INNOVATION Partnerships INITIATIVE
SECTOR INNOVATION Funds

ANNEXURE A

Selected projects for TVAs

Representatives of the sugar industry, nominated to serve on the STEP SF4.0 Technical Review Committee, considered factory problems that might be resolved to some extent by using a data-analytics approach to generate actionable insights from existing and potentially new factory data to improve factory efficiency. Ten problems were discussed and ranked at the TRC meeting of 19 March 2019 and the six most promising projects were selected as listed below.

DIFFUSER OPERATIONS

Introduction

The most common method of juice extraction is diffusion. The prepared sugarcane enters the diffuser at one end and exits at the other end (which takes about an hour). During this time, clean water (imbibition water) is percolated through the bed of prepared cane (10 – 15 times) which washes the sucrose (and other soluble components) out of the fibres. When the fibres exit the diffuser, they are squeezed in dewatering mills to dry the fibre (which is now called “bagasse”), and this bagasse is sent to the steam boilers as a fuel. The juice that was squeezed out of the bagasse returns to the diffuser again. See figure 1 below.

The measure of extraction performance is “Pol extraction” (pol = sucrose). Extraction can be calculated (on a daily basis) as:

Tonnes pol in juice / (Tonnes pol in juice + tonnes pol in bagasse)

Extraction is generally in the range of 96 – 98%.

Through experience, it is understood that the factors that influence extraction (roughly in order of importance) are:

1. Optimal cane preparation: more is better, up to a point. Preparation Index (PI) should be over 90 but not more than 93.

2. The residence time of the cane in the diffuser: longer is better

   Guidelines:

   87 min = 98% extraction
   67 min = 97% extraction
   54 min = 96% extraction
3. Quantity of imbibition water in relation to the quantity of fibre: more is better, but this has consequences for downstream energy required to evaporate additional water.

4. The pol content of the sugarcane: since the pol is dissolved in the water, and the water is absorbed by the fibre, the ratio of pol / fibre is an important determinant of extraction. For the same pol % bagasse, the extraction will be higher from cane with high pol content than from cane with low pol content.
5. Temperature inside the diffuser: steam is added to keep the operating temperature above 80° C.

Guidelines: by reducing the temperature from 80 to 75°C, the diffuser can lose 0.2% extraction.

6. Bagasse moisture: the pol that remains after diffusion, exists in the remaining juice associated with the bagasse. Thus, the dryer the bagasse can be made, the more pol gets squeezed from the fibres. Bagasse moisture is, in turn, determined by the performance of the dewatering mill.

7. Scalding juice flow rate: this refers to the liquid passing through the fresh cane that enters the diffuser - the higher the rate of this juice, the better the diffuser extraction can be expected to be.

   Guidelines: by reducing the bagasse moisture from 51 to 50%, the diffuser can gain 0.1 - 0.2% increase in extraction.

8. Saturation of the cane fibres in the diffuser: It is desirable for good extraction results that the "cane bed" should be saturated to the maximum extent, without over-saturation. Too much saturation, and flooding will result (see the note below). Too low, and extraction will suffer. This needs to be managed by adjusting imbibition and juice flows within the diffuser. However, no reliable method has been found to measure the level of juice within a diffuser, but a model of bed saturation in a diffuser is being developed at SMRI that could potentially be used to predict bed saturation and may have application for process monitoring and potentially even control.

<u>Note:</u> One of the operational challenges that diffusers encounter is called "flooding". This is when the juice doesn't percolate through the cane bed in the diffuser fast enough; the cane bed becomes waterlogged; and juice starts flowing in every direction. This can happen when cane preparation is too fine, or the cane has a high sand content which blocks the passages between the fibres.

Since extraction is calculated daily, the point of control for the extraction engineer is pol % bagasse (a value which is available hourly). The aim is to minimise pol % bagasse, or at least keep it within the "normal" range, which is around 0.9 – 1.5%.

Problem statement

Extraction is one of the major areas of performance in a sugar factory. The process is influenced by a number of factors, many of which can be measured real-time. However, pol % bagasse and moisture % bagasse are analysed in the factory laboratory and reported every hour. The extraction itself is reported daily. It is up to the engineer to check the hourly pol % bagasse results and to decide which of the inputs to vary in order to compensate for a change in performance.

Depending on the engineer’s expertise and responsiveness, the problem may be resolved rapidly or not at all.

In order that extraction operations be optimised continuously, it is required to develop to develop a tool that will consider all available process information, analyse this data and provide insights on how the process can be better controlled in order to optimise extraction performance (or to automatically control the process to achieve the same result).

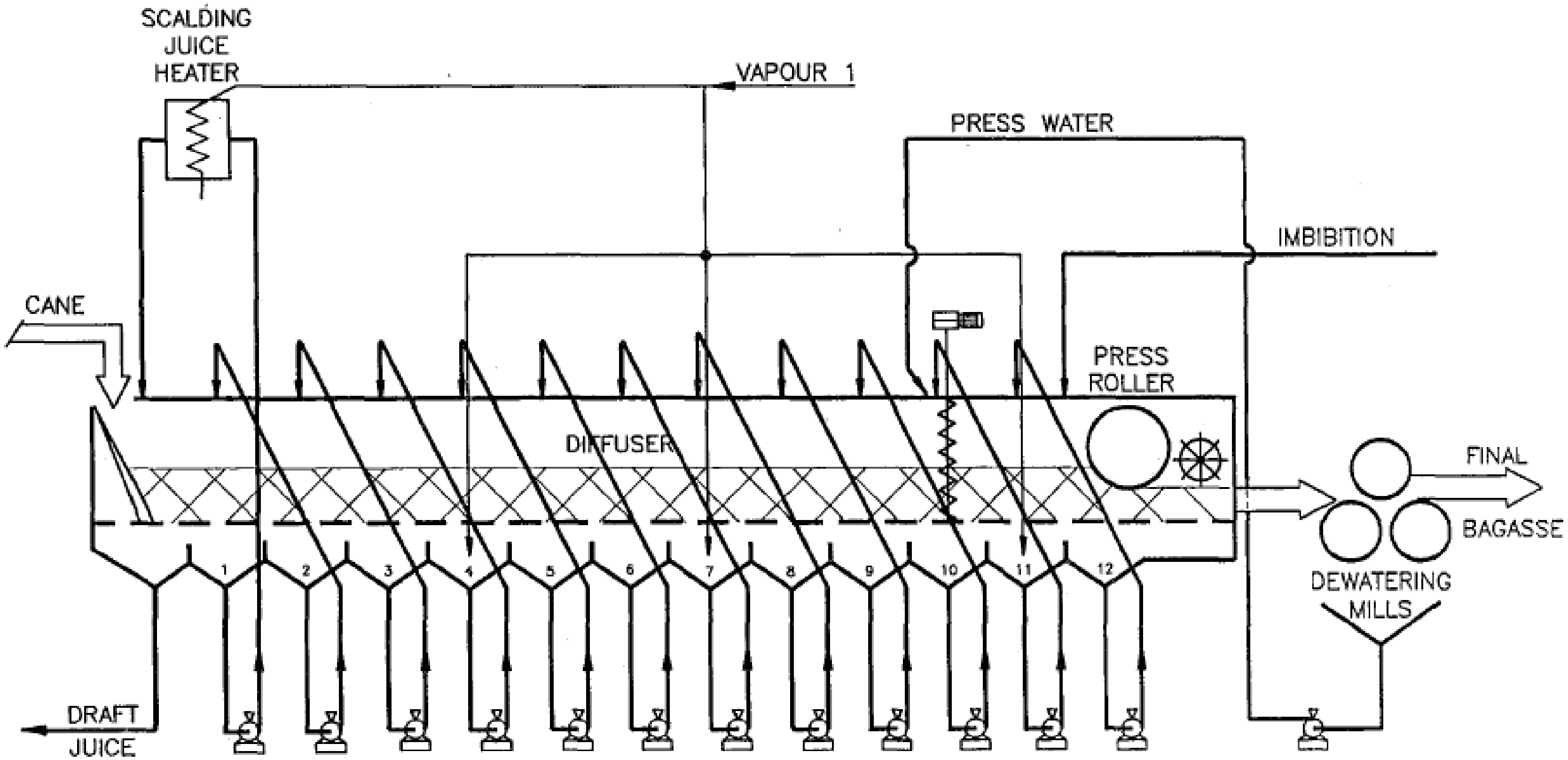

Figure 1 Schematic diagram of a counter current cane diffuser

INVERSION LOSSES / NON-SUCROSE TRACKING

Introduction

Sugar is made of molecules of sucrose ($C_{12} H_{22} O_{11}$). It is a disaccharide, which means it consists of two simple sugars, glucose and fructose (each $C_6 H_{12} O_6$). On their own, these simple sugars are of no use in a sugar factory. The two simple sugars can't be combined in a sugar factory to create sucrose; however, under certain conditions sucrose can be broken down into the mono-saccharides. This process is called "inversion". Should this happen, it represents a loss in sugar production.

Inversion is known to be likely in certain unit operations in a factory, since the necessary conditions are known to exist there. The extent of the inversion isn't measured, since the instruments to do so haven't been available before. However, on a weekly basis the factory mass balance indicates that some sucrose has disappeared, which is termed the "Undetermined Loss" (UDL). UDL is normally in the range of 1 – 2% of the sucrose in process. The minimisation of UDL is every process manager's aim, which they attempt to do through good practice and tight process control.

The conditions leading to sucrose inversion are a combination of high temperature, low pH, low brix and long time periods at these conditions.

In recent years, SMRI has developed the technology to use near infrared spectroscopy (NIRS) in sugar factories to measure fructose, glucose and sucrose (FGS) quickly and accurately (though not online).

<u>Note:</u> While the frequency and magnitude of changes in FGS in the front end of the factory (from cane preparation to evaporation) is fairly high (in the order of minutes), in the back of the factory, mixing and slower reaction times attenuate the variation, and the frequency of oscillations is much lower (in the order of hours).

Undetermined loss is not only associated with inversion. It can also be due to physical losses such and spillages and entrainment, and errors in measurement (such as weighing errors and inaccurate stocktaking) and theft.

Problem statement

Although the unit operations that contribute to UDL are known, management of these unit operations with the aim of reducing inversion isn't easily done. If the FGS composition of factory products and intermediate products was made available at a higher frequency than they have been historically, the management of these unit operations would be improved and UDL reduced. However, such data would need to be interpreted and linked with other process variables to correctly identify instances of high UDL and the conditions leading to such.

CENTRIFUGE MONITORING

Introduction

Sugar crystals are separated from molasses in centrifuges, leaving most of the impurities in the molasses. Although the sugar is washed with water and steam in the centrifuges, some molasses generally remains on the sugar. Any sugar not recovered in the centrifuges will end up in the molasses, which can eventually lead to the sugar being lost to production.

C-sugar is low-grade sugar that is re-processed to be eventually recovered as A sugar. It is separated from the final molasses in centrifuges. Any C sugar not separated will end up in final molasses and be lost to sugar production. Final molasses is the predominant area of sugar loss in a sugar factory, accounting for approximately 7% of the total sucrose delivered in sugarcane. It is thus vital to minimise the sugar lost to final molasses.

Problem statement

Final molasses is sampled hourly and analysed in the factory laboratory. Additionally, the sample that is analysed is a composite sample from multiple centrifuges. The results become available long after the molasses has been produced. It is possible for a single centrifuge to perform poorly (thus losing sugar) and for this condition to remain undetected for days, since the indication may not be immediately evident from the laboratory analyses. If molasses quality data were made available in a less aggregated and more frequent form, and combined with other measurable process indicators such as centrifuge vibration, motor speed, valve positions and process time constants, it may be possible to identify and rectify high cost conditions early. Alternatively, molasses quality data may be used offline to identify patterns within existing data that correspond to high cost conditions. Ultimately, the problem may be addressed by more rapid and precise indication of sucrose loss conditions than can be achieved with current practices.

BOILER OPERATION

Introduction

Steam boilers are used in sugar factories to produce the steam needed for power and heating in processing operations. Their fuel is bagasse (fibrous residue from the sugarcane), and for a raw sugar factory the supply of bagasse is sufficient for all of its energy needs. In sugar factories with an annexed refinery, ethanol plant or electricity co-generation, the bagasse must be supplemented with coal, at great financial cost, to satisfy the additional energy demand.

The efficiency of a boiler is a measure of the quantity of steam produced per quantity of fuel used. Boiler efficiency is thus a massive determinant of the required boiler fuel (including coal) consumption. The efficiency of a boiler is determined by many factors, including:

- Fuel moisture content
- Excess air for combustion
- Fuel ash heat losses
- Losses in unburned fuel
- Fouling of heat transfer surfaces
- Heat losses in flue (exhaust) gases
- Heat losses in blowdown steam and steam leaks

However, many of these could not be measured online historically or while the boiler is in operation, making it difficult to manage boiler efficiency in real time.

The currently controllable parameters of a boiler that affect boiler efficiency are:

- Flue gas volume flow
- Forced draft air volume flow
- Secondary air volume and distribution (limited control)
- Grate speed
- Fuel mass flow rate
- Steam blowdown rate

Problem statement

Many of the factors directly affecting boiler efficiency cannot be easily measured. However, if a model of a “theoretical” boiler could be constructed to indicates to boiler engineers what the optimal parameters should be at any point in time, should the boiler parameters vary from these, the engineer/operator may be guided as how to adjust the boiler, or where to look for causes of inefficiencies.

THROUGHPUT CONTROL

Introduction

A sugarcane processing facility consists of a sequence of continuous and batch operations separated by tanks with a limited amount of capacity for buffering differences in upstream supply and downstream demand. The stages are:

1) Cane receiving: Sugarcane arrives on trucks or by rail at factories, is weighed in and then awaits instruction to offload. Stock can be kept “on wheels” in the cane trucks or rail tracks to provide volume buffering. Some factories have a cane yard where cane is offloaded and stored temporarily when the cane supply exceeds crushing capacity or to provide a stockpile for periods where cane supply will be below crushing capacity.
2) Cane preparation and extraction: Sugarcane is chopped and shredded and then fed into one of two extractions systems. (1) In a milling tandem, cane is fed directly into a series of mills which squeeze juice out of the cane. (2) In a diffuser, sugar is extracted via counter-current leaching. The juice exiting the extraction system goes into a tank, the mixed juice tank, and the residual fibre, the bagasse, is sent to storage or directly to the boiler house as boiler fuel. The mixed juice tank and bagasse store are primary volume buffering facilities. In a diffuser factory, the diffuser may have variable capacity, either by changing the speed at which cane is passed through the system or by varying the bed height in the diffuser, and thereby allowing a semi-independent cane throughput in this section. In addition, there is some juice capacity in troughs below the various stages of the diffuser. There is very limited volume buffering capacity in a milling tandem, although factories may bypass the last mill in the series at very low cane throughput.
3) Juice preparation: Mixed juice is heated, flashed and then clarified in a clarifier to remove suspended solids. The clarified juice, clear juice is fed to a clear juice tank. The clear juice tank provides some volume buffering capacity.
4) Juice concentration: Clear juice is evaporated to syrup in an evaporator train and fed to a syrup tank. The syrup tank provides some volume buffering capacity.
5) Syrup is fed to the pan floor where it passes through three stages of crystallisation, with recycles, to recover high purity crystal sucrose. There are a number of molasses tanks, seed product tanks, blow-up tanks, receivers and transfer tanks, with a different configuration in each factory. There are some batch processes on the pan floor in each factory, for example batch pans and batch centrifuges. There may be very widely varying amounts of pan floor storage capacity between factories. Depending on the factory configuration, product sugar and molasses streams may be sent to different downstream processes such as drying and packaging of brown sugar or remelting and refining to white sugar. Depending on the downstream processing, there may be different amounts and different types of volume buffering capacity for sugar, intermediate and molasses products.

Problem statement

In some factories, the factory sections are managed by different people (e.g. front end and back end managers), with overall process management at arms' length. In some instances, the performance targets of the different managers are in conflict. When the difference in processing rates between two adjacent sections exceeds the buffering capacity between sections, processing bottlenecks form. For example, mixed juice, clear juice or syrup tanks may fill up, causing the cane crush rate to be suddenly reduced. Similarly, low tank levels may result in slowing of later processes, or even making up of process streams with water. When the bottleneck is in the pan floor, either the entire factory must slow down, or the back end manager must compromise sucrose recovery (and therefore product and profit) to allow the front end to maintain crush rate.

Variations in crush rate and in processing rate in the various factory sections have associated costs. These are both hard costs (e.g. increased fuel bill) and soft costs, such as increased proportion of fixed expenses to operating expenses and reduced product per tonne feedstock. Stoppages in the front end may also result in sucrose loss through microbial and chemical deterioration. There is significant potential to mitigate these costs by anticipating and mitigating processing bottlenecks by proactive tank level management, and early warning of conditions likely to result in processing bottlenecks.

STEAM DEMAND MANAGEMENT

Introduction:

Sugarcane processing factories are typically designed to be energy self-sufficient. The fibrous residue from extraction of sucrose from sugarcane, bagasse, is used as boiler fuel to raise high pressure (HP) steam. HP steam drives turbo-alternators (TAs) for power generation and back pressure steam turbines for driving cane preparation and extraction equipment. The collected exhaust from TAs and back pressure turbines is cooled using water (desuperheated) and used to supply process heat. The process heat demand is designed to exceed the rate of exhaust generation from the various turbines. The difference is supplied by letting HP steam down to the exhaust range through a control valve, and then cooling it down (desuperheating). This system allows prime mover and power demand for steam to vary independently of process heat demand. The let-down station is controlled automatically to maintain the exhaust steam range pressure at a set point, and boilers are controlled to maintain the HP steam range pressure at a set point. The fuel consumption rate of the boilers is determined by the overall HP steam demand and the boiler efficiency. Of the three main categories of energy required in the factory, viz. electric power, power for driving front end equipment, and processing heating demand, the last is the largest.

The evaporator station is the heart of the sugar factory energy system. It is responsible for concentrating sugar juice by boiling off around 90% of the water in the sugar juice. Boiling occurs in four or five stages, with the vapour leaving each stage acting as the heating medium for the next stage. Some of the vapour produced is drawn off in bleed streams to supply process heat in other parts of the factory. The energy required to concentrate the juice, and the energy supplied as process heat to other parts of the factory are two of the largest energy demands in the factory. The performance and capacity of the evaporator station varies according to the degree of fouling of the heat transfer area and associated cleaning cycles.

Problem statement:

Although factories are typically designed to be energy self-sufficient, more than half of the South African sugar factories burn large amounts of coal. The high fuel bill may be attributed variously to aging equipment, factory expansions and modifications, diminishing expertise, and especially the existence of an annexed downstream processing facility, or an alternative market for bagasse. Even in the presence of reasonable justification for high energy consumption, most factories believe that their energy consumption is higher than strictly necessary to support their operations. The steam network is controlled using a supply management philosophy. However, the steam demand management has historically received little attention. Factories usually do not have much information to indicate where energy is being used. More information is available for HP supply and demand, while very little information is recorded for exhaust and lower grade steam consumption.

A further complication exists for energy monitoring: steam headers may have several inputs and outputs, such that there are few locations where flow meters can be installed to quantify steam flows. There is a very large number of process units that draw exhaust and lower grade vapours for process heating duties, making comprehensive instrumentation of these streams complex and expensive.

Although there is a large amount of instrumentation on evaporator stations, the traditional parameters used for control and to assess the state of fouling of the evaporators do not provide detailed information on the state of the evaporators. It may be possible to gain much more information for decision support and control if the total condition of the evaporator station was monitored as an integrated whole.

The challenge is therefore to develop a system that allows steam demand management by monitoring dynamic high pressure and exhaust steam demand.