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A COMPARISON OF CANE DIFFUSION AND MILLING

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Abstract

Extraction of sugar from cane by diffusion is compared with conventional milling, based on experience in Southern Africa gained over the last 25 years. The comparison focusses on moving bed cane diffusers, which have proved to be most cost-effective. The comparison covers differences in operation, control, microbiological losses and raw juice quality. Capital and maintenance cost comparisons show the major advantage of diffusion relative to milling.

Introduction

While extraction by milling has always been the conventional method of processing cane, extraction by diffusion is now an alternative option. It first became a feature of the South African cane sugar industry in the 1960's. The early diffuser installations were not without their difficulties, and the type of problems encountered, and the steps taken to solve them are comprehensively reported by van der Riet and Renton (1971). The first installations were bagasse diffusers, i.e. they were preceded by a mill.

Cane diffusion, i.e. extracting sugar from prepared cane in the absence of a first mill, was pioneered in Hawaii (Payne, 1968). Once South African mills had solved the major problems with bagasse diffusers, the step to cane diffusion was taken with the installation of the first South African cane diffuser at Amatikulu in 1974. Cane diffusion appeared to offer advantages over bagasse diffusion, and all subsequent installations in South Africa have been cane diffusers.

The adoption of cane diffusion has been steady in Southern Africa. Including Swaziland and Zimbabwe, diffusers constitute about 80% of all installed extraction capacity in Southern Africa. Installation of diffusers in other cane producing areas of the world has been much slower. However there now seems to be a renewed surge of interest in other parts of the world, and it is predicted that diffusion will increasingly be chosen ahead of milling.

Types of diffuser

Early installations favoured bagasse diffusers, since they represented a smaller step-change from milling, and are still required in countries where payment for cane is based on an analysis of first expressed juice. However cane diffusers have generally shown themselves to be considerably more cost-effective, and are almost exclusively favoured in preference to bagasse diffusers in new installations. This paper therefore concerns itself only with cane and not bagasse diffusers.

The types of cane diffuser which have been used can be categorised as follows:

- true counter-current diffusers (e.g. DDS, Saturne).
- moving bed diffusers (e.g. BMA, De Smet, Silver Ring, Huletts).
- other types (e.g. van Hengel, Rotocel).

Over time, the moving bed diffusers are proving to be the most successful. Most of the other types are being phased out, either because they are more complicated or because they are not able to handle large cane crushing rates economically.

Moving bed diffusers are counter-current extraction devices, but operate on a staged basis. Juice is pumped onto

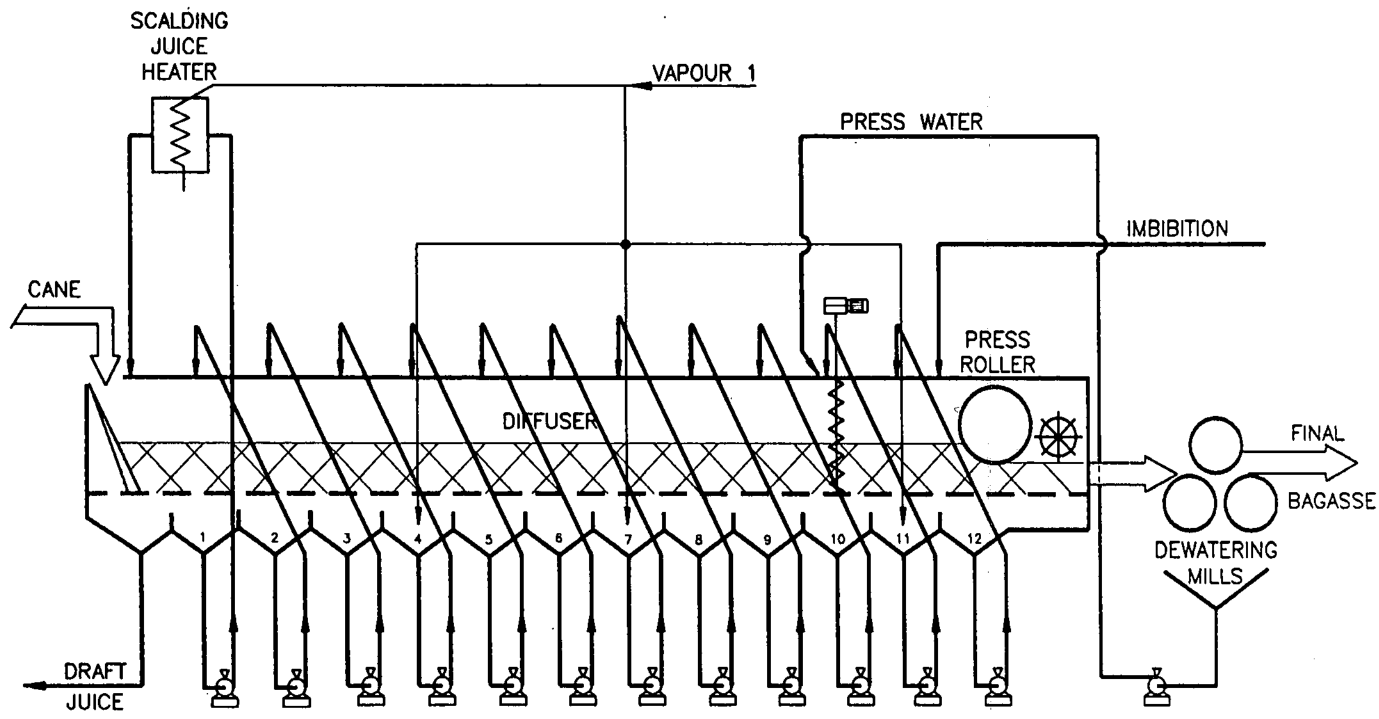

FIGURE 1 Schematic diagram of a cane diffuser.

a moving bed of prepared cane or bagasse, about 50 - 60 m long, in anything from 10 to 18 stages. A schematic diagram of a moving bed cane diffuser is shown in Figure 1.

The BMA and Huletts diffusers differ from the De Smet and Silver Ring in having a fixed screen, with a series of chains which transport the cane bed across the screen. This generally results in a cheaper diffuser for the same screen area.

A comparison of the moving screen and fixed screen diffusers leads to the following considerations:

- Chains dragging cane across the fixed screen generally result in the formation of a more compact cane layer at the screen, which affects percolation.
- The moving screen diffuser requires double the screen area, as half the screen is inoperative on the return strand.
- Fixed screen diffusers have a heavy press roller riding on the cane which leads to a lower moisture content of diffuser discharge bagasse.
- Because of reduced friction, the drive power required on a moving screen diffuser is generally lower, typically 30 kW for a 300 ton/hr diffuser compared to 100kW for a fixed screen diffuser. However most of the power used by diffusers is on stage juice pumps.
- Because moving screen diffusers cannot seal the top surface with a heavy press roller, discharge of cane from moving screen diffusers is by lifting screws (Silver Ring) or lifting drum (De Smet). Discharge from fixed screen diffusers is simpler, by gravity with a kicker to smooth out the flow.
- Perhaps because of the difficulty of sealing between the moving screen and the stationary side walls, moving screen diffusers lead to higher levels of suspended solids in juice (typically 0,6% compared with 0,1% on diffuser juice), requiring draft juice screens and a presswater clarifier.

In general then it can be said that the moving bed type diffuser has captured the cane diffusion market to the exclusion of other types of diffuser, due to their relatively low cost, simplicity of operation and ability to achieve very high extractions. For this reason the comparison with milling will be restricted to this type of cane diffuser.

Cane preparation

While good cane preparation assists in getting good milling results, it is even more important with diffusion. Cane preparation is the most important variable affecting extraction in diffusers. If high extractions are to be achieved it is essential that the cane is prepared in a heavy duty shredder so that most of the sugar containing cells of the cane stalk are ruptured. Laboratory and pilot plant work showed very clearly that more intensive preparation of cane makes more of the sucrose containing juice readily accessible to the extracting liquid, minimising the amount of sucrose which has to be extracted by a much slower diffusional mechanism (Rein 1971).

Not only is it important to rupture a large proportion of the juice containing cells, but the way in which the cane is prepared is also important. Ideally the type of preparation should result in material where all the cells are ruptured but where long fibres are still evident, which will result in a cane bed which is stable and open enough to allow high percolation rates to be achieved. In practice it has been found that this is best achieved in heavy duty shredders with a minimum of knifing, since intensive knifing reduces the average fibre length.

The measurement of the degree of cane preparation is difficult and existing measures are not always reliable. The most common measure used in South Africa is the Preparation Index (PI), which attempts to assess the degree of preparation by measuring how much of the sugar in cane is easily washed out of the prepared cane sample. This is a useful approach since it assesses the preparation in terms of how readily extractable the sugar is. Unfortunately it is not a reproducible measurement since it is affected by cane variety and the amount of extraneous matter in cane. In South Africa it is considered that a PI of at least 92 is required if an extraction of over 97% is to be achieved in a diffuser.

Payne (1968) in Hawaii suggested that a Displaceability Index of at least 94 is required in order to achieve an extraction of 97% or more.

In South Africa, the cane preparation methods and the power required are similar for both milling and diffusion. It has been found that power absorbed in a heavy duty shredder for good preparation in relation to cane crushing rate (tch) or fibre rate (tfh) lies in the range of 4,5 - 6 kW/tch or 30–40 kW/tfh (Marson 1980). Lamusse (1980) considers installed power of 70 kW/tfh to be adequate for good preparation, including knifing and shredding.

Effect on operations

Because of the long residence time of cane in the diffuser, start up and liquidation operations are rather more prolonged with a diffuser. It is common practice to fill all the stages of the diffuser with water before starting up so an adequate supply of water is necessary during the maintenance shutdown. Then there is a period of about an hour before bagasse gets through to the boilers. This means that an adequate bagasse store and system of reclaiming bagasse to the boilers is necessary.

Likewise on shutting down, liquidation of the diffuser takes a much longer time and the clarifiers generally have to handle a reducing brix juice during the liquidation.

In operation, diffusers are more flexible than mills in coping with a wider range of throughput rates. The diffuser speed can be run as slow as the drive will allow, i.e. the turndown is very good, and may be extended even further by changes in bed height. The maximum diffuser bed speed will be set by the ability of the dewatering mills to handle the quantity of diffuser bagasse.

If long stops are encountered due to mechanical breakdowns, it is generally advisable to empty the diffuser if the stop is to last more than about six hours. If this is not done, significant deterioration of the sugar in the diffuser can occur. This is not normally a concern with a milling tandem.

There is no maximum or minimum imbibition rate for diffusion. Since high imbibition rates will enable a smaller diffuser to be utilised to achieve a given extraction, the reduction in the cost of the diffuser would have to be balanced against the cost of additional evaporator capacity and the cost of steam. The optimum imbibition rate for any mill therefore is dependent on the local factors at that mill.

There is however a limit in a milling tandem. Very high imbibition rates are not possible as they jeopardise feeding of the mills and lead to high moisture in bagasse. Experience in South Africa has shown that very high imbibition rates of over 400% on fibre can be handled in diffusers, with consequent extraction benefits providing the interstage juice system is adjusted. Rein and Ingham (1992) give details of a system which will accommodate all levels of imbibition in diffusers, optimising extraction and eliminating flooding.

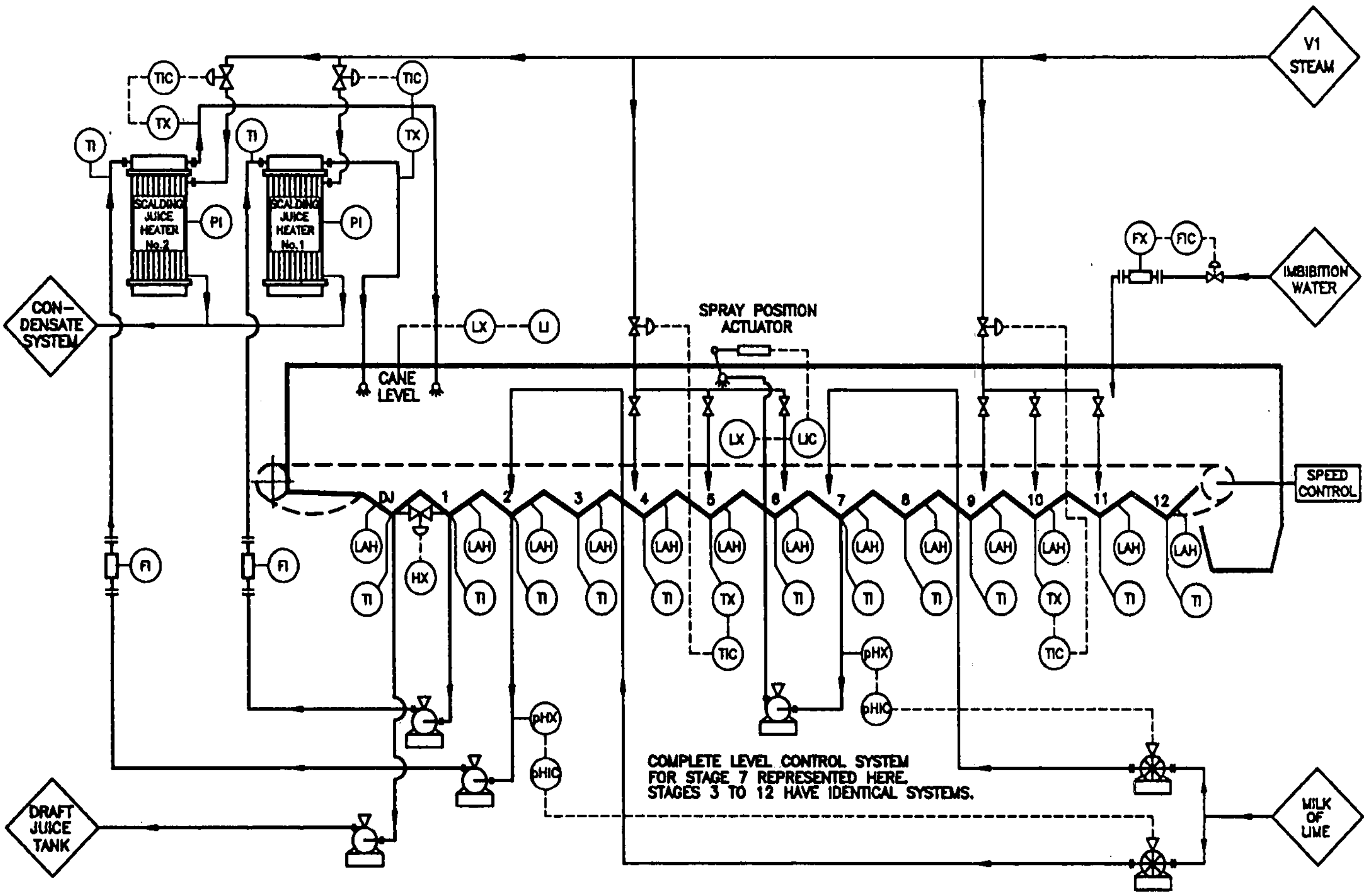

FIGURE 2 Typical instrumentation and process control on a diffuser.

Once in steady operation, a tandem of mills requires more routine supervision than a diffuser. The large pressures and forces involved in milling require that frequent attention be given to the mills, and periodic adjustments are necessary as wear of rollers, trash plates etc. occurs. A diffuser, particularly with an automatic spray position control system installed, requires virtually no supervision once running steadily.

Control of mills and diffusers

The feed to a milling tandem is generally regulated by the speed of the first mill. On the other hand, cane feed rate control to a diffuser is achieved by one of the following methods:

- adjusting the speed of feed rolls beneath a choked feed chute feeding into a shredder ahead of the diffuser.
- using a belt weigher, and adjusting the belt speed to give a constant mass flow.
- measuring the depth of cane on the belt conveyor feeding the diffuser, and controlling the speed of the belt to keep the product of conveyor speed and height constant.

Once the flow rate of cane is approximately constant, the diffuser bed speed is selected to give the required bed height. It is important to keep the diffuser running at a constant speed if good results are to be achieved.

Automatic control of a milling tandem generally involves regulating the speed of each mill to keep a constant level of cane in the feed chute, i.e. one control loop per mill. In addition monitoring and/or recording of hydraulic pressure, mill lift, and bearing temperatures are required.

Typical controls around a diffuser are shown in Figure 2. Temperature control loops are required on scalding juice heaters and direct injection heating, and generally two pH control loops are necessary for control of corrosion and inversion. Variable speed peristaltic pumps are the most consistently successful form of lime addition control device. Other variables requiring monitoring are bed level and stage juice temperatures.

Additional bed liquid level control loops to regulate percolation conditions may also be installed, if optimum performance is required (Rein and Ingham, 1992).

Effect on raw juice quality

The two most marked effects of diffusion on juice quality are higher colour in juice and a much clearer juice, i.e. with lower suspended solids. On average juice colours are about 25% higher than the juice from a milling tandem. This depends on the cleanliness of the cane and the diffuser temperature but can be a disadvantage when attempts are made to produce a low colour raw sugar or a mill white sugar.

An advantage of diffusion is the fact that the starch content of raw juice is much lower than juice from a milling tandem. The higher temperatures in a diffuser cause gelatinization of starch granules, which render the starch available to natural enzymes in the cane which eliminate starch (Boyes, 1960).

Comparison of juice quality at MS from the milling and diffuser tandems is given in Table 1. This shows clearly that suspended solid content of mixed juice is considerably lower from a diffuser, and that lactic acid, a good indicator of microbiological activity, is significantly lower in diffuser juice.

Table 1

Comparison of the quality of raw juice from diffusion and milling (average of 10 years data from Maidstone mill)

	Diffusion	Milling
Gas chromatography sucrose purity	84,1	84,9
Raw juice purity - cane purity	0,12	0,67
Pol/sucrose ratio	0,988	0,985
Suspended solids % juice	0,16	0,64
Lactic acid (ppm on brix)	270	560
Extraction (%)	97,7	97,2

Juice from the diffuser has a lower purity, but this may be partly due to the higher extraction.

Experience with different diffuser temperatures has confirmed that higher temperatures lead to higher juice colours. Measurements at AK showed that a reduction in temperature of about 10°C resulted in a drop of 25% in colour. Lionnet (1988), however, showed that a 10°C change in temperature changes the colour of juice by 10%, but this applies to hand-cleaned cane. The presence of tops and trash has a significant effect on the colour of diffuser juice.

Microbiological losses in mills and diffusers

Low brix raw juices degrade readily as a result of microorganism activity. At room temperatures a large range of organisms will ferment sugar juices. Perhaps the most evident micro-organism activity is shown by *Leuconostoc spp*, which are slime-forming bacteria. Such slime is commonly observed in milling tandems where insufficient attention is given to cleanliness of the mills.

In diffusers where temperatures are considerably higher, mesophilic organisms are rendered inactive, but hyperthermophiles can be active. These are generally lactic acid producing bacteria, and are active at temperatures up to 70°C. The pH range from 5 to 6.5 found in mills and diffusers does not have a significant effect on micro-organism activity.

Control of such losses in milling tandems involves keeping the mills as clean as possible at all times. Particularly where bagasse is allowed to accumulate, micro-organism activity can be very high. Ideally mills should be steamed at regular intervals, and on mill stops or shut-down, the mills should be properly cleaned down.

In diffusers, losses of sugar can be very high if temperatures are not kept well above 70°C. It is not considered feasible to operate diffusers at lower temperatures, as losses under these conditions can be severe. It is common practice to control diffusers at an average of about 85°C. This ensures that the temperature at no stage drops below 75°C, which is considered to be the minimum operating temperature. Sufficient heater capacity must be installed on scalding juice duty at the feed end of the diffuser, in order to achieve a bed temperature of at least 75°C within one stage. Scalding juice is circulated through the heaters at the feed end of the diffuser at a rate of about 300% on cane. Under these conditions, raw juice leaving the diffuser is at a temperature of about 65°C.

Measurement of microbiological losses

Measurement of microbiological losses in milling tandems has not received much attention, particularly as they are very difficult to measure. Even when extensive losses occur, no significant reduction in apparent juice purity is evident. This is partly due to the fact that dextran produced in large quantities by mesophiles is strongly dextro rotatory, artificially inflating the pol measurement. In general the extent of losses in milling tandems is unknown, since a means of measuring such losses routinely is not available.

In diffusers, the situation is different since the major degradation product of hyperthermophiles is lactic acid which can be routinely measured. In addition, significant cases of microbiological losses will be evident by an accompanying drop in juice purity.

Experiments in the laboratory have established an approximate conversion equivalence between lactic acid formed and sucrose lost (Mackrory *et al.*, 1984). Each part of lactic acid formed in a diffuser corresponds to two parts of sucrose loss. A different equivalence was found at temperatures corresponding to milling tandem operation; in this case, each part of lactic acid formed means a loss of about eight parts of sucrose. However this relationship is considered to be less reliable.

The routine measurement of lactic acid in juice is recommended as a control measure. Average values of 300 ppm lactic acid on brix represent a realistic target for both mills and diffusers. Data from MS in Table 1 show that the lactic acid content in mill raw juice can easily be twice that in diffuser juice. Based on the equivalence ratios between lactic acid and sucrose established by Mackrory *et al.* (1984), the loss in mills is about 16 times that in diffusers, and is close to 0,5%. They concluded that with good diffuser temperature control, microbial sucrose losses are significantly lower in diffusers than in milling tandems.

Effect on steam balance and power requirements

Additional heat is required in the diffusion system, generally obtained from either Vapour I or Vapour II bled from evaporators at an amount of about 11% on cane. The mixed juice leaving the diffuser is at a higher temperature and so roughly half of this heat is recovered, but the rest of the energy is lost in the final bagasse. The net effect after evaporation is to increase the total amount of steam required in a conventional sugar mill by about 3% on cane.

A disadvantage of diffusion is the fact that more of the sand coming in with the cane ends up in the final bagasse and less in the mixed juice. Typically for cane containing 2% ash, ash % bagasse from a milling tandem would be 3,3 by comparison with a figure of 4,0 from a cane diffuser (Lamusse 1984). The effect of this is to reduce the calorific value of the bagasse marginally, but a more severe disadvantage is the fact that additional sand in bagasse leads to considerable wear in boilers. The effect of this can be minimised by changes to the design of the boiler generating tube banks. On the other hand, less sand in draft juice leads to less mud and a lower loss in cake.

Diffusion is of considerable advantage to a factory which exports power and this aspect is likely to become increasingly important in future as power generation from renewable resources becomes more popular. Typically installed power values (excluding cane preparation) are 90 - 100 kW/tfh for a milling tandem and 45 - 50 kW/tfh for a diffusion plant, i.e. roughly half of the power required in milling. More comprehensive details are given elsewhere (Rein and Hoekstra, 1994).

Comparison of capital and operating costs

The extraction plant is generally a high cost item in the total sugar mill complex. In this respect the diffuser offers considerable advantage over conventional mills.

Comparisons should be made between a diffuser together with its dewatering mills compared with a full milling tandem. Lamusse (1984) has suggested that the ratio of capital costs of the diffusion to milling plant would be 1:1,5 and perhaps even 1:1,8 if a single mill only is used for dewatering after the diffuser. In-house figures derived by Tongaat-Hulett Sugar confirm the ratio of 1:1,5 where two dewatering mills are required and where an extraction of 96% is desired.

However once a higher extraction of 98% is required, the ratio of diffusion to milling plant capital costing changes to 1:1,65. Thus the capital cost advantage of diffusion increases as higher extractions are sought. These ratios are reduced if pressure feeders are required on the dewatering mills in order to achieve acceptable bagasse moistures, but are increased if a pressure feeder enables only one dewatering unit to be used.

One of the main advantages of diffusion is the significantly reduced maintenance requirements. Milling units are highly maintenance intensive. Extensive repairs and overhaul are required every off-crop. By contrast, annual maintenance required on diffusers is minimal, involving checking and inspecting screen condition, chain and chain runner wear, and bed disturbance screw flight repair.

Lamusse (1984) has estimated that the maintenance costs of a milling tandem are 70 to 80% higher than those on an equivalent diffusion extraction system. This is confirmed by Anderson and Smith (1981). This comparison takes into account the fact that a diffuser chain either has to be replaced or have new pins and bushes installed periodically, between 5 and 20 years, depending on the design of chain.

Analysis of stores costs over the last five seasons, for the diffuser and mill extraction lines at MS, including cane preparation, shows in-season, off-crop and total stores costs for the diffuser line to be 71%, 48% and 64% respectively of those for the milling line. If the cane handling and preparation costs were to be removed, the estimates of Lamusse and Anderson and Smith above would probably be substantiated.

It is also possible to run a diffuser with less supervision and fewer operators than a milling tandem. A change from milling to diffusion at MS resulted in a drop in number of operators from 5 to 2 per shift. Offcrop maintenance labour requirements for a milling tandem are halved by the installation of a diffuser.

Expansion of mill and diffuser capacity

Most diffusers in South Africa have been installed as a result of a required increase in crushing capacity. Small increases in capacity can be obtained from a milling tandem by fitting pressure feeders or by replacing critical milling units, say the first and the last mill with larger units, but the increase obtainable by this means is limited. A cost-effective method of expansion involves installing a diffuser and utilising some of the existing milling units as dewatering mills for a diffuser. Rivalland (1984) has confirmed the effectiveness of this approach from a capital cost point of view.

Once the diffuser is installed and further expansion is required, the installation of a complete additional diffuser can be expensive. Alternatively, a reduction in extraction as a result of reduced cane residence time is an option. However if it is envisaged that an expansion will be required at the time that a new diffuser is being installed, it is probably wise to pre-invest in incorporating headshaft and chain designs which can operate with an expanded diffuser. It is relatively cheap to increase the length of a diffuser to obtain additional capacity in this way.

Conclusions

A comparison of milling and diffusion shows the major advantages of diffusion to be lower capital and operating costs, and the ability to achieve a very high sucrose extraction. Pre-requisites are an adequate preparation, achieved through a heavy duty shredder, and steady operation incorporating adequate temperature control.

Disadvantages of diffusion are higher levels of sand in bagasse and colour in juice, and longer start-up and shutdown procedures because of the larger cane holdup in the system. The advantages of cane diffusion have led to a marked swing to extraction by cane diffusion in the Southern African cane sugar mills.

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