REFEREED PAPER

THE RETURN OF BAGASSE DIFFUSERS

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Abstract

The introduction of diffusers into the modern cane sugar industry occurred during the 1960s, and the first diffusers in South Africa were installed in 1968. These early diffusers were all bagasse diffusers, meaning that they processed bagasse that had been crushed in at least one mill. Ultimately, before the adoption of cane diffusion, a conventional bagasse diffuser installation was preceded by only one mill. Cane diffusion became the acceptable technology in the South African industry and in most other cane industries from the late 1970s. Almost 40 years later, bagasse diffusers are again being installed in both brownfields and greenfields projects.

This paper reviews the performance of early bagasse diffusers in South Africa and elsewhere. It also explains the reasons for cane diffusion becoming more acceptable and finally explores the reasons for the modern trend back to bagasse diffusion. It questions whether bagasse diffusion has a future in the southern African industry. Finally it considers modern case studies and discusses the design features of a modern bagasse diffuser.

Keywords: extraction, bagasse diffuser

Introduction

The first reported diffuser installation in South Africa was a Raabe diffuser at Tinley Manor factory, supplied by Duncan Stewart of Glasgow in 1927(Buck, 1965). Other than this, the current shift to diffuser technology in southern Africa started in 1966/67 when diffusers were commissioned at Nchalo (Malawi), Dalton and Entumeni (Buchanan, 1967). These were bagasse diffusers, as were those that followed until the first cane diffuser was installed at the new Amatikulu mill in 1974 (Lamusse, 1975). Frequent justification for the installation of bagasse diffusers was the savings to be gained in the costs of maintenance when compared with mills rather than extraction benefits (Fitzgerald and Lamusse, 1974).

Bagasse diffusers in South Africa

Details of the installations (Allan, 1973) and records of the performance of early bagasse diffusers can be found in South African Sugar Technologists' Association (SASTA) proceedings (Buchanan, 1967), and the performance of four early diffusers have been compared. These four installations are Malelane (De Smet), Empangeni (BMA), Entumeni (De Smet) and Union Co-Op (BMA). These results for the seasons 1969 to 1974 are presented in Table 1, and some parameters are derived (e.g. diffuser screen area and specific screen area).

Table 1. Performance of four bagasse diffusers in southern Africa from 1969 to 1974.

Malelane						
Calculated diffuser area (m²)	159.1					
	1969	**1970**	**1971**	**1972**	**1973**	**1974**
Pol % cane	13.11	14.02	13.59	13.68	12.72	13.32
Fibre % cane	13.64	14.25	14.42	14.79	14.67	14.82
Imb % fibre	288	293	289	286	303	303
Extraction (%)	94.86	95.67	95.6	94.57	95.69	95.14
Whole reduced extraction (%)	94.99					
Pol % bagasse	2.09	1.84	1.78	2.13	1.71	1.95
Moisture % bagasse	54.56	54.06	54.41	54.19	54.01	54.37
Pol lost in bagasse (%)	5.15	4.33	4.4	5.43	4.31	4.86
Corrected reduced extraction (Calc)	**94.0**	**95.0**	**95.1**	**94.1**	**95.5**	**94.8**
Throughput (tch)	195.0	196.6	222.2	224.0	217.0	209.6
kgf/m²/h	176.0					
Specific screen area (m²/tfh)	**5.99**	**5.68**	**4.97**	**4.80**	**5.00**	**5.12**
Preparation Index	85					
Empangeni						
Calculated diffuser area (m²)	184.8					
	1969	**1970**	**1971**	**1972**	**1973**	**1974**
Pol % cane	12.93	13.7	12.56	12.88	12.89	13.11
Fibre % cane	18.04	18.45	17.07	16.13	17.05	16.73
Imb % fibre	285	299	290	284	299	304
Extraction (%)	94.28	95.23	95.71	96.24	95.97	96.02
Whole reduced extraction (%)	95.81					
Pol % bagasse	2.09	1.53	1.39	1.34	1.37	1.4
Moisture % bagasse	54.32	54.67	53.92	53.12	53.92	53.76
Pol lost in bagasse(%)	5.72	4.77	4.29	3.76	4.03	3.98
Corrected reduced extraction (Calc)	**95.2**	**96.0**	**96.3**	**96.4**	**96.4**	**96.3**
Throughput (tch)	189.0	180.3	198	203	210	196.9
kgf/m²/h	180.0					
Specific screen area (m²/tfh)	**5.42**	**5.56**	**5.47**	**5.64**	**5.16**	**5.61**
Preparation Index	85					
Entumeni						
Calculated diffuser area (m²)	63.9					
	1969	**1970**	**1971**	**1972**	**1973**	**1974**
Pol % cane	13.04	14.56	12.84	13.89	13.45	13.5
Fibre % cane	13.16	13.63	13.53	13.94	14.6	14.55
Imb % fibre	300	320	333	312	311	281
Extraction (%)	96.04	97.04	97.56	97.02	97.11	96.55
Whole reduced extraction (%)	96.01					
Pol % bagasse	1.6	1.32	1.05	1.33	1.2	1.45
Moisture % bagasse	56.75	56.04	53.13	52.85	54.31	54.42

Pol lost in bagasse (%)	3.96	2.96	2.44	2.98	2.89	3.45
Corrected reduced extraction (Calc)	**95.2**	**96.3**	**97.2**	**96.5**	**96.8**	**96.2**
Throughput (tch)	49.7	48.3	47.3	48	43.6	45.05
kgf/m²/h	103.0					
Specific screen area (m²/tfh)	**9.77**	**9.71**	**9.99**	**9.55**	**10.04**	**9.75**
Preparation Index	64					
UCL						
Calculated diffuser area (m²)	48.1					
	1969	**1970**	**1971**	**1972**	**1973**	**1974**
Pol % cane	12.3	13.48	12.18	13.01	12.2	12.18
Fibre % cane	15.01	14.63	13.92	13.36	14.01	13.23
Imb % fibre	235	240	227	228	170	186
Extraction (%)	97.91	97.57	97.81	96.92	95.76	95.32
Whole reduced extraction (%)	98.2					
Pol % bagasse	0.85	1.09	0.99	1.4	1.82	2.08
Moisture % bagasse	49.35	49.68	49.04	50.41	49.76	51.86
Pol lost in bagasse (%)	2.1	2.43	2.19	3.08	4.24	4.68
Corrected reduced extraction (Calc)	**97.9**	**97.3**	**97.6**	**96.3**	**95.4**	**94.6**
Throughput (tch)	52.3	51.6	55.3	59.6	63.7	65.7
kgf/m²/h	157					
Specific screen area (m²/tfh)	**6.13**	**6.37**	**6.25**	**6.04**	**5.39**	**5.53**
Preparation Index	75					

It is immediately evident that the extraction performance of these bagasse diffusers was reasonably good when compared with milling performance of the day (Lamusse, 1973). When considered on the basis of corrected reduced extraction (CRE), their averages over the period were as per Table 2.

Table 2. Average Corrected Reduced Extraction for the period 1969 to 1974.

Factory	Corr. Reduced Extraction	Imbibition % fibre
Malelane	94.7	294
Empangeni	96.1	294
Entumeni	96.4	310
UCL	96.5	214

The cane preparation plant installed in each factory is represented in Table 3 below (Fitzgerald and Lamusse, 1974).

Table 3.Cane preparation equipment in use at four bagasse diffuser plants.

Factory	Cane Knives	Shredder
Malelane	1 co-current, 1 counter current	No
Empangeni	2 counter current	No
Entumeni	2 co-current	Yes
UCL	1 counter current, 1 co-current	No

It is a well-recorded fact that a lot of thought and effort went into the management of flooding in these diffusers, since this factor is frequently mentioned in the SASTA proceedings. In fact, at the Empangeni factory, the shredder was removed from service in 1968 in order to reduce flooding in the diffuser. This was before bagasse lifting screws had been invented and installed to overcome this same problem.

Bagasse diffusers in Australia

The proceedings of the Australian Society of Sugar Cane Technologists (ASSCT) provide some information about the performance of bagasse diffusers in that country. A diffuser was installed at Fairymead in 1965 as part of a 5-mill tandem (McGinn*et al.*, 1981)) and in 1976 another diffuser was installed at Inkerman in Queensland (Kelley and Porter, 1978). The Inkerman extraction system consisted of a shredder (1829 mm); No. 1 mill (2134 mm); BMA diffuser (5.9 m wide); No. 2 mill (1829 mm); and No. 3 mill (1829 mm). During its second season in 1997, reduced extraction of 97.7% at 214 tch was achieved using 241% imbibition on fibre.

Andersen and Smith (1981) reported that flooding was a constant concern and that 50% of the juice in the diffuser passed from stage to stage underneath the bed. They also reported that the cane preparation (POC) increased by almost seven units over the first mill, which may provide some insight into the causes of flooding.

Results from other bagasse diffusers

The results from a bagasse diffuser factory in the Indian Ocean islands during the period 1992 to 2000 is presented in Table 4.

Table 4.Performance of a bagasse diffuser at a factory in the Indian Ocean islands.

Parameter	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**	**2000**
Tons cane per hour	256.2	256.1	288.9	302.8	328.6	335	321	336	324
Fibre % cane	16.93	16.78	17.2	17.38	15.95	15.3	15.6	15.1	15
Pol%cane	13.29	12.18	11.83	11.78	12.66	12	12	12.7	12.5
Imbibition % fibre	350	312	283	240	279	310	348	302	326
Pol % bagasse	0.79	0.88	0.9	1.13	1.17	0.75	0.97	0.95	0.96
Extraction	97.96	97.66	97.52	96.88	97.15	98.1	97.5	97.9	97.8
Screen area	420	420	420	420	420	420	420	420	420
Corrected reduced extraction	**98.1**	**98.0**	**97.9**	**97.4**	**97.3**	**98.2**	**97.6**	**97.9**	**97.8**
m^2/tfh	9.7	9.8	8.5	8.0	8.0	8.2	8.4	8.3	8.6
Bagasse moisture	50.39	48.42	48.44	46.53	49.53	49	49.3	46.8	49
Preparationindex	91.9	90.1	90.6	92	N/A	N/A	N/A	N/A	N/A

This bagasse diffuser is reported to operate with no particular problems. Its cane preparation system consists of a whole stick shredder and the first mill is a modern two-roller mill.

Another bagasse diffuser, at the Meridiano factory in Brazil, is a chainless diffuser that was originally installed as a cane diffuser. In 2013, a 100” mill was installed upstream of the diffuser to increase its capacity to 20 000 tcd. The cane preparation system at this installation consists of a whole stick shredder and the first mill is a conventional four-roller mill.

Unfortunately the lack of access to performance data from this factory makes an analysis impossible.

The progression from bagasse diffusion to cane diffusion

The development of bagasse diffusers originated with attempts to find a more cost effective alternative to milling.

Early continuous diffusers were simply ‘maceration carriers’ that were installed between mills. Such systems called the ‘Nobel’ maceration systems were installed in Queensland prior to 1950 (Foster and Shann, 1971). When the industry increased its capacity, these Nobel diffusers made way for additional mills and extraction rates actually reduced. In 1965 a Burnett diffuser, a development on the above system, was installed between mills 2 and 3 at Fairymead.

Interestingly, factories in Hawaii, where the first diffuser was installed at Pioneer in 1967, immediately adopted cane diffusion with excellent results (Idehara, 1995).

Fitzgerald and Lamusse (1974) noted that the preference for diffusion in South Africa was due to the “higher capital and maintenance costs of mills to achieve the same extraction.” They reported that the extraction from a bagasse diffuser unit was equivalent to the extraction obtained by three mills, and that the relative costs (in 1973) for equipment were:

Bagasse diffuser:	R500 000
Cane diffuser:	R570 000
Mill with drive:	R400 000.

Thus the capital cost of cane diffusion would be 57% and bagasse diffusion 71% of a six mill tandem installation. Maintenance costs were also reported for a diffuser, being around one third of that of a single mill. The comparison at Inkerman was that the diffuser maintenance cost was 12.5% of that of the entire extraction system (Andersen and Smith, 1981).

The feasibility of installing cane diffusers in South Africa was initially hampered by the First Expressed Juice cane payment system. Once this was overcome, the first cane diffuser was installed at Amatikulu in 1974 and all future diffuser installations were cane diffusers. The problem of flooding seemed not to have been significant since the early cane diffusers, despite the introduction of heavy duty shredders and very high preparation index (PI).

So the change from bagasse to cane diffusers in South Africa can be said to have been promoted by the lower investment and operating costs associated with having less mills in the extraction system.

The comparable situation in 2014

An attempt is made here to compare the economics of bagasse and cane diffusion, from a capital investment perspective. Since no information on maintenance costs was available to the authors, this aspect is not discussed.

Bosch Projects has a data base of capital costs from projects in a number of cane sugar industries. Some select mill and diffuser equipment costs (at the time of the project) are presented in Table 5.

Table 5.Investment cost for various diffuser projects in 2014 terms.

Country	**Diffuser type**	**Capacity (tch)**	**Equivalent in Rands (2014)**	**Comment**
Brazil	Cane	500	R96 600 000	Installed, excl civils
Southern Africa	Cane	350	R83 000 000	Installed, excl civils
Thailand	Bagasse	833	R92 600 000	Installed, incl civils

When accounting for price escalation, it may be generalised that cane diffuser investment costs are between R250 000 and R280 000 per tch and for a bagasse diffuser, R116 000. However, considering the low cost of manufacture in Thailand, the comparable figure (for the South African context) is probably R193 000 per tch for a bagasse diffuser. (The bagasse diffuser on which this price is based has a low aspect ratio, which reduces the construction cost by about 3% in comparison to a more conventionally designed diffuser.)

Typical prices for mills are presented in Table 6. These prices include delivery and exclude installation, and have been adjusted for price escalation and equivalency of scope, being mills with four rollers; Donnelly chutes; rope coupling; electric drive; lubrication system; and hydraulic system (unless otherwise noted).

Table 6. Investment cost for various mill projects in 2014 terms.

Country of supplier	**Mill type**	**Size**	**Equivalent in Rands (2014)**	**Comment**
Brazil	4 rollers	90”	R26 000 000	Ex-works
Southern Africa	4 rollers	84”	R26 562 000	
Europe	4 rollers	90”	R27 400 000	
India	4 rollers	90”	R24 000 000	
China	6 rollers	2400 mm	R21 500 000	

It may be generalised that the cost of a mill for a 500 tch capacity tandem will be approximately R25 000 000. On this basis, the equivalent 2014 calculations to Fitzgerald and Lamusse’s 1973 exercise have the following results:

Bagasse diffuser:	R96 500 000
Cane Diffuser:	R125 000 000 to R140 000 000
*Mill with drive:	R25 000 000

(*Care must be taken if this figure is to be used for price comparisons between milling and diffusion. This price does not include the cost component for an inter-carrier, juice tank and pump, piping and mill foundation. The mill foundation in particular is very costly.)

Using this data, the costs of a 500 tch extraction plant may be estimated:

Bagasse diffuser with three fourroller mills:	R171 500 000
Cane diffuser with two fourroller mills:	R175 000 000 to R190 000 000

It would appear that the biggest change (other than expected price escalation) since the research published in 1973 is the reduced relative cost of mills. It further appears that the economic viability of bagasse diffusion (from an investment perspective) is justifiable.

Energy consumption

It is unfortunate that, with a number of bagasse diffuser installations available for observation, the authors do not have reliable information regarding power consumption measurements. However, general information is available from a number of sources and is summarised in Table 7.

Table 7. Typical absorbed power for mills, cane diffusers and bagasse diffusers.

Extraction type	Specific power consumed	Units
Mill*	12	kWh/tf
Cane diffuser**	1.9 – 2.5	kWh/tc
Bagasse diffuser**	1.5	kWh/tc

*Rein (2007)
**Bosch Projects design information

This implies that the electrical power consumed in a 500 tch extraction plant should be as follows:

Cane diffuser with two dewatering mills:	2 745 kW
Bagasse diffuser with one primary and two dewatering mills:	3 180 kW

A comparison between the steam demand in a cane and bagasse diffuser is also possible. Assuming V2 heating steam of 115 kPa, the mass of steam demanded in a cane diffuser is approximately 9-10% of cane mass; and in a bagasse diffuser (in which the entering fibre has less liquid content) the steam demand is approximately 3.5% on cane.

Thus, it appears that a bagasse diffusion extraction system absorbs at least 16% more power (even more if the required additional carriers and conveyors are considered), whilst it demands about 6% less process steam.

Considerations when converting from cane to bagasse diffusion

Recently, diffuser factories that want to increase their sugar production are beginning to consider the installation of a mill prior to their cane diffusers, thus converting to bagasse diffusion. Since a bagasse diffuser is normally about 40% smaller than a cane diffuser of equivalent capacity, the extraction system capacity can be increased by 40% by adding a pre-extraction mill (as long as the bagasse dewatering mills can also process the increased quantity of bagasse). This has been done at a number of factories in Mauritius and Reunion and has also been done at UsinaMeridiano in Brazil, and is being considered in some factories in southern Africa.

When a diffuser is converted in this way, a number of factors must be considered. Firstly, to process the higher rate of cane, the diffuser must work at a greater speed. This might necessitate a drive gearbox with a different gear ratio and also greater installed drive power. The increased wear rates of the diffuser chain must also be considered and so too the load on the diffuser head shaft. Secondly, the capacity of the infeed distributor carrier must be increased to transport the higher rate of cane supply. Thirdly, because of the higher diffuser speed, the point of application of stage juice in the diffuser must be recalculated to ensure that no diffuser flooding will occur. Diffuser pump capacity must also be evaluated for the revised capacity.

Cane preparation must be carefully considered. In a bagasse diffuser, the well-prepared cane from the shredder becomes more finely prepared in the first mill and can become so fine that it restricts the percolation of juice in the diffuser (especially at high levels of ash in cane). If the work in the shredder is reduced to solve this problem, first mill extraction (and capacity) will reduce and more extraction work will be needed in the diffuser. Some shredders are more appropriate for a bagasse diffuser than others (Voigt and Bellam, 2013) and any sugar factory considering a conversion of their cane diffuser to a bagasse diffuser must consider this aspect carefully.

Adding a pre-extraction mill has some disadvantages. The extra mill adds to the cost of maintenance of the factory and also adds to the factory power consumption, which reduces the amount of energy that may be exported.

The modern bagasse diffuser

With the modern international trend toward diffusion due largely to the energy benefits that diffusion offers over milling, new installations have been carried out over the past five years in Brazil, Bolivia, India, Vietnam, Ethiopia, Zambia, Mozambique, Swaziland and more recently in Thailand. In Thailand, cane payment is still calculated according to the analysis of first expressed juice, so the presence of a first mill in the extraction system is mandatory. A bagasse diffuser was installed at Mitr Phol Group's MitrKalasin factory in 2012, and Bosch Projects designed a chainless diffuser for Khon Kaen Sugar (KKS) in 2013.

Different design parameters than for a cane diffuser must be considered. The early bagasse diffusers in South Africa were reported (Fitzgerald and Lamusse, 1974) to have a fibre loading/unit screen area of 0.18 tfh/m^2, equating to a specific screen area (ssa) of 5.5 m^2/tfh. Entumeni diffuser had a ssa in operation of almost 10, while the designed ssa for the Inkerman diffuser was 8.7 m^2/tfh. The bagasse diffuser operating in the Indian Ocean islands mentioned previously works with ssa of greater than 8.0 and achieves CRE of greater than 97.5. For a cane diffuser design, the ssa parameter is generally between 10.5 and 12. For the bagasse diffuser at KKS, Bosch Projects selected assa of 6.9 m^2/tfh.

The other parameter to be considered (possibly more importantly) is the bagasse retention period, which is a factor of cane throughput, diffuser length, bed height and bed speed. For a cane diffuser, 70-85 minutes was considered by Bosch Projects as being suitable, whereas evidence is that bagasse diffusers had a retention period of 36-44 minutes (Anon, 1999). For KKS, Bosch Projects selected a retention period of 40.6 minutes.

Also related to both parameters already mentioned, the aspect ratio (i.e. length/width) must be considered. The aspect ratio for other installations is given in Table 8.

Table 8.The ratio of length/width for a number of bagasse diffusers.

Diffuser	Length (m)	Width (m)	Aspect ratio (m/m)
Malelane	33.2	7.0	4.7
Empangeni	35.4	4.8	7.4
Entumeni	73.6	2.5	29.6
UCL	28.5	2.2	12.9
Inkerman	46.75	5.9	7.9

For the same diffuser floor area, a smaller aspect ratio means a shorter diffuser and lower bed speed (given equivalent retention period). Presumably this leads to reduced power consumption and chain wear. The aspect ratio also plays a part in percolation rate calculation, which is a very important design consideration to reduce the possibility of flooding.

The percolation rate for a bagasse bed is defined as juice flow rate (m^3/min) divided by bed area (m^2) and has units of m^3/m^2.min. It describes the quantity of juice that can percolate through unit area of bagasse. In texts (17), this parameter is given 0.15-0.3 m^3/m^2.min.

For a given number of stages, a wider diffuser creates a larger area of bagasse through which the juice can percolate, whereas a narrow diffuser concentrates the juice in a smaller percolation area. It is thus considered beneficial for a bagasse diffuser to have a low aspect ratio (i.e. a shorter but wider diffuser). This characteristic can be explained by way of an example.

Assuming that the stage juice sprays throw their juice a certain distance onto the bagasse bed, the area onto which the juice lands can be calculated. Typically, the juice lands in the region from zero to two metres from the juice spray position, so in a 12 m wide diffuser, the percolation area is (2 x 12) = 24 m^2. In a 15 m wide diffuser, the juice still lands in the region of zero to two metres from the spray position, so the percolation area increases to (2 x 15) = 30 m^2. Hence the same quantity of stage juice has a 25% greater area through which to percolate.

Given the reported tendency in bagasse diffusers for flooding, attention should also be paid to the factors that may cause this. These include the fineness of prepared cane, sand and other impurities in the cane, and the solids in press water.

The design of the diffuser at Khon Kaen Sugar

Table 9. Performance requirements and the derived design of the Khon Kaen Sugar diffuser.

Specified performance		
Cane throughput	Ton/hour	833
Fibre % cane	%	12.5
Pol % cane	%	13.5
Ash % cane	%	4.0
Preparation index (PI)	%	91
Imbibition % fibre	%	240
First mill extraction	%	68
First mill bagasse moisture	%	59
Reduced mill extraction (RME)	%	96
Final bagasse moisture	%	53

Derived design values		
Effective length	metres	43.65
Number of extraction stages		9
Width	metres	16.5
Diffuser floor screen area	m^2	720
Specific screen area	m^2/tfh	6.92
Bed height	metres	1.4
Aspect ratio	m/m	2.6
Bed speed	m/min	1.08
Retention time	min	40.6
Steam consumption	t/h	29.7

A few interesting points to take note of are:

- The diffuser specific screen area (ssa) is 6.9 m^2/tfh. This is greater than that of three of the South African bagasse diffusers reviewed in this paper, but smaller than the Inkerman diffuser. Given that the specified extraction is 96%, this design was considered sufficient.
- The diffuser aspect ratio is 2.6 m/m. Practically this means that this diffuser is shorter and wider than any yet constructed and should be capable of very high stage juice flow rates without flooding. Because of the unique design of chainless diffusers, very low aspect ratios are achievable.
- Due to this aspect ratio, the bed speed of 1.08 m/min is low when compared to the bed speed that would be needed in a narrower diffuser. For the equivalent diffuser of 13 m width (which is the largest chain diffuser size), the bed speed would be 1.4 m/min.
- At the design stage juice flow rate, the percolation rate is 0.155 m^3/m^2.min. This is well within the range of 0.15-0.3 m^3/m^2.min which is considered achievable (Rein, 2007).
- The scalding juice flow rate is equivalent to 170% of the cane rate. The normal range used for designing cane diffusers is 230-300%. However, because of the lower moisture content of first mill bagasse, the amount of energy needed to increase the bagasse temperature up to the diffuser operating temperature is far lower than for a cane diffuser.
- Scalding juice heating in this diffuser is performed by direct contact. Steam at 102°C is injected into the air space above the scalding juice trays, where it encounters a rain of juice from the bagasse bed. The very large surface area of the two scalding juice stages (as created by the very wide diffuser) provides a sufficient environment to achieve the scalding juice temperature that is required to heat up the bagasse to the required operating temperature. Whilst it is true that the heating vapour condenses in the scalding juice and should later be evaporated, the quantity of steam is so low that it was considered acceptable by the owners. From an investment perspective there was a saving in the cost of scalding juice heaters, and the structure, piping and valves required for them. From an operational perspective, there is no need for the cleaning of juice heater tubes and there is also a saving in the scalding juice pumping power, due to an avoidance of the head loss in a bank of shell and tube heaters.
- At the time of writing this paper, the diffuser at Khon Kaen was recently commissioned and has operated for a few weeks. Throughput has been proven, as has the effectiveness of the scalding juice direct contact heating. No flooding problems have been reported. Due to problems with the mills, the performance testing had not yet been completed, but every indication is that the diffuser is working as was intended.

Conclusions

The history of bagasse diffusion in South Africa was reviewed and it was found that bagasse diffusion performed reasonably well, especially in light of the cane preparation systems in use at the time. Bagasse diffusion in some other countries was also reviewed and found to be an effective system of extraction. The relative investment costs of cane and bagasse diffuser extraction systems was estimated and found to be similar. The energy consumption of bagasse and cane diffusers was reviewed and bagasse diffuser systems found to absorb more motive power, but to use less thermal energy. The conversion of cane diffusers to bagasse diffusers was discussed and is considered feasible. Finally the design of a bagasse diffuser was discussed in light of the technology now available, especially the important advantages of a low ratio of diffuser length to width.

Given the changing costs of extraction systems (especially the lower relative cost of mills); the energy and maintenance advantages offered by diffusion over milling; the persistence of cane payment by analysis of first expressed juice in some countries; the need to increase the capacity of existing cane diffusers; and the improved design of modern diffusers, it is reasonable to assume that bagasse diffusion may again become a relevant extraction technology in cane sugar factories in the near future.

REFERENCES

Allan GN (1969). Process plant installations at South African sugar factories.*Proc S AfrSugTechnol Ass* 43: 177-189.

Allan GN (1973). Developments in South African sugar factory plant installations 1969-1973. *Proc S AfrSugTechnol Ass* 48: 83-99.

Andersen NW and Smith DF (1981). Performance and operation of Inkerman's diffuser/milling train. *ProcAustSocSug Cane Technol*3: 255-259.

Anon. (1999), "Characteristics and economics of the cane diffusion process", Paper presented at the First *Integrated Conference and Exhibition on Sugar and Integrated Industries Present and Future*, 15 – 18 February 1999, Luxor – Egypt, 28 pp.

Buck WR (1965). Dalton – South Africa's first milling diffusion factory. *Proc S AfrSugTechnol Ass* 39: 144-121.

Buchanan EJ (1967).The appraisal of diffusion performance without confusion.*Proc S AfrSugTechnol Ass* 41: 94-100.

Fitzgerald JR and Lamusse JP (1974).Diffusion in South Africa.*ProcIntSocSug Cane Technol* 15: 1486-1498.

Foster, DH and Shann DS (1971). Experiences with cane diffusion in Queensland.*ProcIntSocSug Cane Tech* 14: 1267-1298.

Idehara H (1995). Hawaiian experience with cane diffusion.*Int Sug J* Vol 97, No. 1153E: 6-10, 4547.

Kelly PS and Porter RG (1978).Operation of the Inkermandiffuser.*ProcQldSocSug Cane Technol*38: 19-25.

Lamusse JP (1973). Forty-eighth annual review of the milling season in southern Africa (1972-73).*Proc S AfrSugTechnol Ass* 48: 1-23.

Lamusse, JP (1975). Fiftieth annual review of the milling season in Southern Africa.*Proc S AfrSugTechnol Ass* 50: 1-21.

McGinn JA, Vidler TL, Zemek RJ and MacCarthy WN (1981). Performance measurements at the Inkerman mill diffuser extraction train. *ProcAustSocSug Cane Technol*3: 261-266.

Rein PW (2007). *Cane Sugar Engineering*.Bartens, Berlin, Germany.119 pp.

Voigt I and Bellam F (2013).The comparison of different cane shredders with reference to diffuser performance. *ProcIntSocSug Cane Technol*, **28**, Paper FE 08, 16 pp.