THE APPRAISAL OF DIFFUSION PERFORMANCE WITHOUT CONFUSION

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Introduction

During the 1966-7 season three continuous counter current cane diffusers were commissioned in Southern Africa, one at Nchalo Sugar Estates in Malawi and two in Natal at Dalton and Entumeni. As may be expected, the performance of these units has not been *consistently* impressive, due mainly to various adjustments made while gaining experience with the new equipment. However, extractions of 97 per cent (lost absolute juice per cent fibre in final bagasse of 23) have been recorded and this together with the promise of a considerable saving in installed and running costs suggests that milling will in future be superseded at least partly by diffusion. With this prospect in view it is important that performance data available from the first "diffusion season" be appraised and expressed in a manner least conducive to confusion.

The purpose of this paper is to provide, on the basis of experience gained from the S.M.R.I. Mutual Milling Control Project, a basis for the assessment of diffusers in general using specific performance data from existing diffusers as an example. It is hoped that this will eliminate some of the anomalous conclusions which could be drawn on the basis of more superficial data available at present.

Specific Performance of Diffusers

In order to illustrate the various facets of diffuser and associated milling performance the discussions in this paper are based on the mean data up to the end of January, 1967, for the three factories mentioned above. These data are shown in Tables I and II. The mean data represent a wide variety of operating conditions and their use avoids anomalies which may result from selection of short period data.

(a) *Diffuser Capacity*

The comparison of feed rates for diffusers of various sizes and processing different cane varieties on the basis of tons cane per hour is certainly anomalous. The only fixed characteristic of a diffuser is the effective length and breadth, i.e. the area covered by cane. The only constant material in the feed is fibre since the juice to fibre ratio changes after the first mill. This suggests that the specific diffuser feed rate should be expressed as lb fibre/sq ft/hr. Table I (data 3 and 10) shows that while the capacity in ton cane/hr varies by a maximum of 18 per cent, the difference in specific feed rate between the two particular diffusers is only 4 per cent and in fact there is very little difference between the specific feed rates of all three diffusers.

(b) *First Mill Performance*

This may be assessed most logically by the residual absolute juice % fibre in first mill bagasse and the lb fibre/cu ft t.r.v.–hr* (data 24 and 25 in Table I). It has been shown under local conditions that the first mill has a bearing on overall milling performance.[2] Similarly, experience in Reunion and Tanzania indicates that juice per cent fibre in first bagasse has a direct bearing on the pol in bagasse in a diffuser.[5] The data in figure 1 also support this contention and seem to show that the overall performance is dependent solely on the first mill performance. For this reason it would be misleading to quote overall performance as an indication of diffuser performance without reference to first mill performance, or to the first mill bagasse analysis.

Comparing the data quoted above with Table II, it appears that for good first mill performance preparation should be efficient and the mill should not be overfed. The importance of shredding before milling was shown by the Mutual Milling Control Project and while this may not apply in the case of certain soft cane varieties, diffuser suppliers who find their machinery incompatible with shredders should bear this aspect in mind, particularly in view of the relationship in figure 1.

(c) *Diffuser Performance*

As discussed in an earlier paper[3] the performance of continuous multistage leaching equipment may be expressed in terms of the stage efficiency which compares the number of actual stages with the number of ideal stages under conditions of complete mixing. In the case of fully continuous operation as in cane diffusion it may be possible to make use of a diffusion coefficient based on analysis of the various diffuser juices or alternatively the "height of a transfer unit" concept. Until some such assessment has been evolved, more superficial criteria will have to suffice.

In general Chemical Engineering leaching calculations, the work done by the diffuser is expressed by the change in solute/underflow inert solid ratio. In cane diffusion this would be equivalent to comparing the sucrose/fibre ratio in first and last bagasses.

Unfortunately only data 12 and 17 (Table I) are available but a comparison of absolute juice per cent fibre in bagasse entering and leaving the diffuser is equally applicable (data 14 and 15). The straight line relation between these data (fig. 1) passes

* t.r.v. = total roller volume.

through the origin showing clearly that absolute juice extraction is identical for all three diffusers and that the lost absolute juice is dependent only on the first mill performance.

(d) *Diffuser Imbibition Control*

An important controlled process variable is the imbibition ratio on fibre. This is usually controlled basically by a signal from either a first bagasse belt weigher or a killer plate resting on the cane fed to the first mill after knife preparation. The stability of control may be assessed from the mean percentage deviation in imbibition per cent fibre (data 20 in Table I). The lower value corresponds to a greater stability.

(e) *The Effect of Inversion on Extraction*

It has been said that calculated extraction efficiency would be enhanced if abnormal inversion occurred during diffusion. This is incorrect since if inversion occurred it would reduce not only the *total* sucrose determined by mass balance but also the *recovered* sucrose. Calculated extraction efficiency would therefore not be significantly affected by inversion.

Comparative figures for reducing sugar ratios in mixed juice at local diffusion factories do not give rise to undue concern. For example, at Dalton this figure averaged 4.48 compared to 5.04 for the neighbouring mill at Jaagbaan. At Entumeni the diffusion season's average was 2.79 compared to 2.89 for the 1965–6 milling season. At Nchalo the ratio was considerably higher due to immature cane.

From the above discussion it appears that any conclusions regarding the relative rates of inversion during milling and diffusion should be regarded as speculative, particularly in view of the primary dependence of reducing sugar ratios on cane quality.

(f) *Extraction of Impurities*

Experienced millers frequently comment on the possibility of additional non-sugar extraction by diffusion due to the use of hot water. However, owing to the separate clarification of press water and the filtering action of the bagasse mat through which the juices are percolated, the diffuser juice can be brilliantly clear. This partial elimination of colloidal matter before boiling the juice reduces the load on clarifiers and filters (data 31 in Table I) and should be expected to enhance the quality of clarified juice.

This deduction is probably best illustrated by considering the extraction of starch from cane during diffusion. In fig. 2 two sets of analyses[6] for starch in consecutive diffuser juices are shown. The two runs were conducted at high and low temperature levels. These results infer that the starch on brix in diffuser juice may be reduced by about 70 per cent by lower temperature operation and (from previous tests on secondary mill juices)[1] the level of the starch is considerably lower than for a normal milling tandem. Subsequent tests have indicated that starch dissolves slowly at 70°C and that enzymatic destruction appears to occur at almost the dissolution rate. This infers that starch displaced from the bagasse into the juice may be removed by a combination of enzymatic destruction and filtration.

The peaks in the curves of fig. 2 correspond to the return of clarified press water and this high starch level after milling confirms that milling extracts a higher amount of suspended colloidal matter from bagasse than diffusion. It also suggests that starch (which is not removed by clarification) may be removed by filtration through the bagasse bed.

The last expressed juice purity (data 32 in Table I) is generally commensurate with the low level of sucrose in final bagasse and any abnormally low results could be attributed to the fact that the dewatering mills express an abnormal amount of low solubility non-sugars which are not extracted by the diffuser (e.g. starch).

(g) *Performance of Dewatering Mills*

The dewatering mill capacity may be assessed on the same basis as the first mill. Data 28 and 29 of Table I indicate considerable discrepancy when comparing the moisture in final bagasse against the specific capacity of dewatering mills based on the total roller volume of *all* dewatering units. However, if the moisture in bagasse is compared against the specific capacity for only *one* mill (data 30 in Table I) then a direct relationship between moisture and capacity is evident even when comparing installations with one and two units. This obviously infers that the dewatering effect of the third mill (second dewatering mill) is not very significant. Data 29 and 30 suggests also that under 52 per cent moisture could be achieved using only one dewatering unit provided it is fed at a rate of less than 180 lb fibre/cu ft t.r.v.–hr and that for fibre rates exceeding the capacity of a single unit it would probably be more advantageous to operate two mills in parallel than in series.

These conclusions are supported by theory. Firstly, the bagasse discharged from a diffuser is a saturated porridge-like mass with little rigidity compared with normal final bagasse from a milling tandem. Hence, after passing through a dewatering mill its consistency does not facilitate further dewatering by a second unit. Secondly, the Burke-Plummer equation[4] (which relates pressure drop through a porous bed to the velocity of a liquid passing through the bed in the turbulent flow region) indicates that the pressure drop through the bagasse bed is proportional to the height of the bed and the square of the superficial liquid velocity through the bed. In a certain sense, the velocity of the draining liquid is directly proportional to the height of the bed since during rapid expression the amount of liquid expressed through unit area increases with bed height. In this sense the pressure drop through the bed is proportional to the third power of the bed height. This condition would be most likely to occur in a highly saturated bed undergoing rapid dewatering. Hence the bagasse bed height is rather critical in determining the efficiency of dewatering. Obviously mill speed and bed height are inter-related so that there is no advantage in running the mill fast in order to thin out the bed. This simply increases the liquid velocity until reabsorption occurs when the pressure drop equals the pressure on the bagasse bed.

Summary and Conclusions

This paper has pointed out that the indiscriminate use of superficial capacity and efficiency ratings can lead to confusion in the appraisal of diffusion performance. Diffuser capacity should be based on the fibre rate and a fixed characteristic of the diffuser size, viz. the effective area. Mills may be similarly rated by the use of fibre rate and total roller volume.

In assessing efficiency, mills and diffuser should be treated individually and on the basis of absolute juice per cent fibre in preference to extraction of sucrose. Since diffusion is dependent on concentration difference it is incorrect to compare diffusers on the basis of residual absolute juice per cent fibre in final bagasse alone and the residual juice in first mill bagasse should be taken into account. Hence the change in absolute juice/fibre ratio through the diffuser should be used.

On the above basis it has been shown that the three diffusers operating in Southern Africa have (for practical purposes) the same specific capacity and efficiency and that efficiency differences can be directly attributed to the first mill performance. This has clearly pointed out the importance of first mill efficiency. The conclusion is supported by results from other diffusers.

In passing, it has been shown that inversion should not effect extraction as calculated by standard methods and there is no conclusive evidence to show that inversion is higher in diffusion than in milling. Furthermore, there is no evidence to show that non-sugar extraction is higher in diffusion. In fact the reverse may apply, particularly with respect to starch.

There is some evidence to show that the imbibition rate control may be more stable when based on the feed rate of first bagasse. It appears that diffuser bagasse may be more efficiently dewatered by the use of a single over-sized mill than by two normal-sized units in series. At high feed rates it is suggested that two units be operated in parallel.

By the use of specific performance data experience in diffusion may be applied to advantage in the design of future installations.

Acknowledgements

The author wishes to thank the management of Nchalo Sugar Estates, Malawi, Entumeni Sugar Milling Co. (Pty) Ltd. and the Union Co-operative Bark and Sugar Co. Ltd., Dalton, for permission to publish process data from their diffusion plants.

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TABLE I

Diffuser performance data

Factory	NS†	EN	UC
1. Type of diffuser	de Smet	de Smet	B.M.A.
2. Rated ton cane/hr	63-99	63-99	55-109
3. Actual ton cane/hr	41	46	50
4. Effective length	77′-6″	77′-6″	93′ 6″
5. Effective width	8′-2½″	8′-2½″	7′ 2⅝″
6. Effective area, sq ft	636	636	675
7. Fibre % cane	15.99	13.32	14.45
8. Ton fibre/hr	6.56	6.13	7.23
9. Lb cane/sq ft-hr	129	145	148
10. Lb fibre/sq ft-hr	20.6	19.3	21.4
11. Sucrose % cane	12.19	13.63	12.26
12. Sucrose % fibre in cane	76.24	102.33	84.84
13. Absolute juice % fibre in cane	525	651	592
14. Residual abs. juice % fibre first bag.	224	295	328
15. Lost abs. juice % fibre final bag.	28	34	37
16. Sucrose % final bagasse	1.62	1.87	2.00
17. Sucrose % fibre final bag.	3.55	4.42	4.51
18. Extraction % overall	95.34	95.66	94.59
19. Imbibition % fibre	235	299	222
20. Imbibition mean % deviation	—	11.0	14.3
21. Speed of diffuser conveyer, ft/hr	118	118	138
22. Retention time of bagasse, min.	39.4	39.4	40.7
Milling data:			
First Mill:			
23. Total roller volume, cu ft	73.7	55.6	127.3
24. lb fibre/cu ft t.r.v.-hr	178	220	114
25. Residual abs. juice % fibre first bag.	224	295	328
Dewatering mills:			
26. No. of units	1	2	2*
27. Total roller volume cu ft	73.7	111.2	147.3
28. Lb fibre/cu ft t.r.v.-hr	178	110	98
29. Moisture % final bagasse	51.94	55.78	52.75
30. Lb fibre/cu ft t.r.v.-hr (one unit only)	178	220	196
31. Filter cake % cane	2.24	4.00	3.00
32. Purity last expressed juice	69.2	67.8	70.7

*preceded by dewatering drum †Nchalo, Malawi

TABLE II

Preparatory and milled equipment

Unit	NS	EN	UC
Primary knives:			
No. of knives	32	32	32
Pitch, in	2	3	5½
Pitch, circle diam., in ..	60	54	59
Speed, r.p.m.	580	600	588
Installed h.p.	150	120	268
Secondary knives:			
No. of knives	48	32	64
Pitch, in	1½	3	1¾
Pitch, circle diam., in ..	60	54	59
Speed, r.p.m.	580	600	588
Installed h.p.	200	150	335
Shredder:			
Type	N.A.	Gruendler	N.A.
Size, in		30 x 40	
No. rows hammers ..		4	
No. hammers operating		32	
Speed, r.p.m.		960	
Installed h.p.		120	
First Mill:			
Type	Mirrlees	Stewart	B.M.A.
Size, in	30 x 60	28 x 52	36 x 72
Installed h.p.		175	375
No. dewatering mills ..	1	2	2
Second Mill:			
Type	Mirrlees	—	Mirrlees*
Size, in	30 x 60	28 x 52	30 x 60
Installed h.p.		300	275
Third Mill:			
Type	N.A.	—	Stewart
Size, in	N.A.	28 x 52	30 x 60
Installed h.p.	N.A.	coupled	275

*preceded by dewatering drum

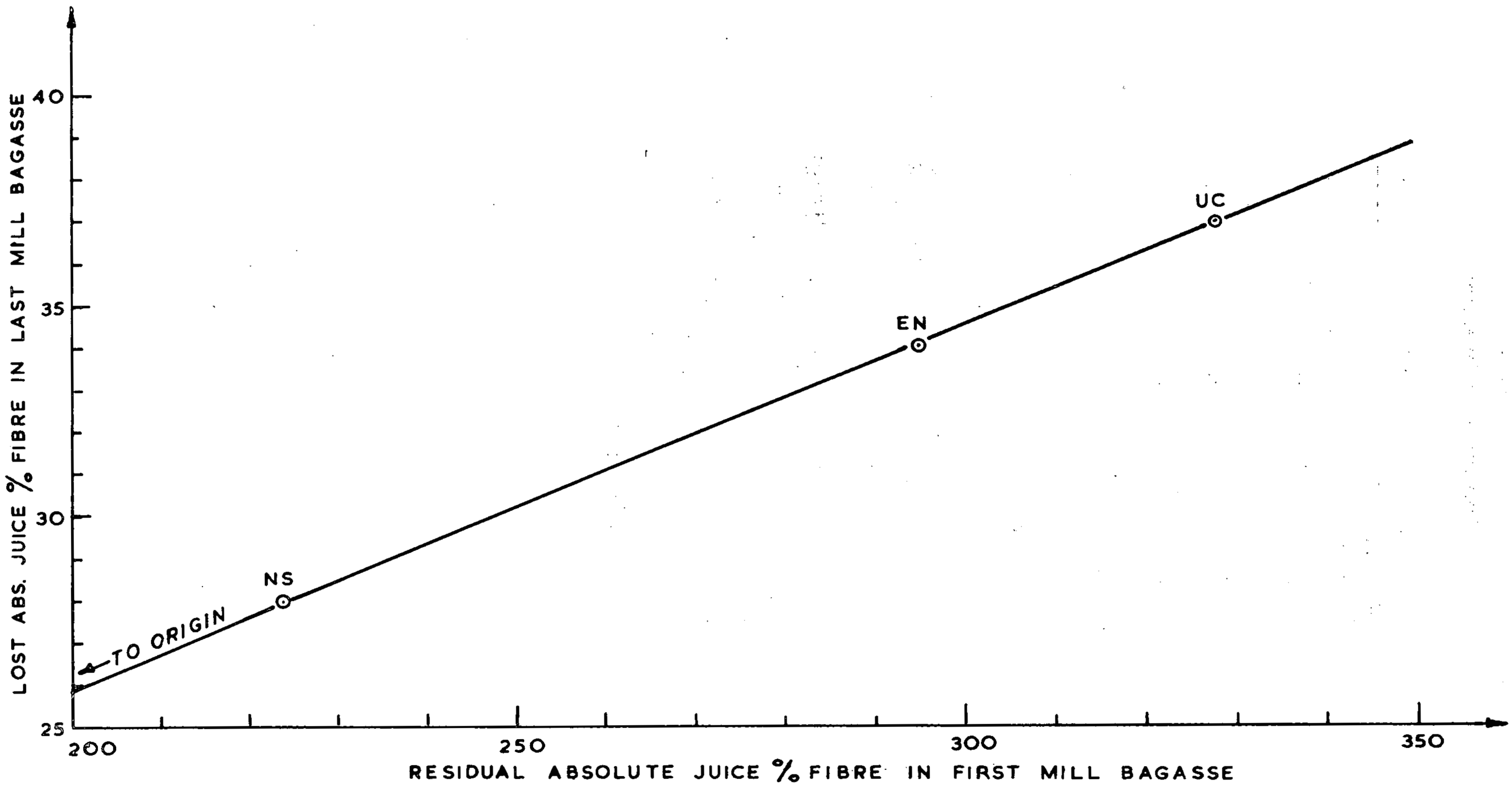

FIGURE 1: Relation between first mill **and overall diffusion performance**

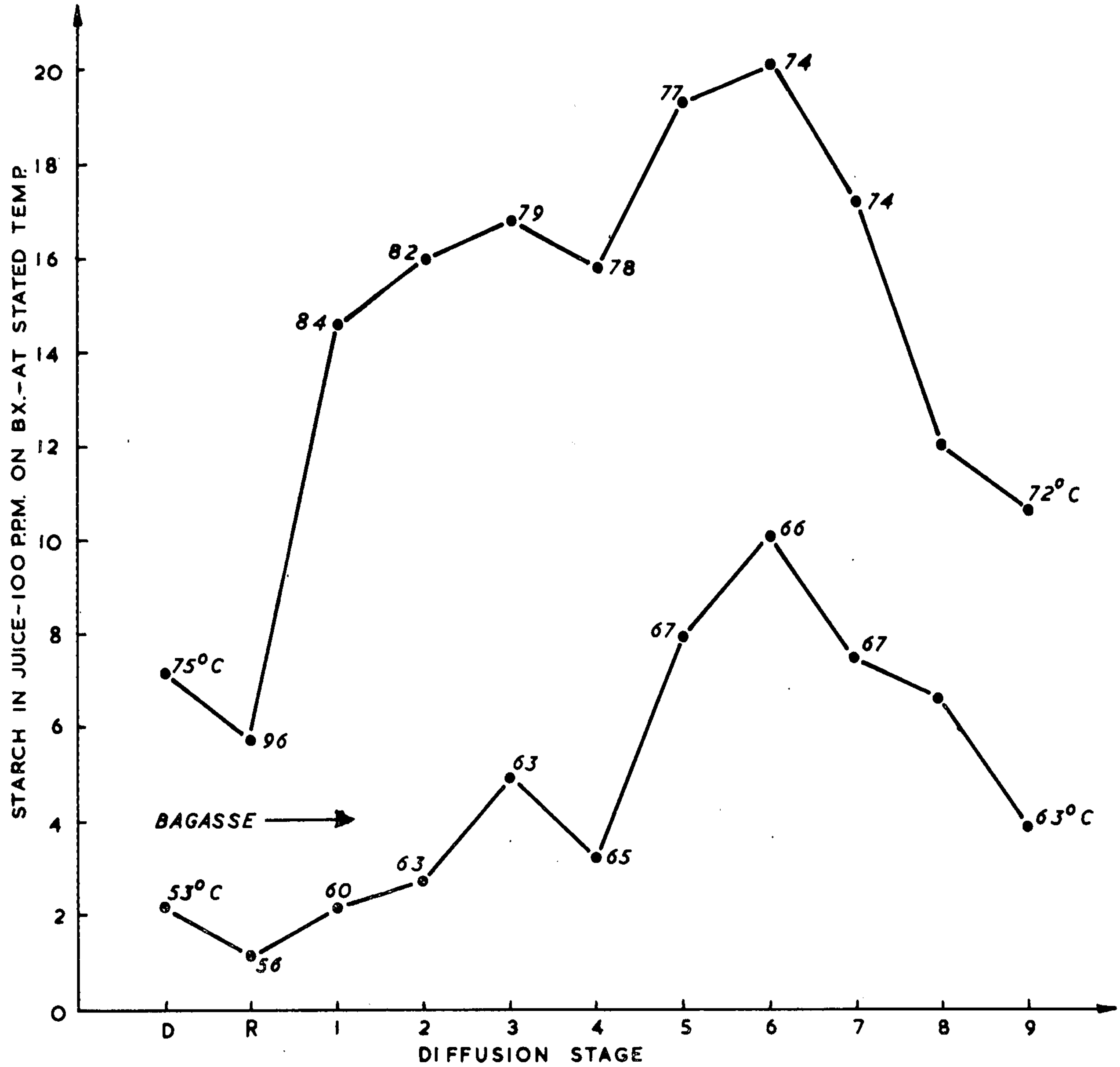

FIGURE 2: Starch extraction with diffuser operating at high and low temperatures
D: diffuser juice R: recirculation juice

Discussion

Mr. Hulett: Mr. Buchanan says that better results would be achieved by dewatering the diffusion bagasse with two mills in parallel instead of in series and, going by our experience at Darnall, where very heavy imbibition is applied, I am sure he is correct.

Mr. Renton: You cannot compare milling and diffusion regarding retention time. At Darnall our retention time is at the most fifteen minutes, whereas in a diffuser it is at least thirty minutes. There are five leaching stages in our mill whereas there are as many as nine in a diffuser. There is probably some diffusion going on in the Darnall tandem, particularly in view of the heavy imbibition.

Mr. Buchanan: When a mill roller is fed with bagasse, no matter what sort of mixing device is put between two mills to get better mixing, e.g. Rivere carriers, very little additional mixing is achieved.

The effective diffusion time in a milling tandem is so limited, and mixing so poor that very little diffusion can take place within the bagasse particles.

Mr. Renton: At Darnall imbibition is applied immediately after the preceding mill so that only while the bagasse is moving through the rollers is it not subject to diffusion. There is therefore time for it to take place. Also, enough water is applied to saturate the bagasse and allow for good mixing.

Mr. Buchanan: The diffusion rate from within the bagasse particle to the surface is controlling. In a milling tandem there is no relative movement between bagasse and juice during conveying and some time is required for the bagasse to absorb the imbibition. Hence the efficiency of the controlling diffusion is low.

Mr. Bentley: Honolulu Iron Works have produced a plant consisting of a series of presses fed by chutes which it is claimed overcomes the disadvantage of a diffuser. The bagasse is fed by a large chute, liquid is poured on to it, the juice is squeezed out by the press and the bagasse is then transferred to the next chute.

What are the so-called disadvantages of a diffuser?

Mr. Buchanan: Possibly the rather cumbersome vessel that has to be installed in a factory and the potential disadvantage of a high retention time, although the danger of inversion has not yet been proved.

Mr. van Hengel: What was the quality of the cane at Nchalo—was is very clean or very dirty? If it was very clean is it not perhaps presumptuous to assume that one small dewatering mill is sufficient?

Mr. Buchanan: The cane was neither particularly clean nor particularly dirty. There was not much mud attached to it and trash was not particularly high. I maintain that the lack of rigidity of the bagasse fibre discharged from the diffuser makes the bagasse almost impermeable after passing through one dewatering mill.

Mr. Covas: When I visited Nchalo some months ago and expressed surprise at the high figure of 16% I was told that a proper factory control method was not yet in operation and that all figures should therefore be treated with reserve.

The cane was fairly clean by South African or Moçambique standards.

Mr. Buchanan: Apart from a possible discrepancy through not weighing the final bagasse factory control seemed adequate. During my visit I concluded that any errors would not detract significantly from the conclusions in this paper.

Mr. Bax: On page 2 the figure of 180 lbs. fibre per total roller volume per hour is given as the maximum efficient figure for a dewatering mill. I think that a much higher figure is allowable provided adequate juice grooving is provided.

In a Walker mill provided with a pressure feeder, are five rollers or three rollers taken into account when assessing total roller volume?

Mr. Buchanan: I do not think mill grooving would have much effect on the impermeability of the bagasse, which is the chief factor.

We are not very impressed so far by the achievement of Walker mills and are awaiting with interest results from Malelane. Only three rollers are considered since the first two are mainly for feeding.

Mr. Hurter: The wattle industry operates a diffusion process and the experience has been that in order to diffuse with minimum impurities in juice the bark must be cut as cleanly as possible without rupturing cells. Would it not be advisable to do away with a shredder and replace it with a machine that could chop cane without rupturing cells?

Mr. Buchanan: If cane was chopped into cossettes without rupturing individual particles removal of the sugar would have to take place by osmosis or, in order to avoid this, the temperature would have to be raised to 85°C to make the cells permeable and starch would be dissolved. This is precisely what we are trying to avoid.

Mr. Carter: In order to prevent inversion in a diffuser is it beneficial to add lime?

Mr. Buchanan: It is essential to add lime along the diffuser to maintain a consistent pH and avoid inversion.