THE SIGNIFICANCE OF STAGE EFFICIENCY IN A CANE MILLING TANDEM

By E. J. BUCHANAN

Introduction

The history of the sugar industry in Natal has shown that enormous advances have taken place both in capacity and technology of plants. Recent years in particular have seen a marked upward surge in the graph of production — an achievement due in no small way to the dedicated efforts of chemists and engineers in charge of the operation and expansion of sugar factories. It is perhaps typical of such conditions of rapid expansion that sugar technologists, with their attention fixed on rapidly rising production targets, have had little enough time to contemplate the wealth of process data inherited from their own considerable experience — let alone the application of the more fundamental techniques of modern chemical engineering. So often the necessity to contemplate the view on the horizon causes the scene in the foreground to go unnoticed.

During this period of tremendous growth the sugar industry has developed its own empirical approach to performance figures and design calculations and the progress in this direction can be viewed as one of the achievements of sugar technologists. However, in pursuing this specialised approach to process technology the dangers of seclusion from the rapidly expanding fundamentals of chemical engineering should not be overlooked. It is possible for example that opportunities could be missed for advancement due to our failure to assess the merits of changes in process and units on a more general and fundamental basis.

The extraction of sucrose from sugar cane and the recovery of crystal product involves almost every unit operation of chemical engineering with one exception — distillation. Hence it is unfortunate that so few chemical engineers are employed at sugar factories. The more general use of heat and mass transfer coefficients, stage efficiencies, transfer units and dimensionless numbers would for example provide a more rational basis for scale-up problems in design and specification of new units and a better insight into the performance and mechanism of unit processes.

The object of this paper is to describe the application of one of these chemical engineering techniques to the extraction of soluble solids from sugar cane in a milling tandem. The process involves two unit operations — size reduction and leaching. This paper deals mainly with an analysis of the leaching operation and discusses its merits in the light of analyses applied to local tandems.

Principles of Multistage Countercurrent Leaching

Terminology

The operation which sugar technologists refer to as milling is classified in chemical engineering unit operations terminology as "continuous multistage countercurrent leaching with variable underflow preceded by size reduction". Leaching is the process of removing a solute from an inert solid by the use of a solvent. The imbibition system of the tandem shown in fig. 1 is analogous to the leaching system shown

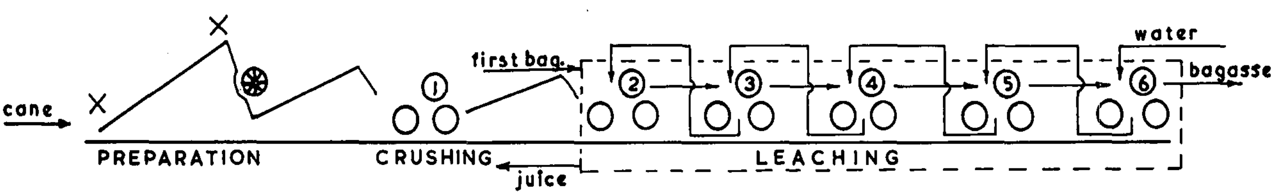

FIG. 1- THREE OPERATIONS OF MILLING

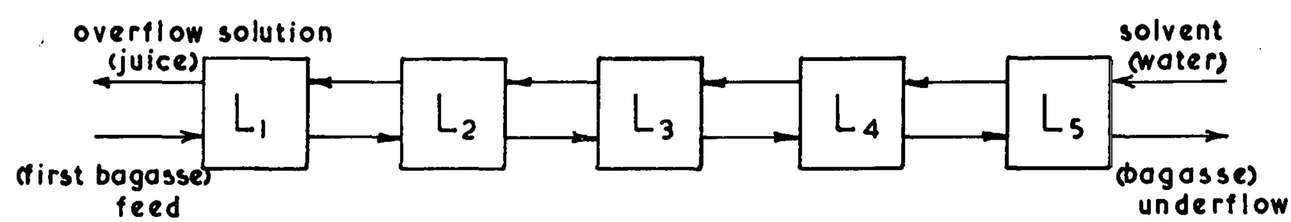

FIG. 2- COUNTERCURRENT LEACHING SYSTEM

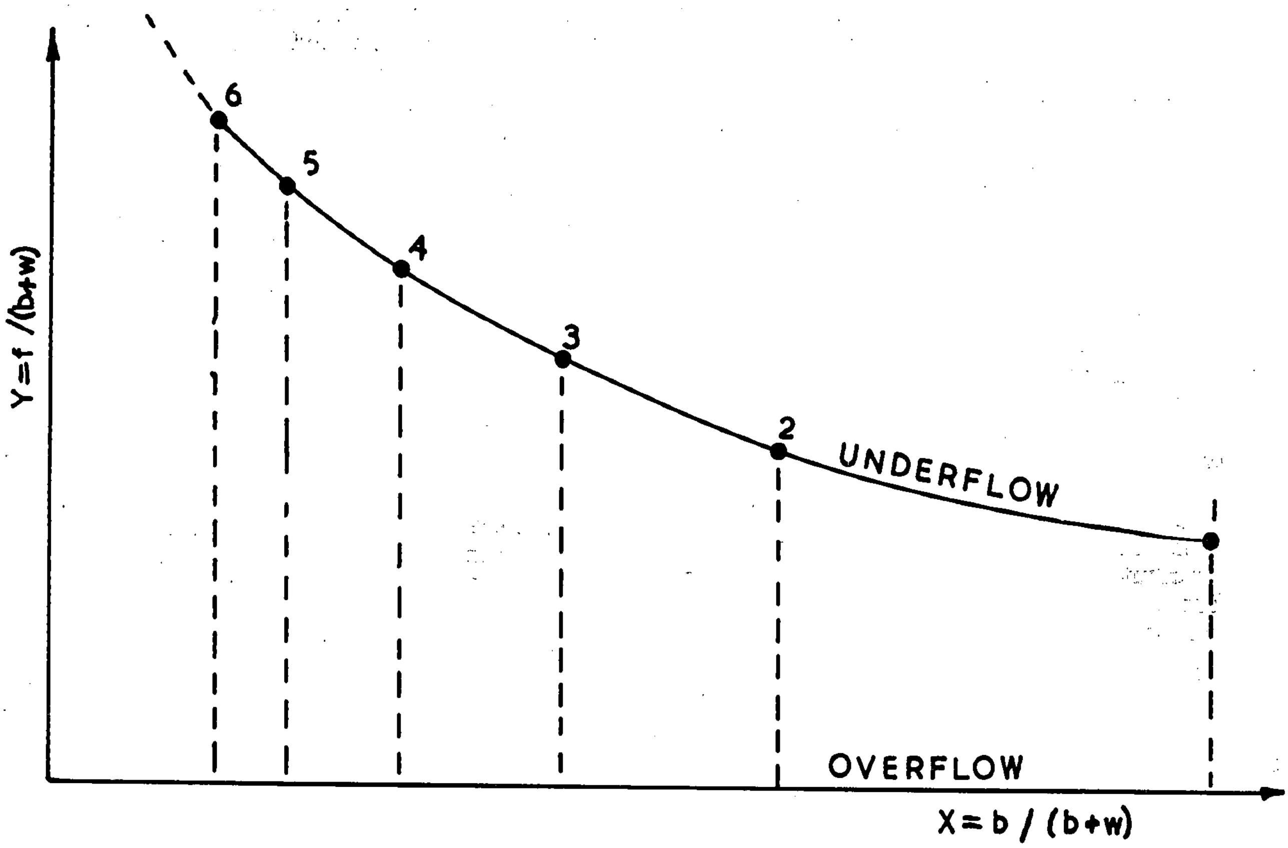

FIG.3 PONCHON SAVARIT XY DIAGRAM

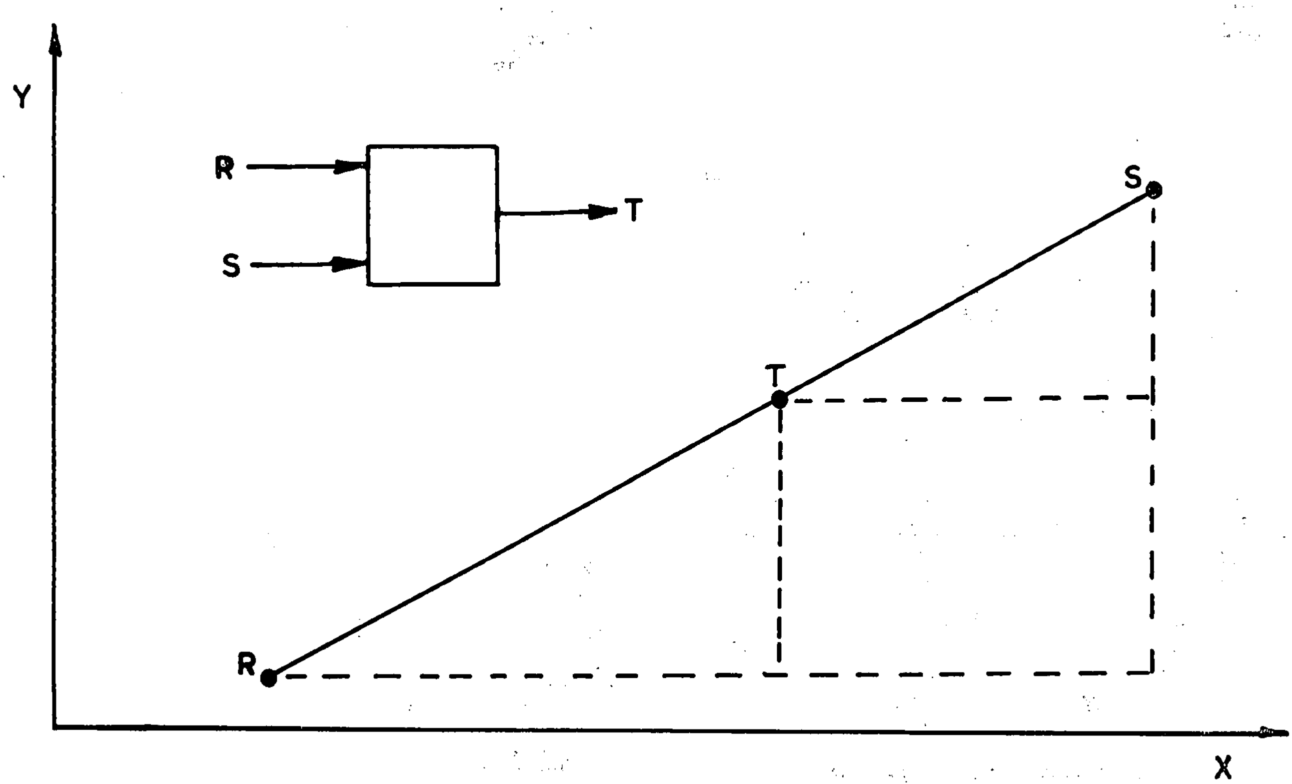

FIG.4 CENTRE OF GRAVITY PRINCIPLE

in fig. 2. The degree of leaching is logically expressed in terms of the ratio: solute/inert solid. (Use is made of the reciprocal when necessary for ease of calculation.)

In the case of a milling plant a simple balance is facilitated by taking the three component system

solute = brix
inert solid = natural fibre
solvent = water

and the degree of leaching is then expressed by the ratio: brix/natural fibre.

Variable Underflow

The ratio: natural fibre/juice in bagasse increases along the milling tandem (approximately 0.5 to 1.4) hence the underflow concentration is variable. This variation may be attributed to the effect of changing density and viscosity of the expressed juice along the tandem and also to changing compressibility and voidage of the bagasse after successive compressions. Variations in mill settings, pressures and speeds could also contribute to the changing underflow concentration but ultimately it is dependent on the former physical characteristics.

Ideal Stages

For the leaching system shown in figs. 1 and 2 bagasse from the first mill is fed to the first leaching stage, the overflow and underflow being transported countercurrently. If complete mixing occurs between the imbibition and residual juices the stages are ideal. Procedures have been devised for the design of multistage leaching systems. The number of ideal stages (S'_i) is first determined and with a knowledge of the overall stage efficiency (E'), the number of actual stages S' may be calculated from the formula

$$S' = \frac{S'_i}{E'} \quad . \quad . \quad (1)$$

in which E' is determined from practical experience (or in some cases experimental diffusion data[5]). The number of ideal stages may be determined in the case of constant underflow by mathematical analysis using the McCabe-Smith method[6]. In the milling of cane, variable underflow exists and it is necessary to adopt a graphical solution known as the modified Ponchon-Savarit method.[6, 7, 8]

Mixing Efficiency

In an existing milling plant we already know the number of actual stages. The number of ideal stages may be determined by the use of the Ponchon-Savarit method. The stage efficiency may then be calculated by formula (1). This represents the overall efficiency of mixing between imbibition and residual juices under the particular milling conditions.

The Ponchon-Savarit analysis of leaching systems has been discussed on a general basis in most chemical engineering reference books but not in literature associated directly with the sugar industry, hence the method is outlined in the next section.

The Ponchon-Savarit Analysis

Principles of the XY Diagram

In the modified Ponchon-Savarit graphical method each underflow stream in fig. 2 is considered to be a mixture of inert solid and solution and the solution, a mixture of solute and solvent. Let b represent the amount of solute, f the solid, and w the solvent. Then if we take two ratios:

$$X = b/(b + w), \quad Y = f/(b + w) \quad . \quad . \quad (2)$$

and plot these co-ordinates for each stage in the leaching system we obtain an XY diagram of the form shown in fig. 3. This is a plot of the ratio of solid to retained solution (Y) as a function of the concentration of the solution being drained (X). For a milling tandem this plot takes the form shown in fig. 3 in which the numbered points represent the condition of the underflow leaving each stage. The slope of the underflow curve is due to the changing drainage conditions. The overflow streams are represented by the line Y = O since no inert solid is present.

Three principles facilitate subsequent constructions on the XY diagram:

(i) Lines joining overflow and underflow streams leaving the same stage are vertical since solution concentrations (for ideal stages) are equal. These are called tie lines and are shown as dotted lines in fig. 3.

(ii) The point representing the mixture of two streams lies on a straight line joining the points which represent the two streams, e.g., line RTS in fig. 4 represents the mixing of two streams R and S to form stream T.

(iii) The weight of solution in each of the streams R and S which are derived from the mixture represented by T is inversely proportional to the length of the corresponding segments RT and TS as in fig. 4.

These principles can be proved mathematically[6].

Application to a Milling Tandem

In the case of a milling tandem, first bagasse enters the leaching system at the second mill as in fig. 1. Observing that the drainage of the bagasse at each stage is dependent more on the concentration of the back roller juice than the residual juice in each bagasse, the underflow curve may be plotted as in fig. 3 using

$$X = \frac{\text{brix back roller juice}}{100} \qquad Y = \frac{\text{natural fibre}}{\text{juice}} \quad (3)$$

This is consistent with the terminology outlined earlier in the previous section so that the nomenclature for equations (2) becomes:

b = weight brix in juice or bagasse
f = weight natural fibre in bagasse
w = weight free water in juice or bagasse.

Assuming that a 6-unit tandem as in fig. 1 is being analysed, the underflow curve will be similar to $M_1 M_6$ in fig. 5. This curve is established from practical milling figures and represents the XY relationship for the particular tandem.

Overall Balance

In order to develop operating lines which radiate from P in fig. 5 an overall balance must first be established from the four streams:

first bagasse + imbibition = last bagasse + juice

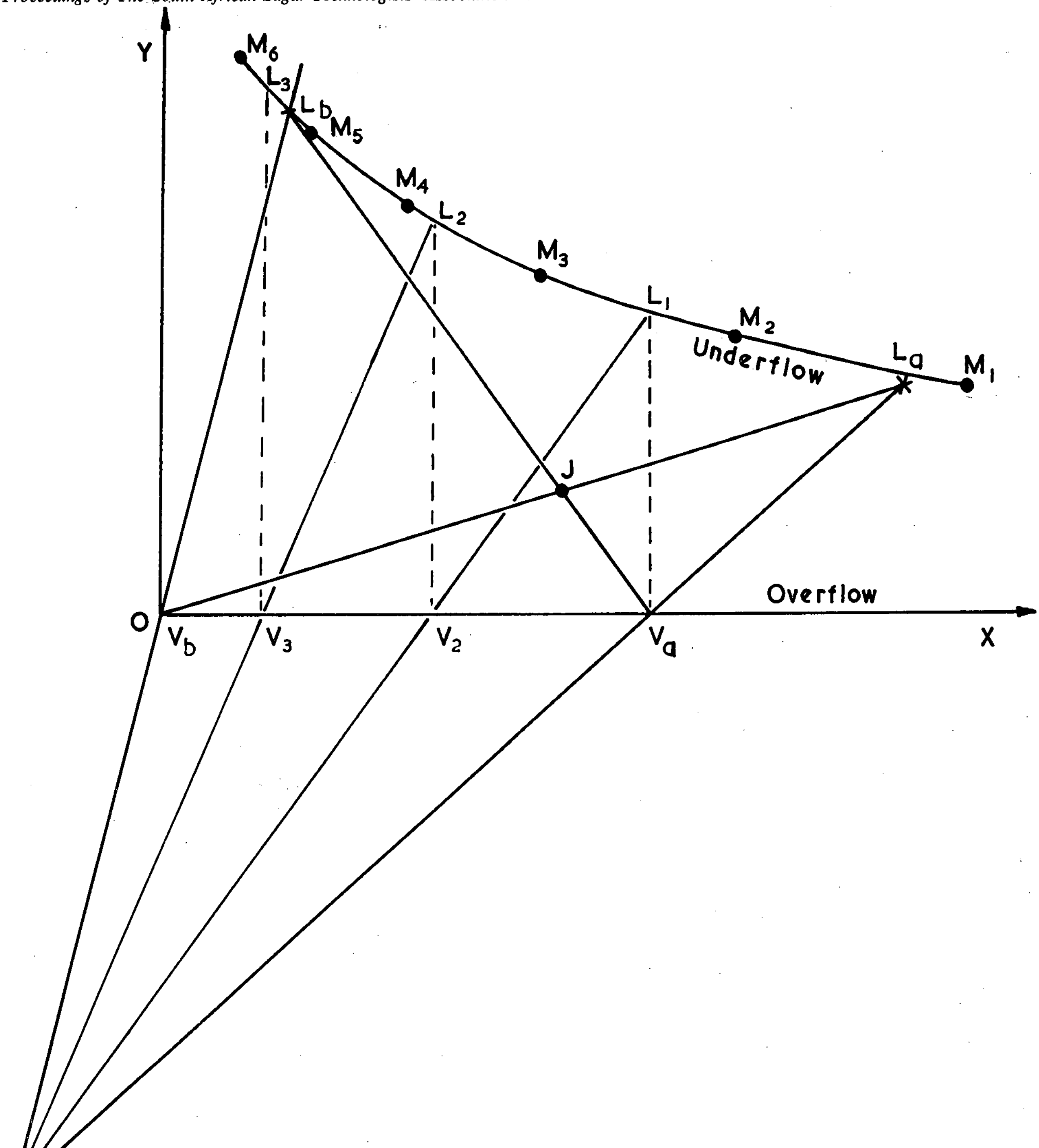

FIG.5 PONCHON SAVARIT DIAGRAM CONSTRUCTION

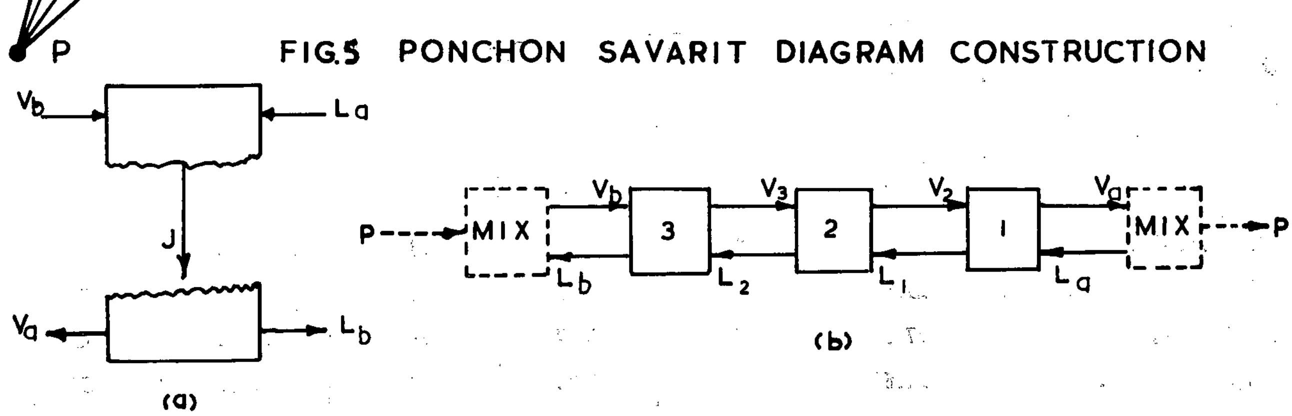

FIG.6 OVERALL BALANCES IN LEACHING SYSTEM

or

$$L_a + V_b = V_a + L_b = J \quad . \quad . \quad . \quad (4)$$

as shown in fig. 6 (*a*).

The co-ordinates of L_a may be established from the first bagasse analysis. It is required that L_b, the point representing the last bagasse, lie on the underflow curve. Any line through the origin has a slope of

$$\text{slope} = \frac{\text{fibre/juice}}{\text{brix/juice}} = \frac{\text{fibre}}{\text{brix}} \quad . \quad . \quad . \quad (5)$$

Hence a line drawn through the origin with a slope equal to the fibre/brix ratio in last bagasse will intersect the underflow curve at L_b. This line is $V_b L_b$ in fig. 5. The fact that L_b does not coincide with M_6 is immaterial since M_6 simply represents the degree of drainage at this stage while L_b represents the degree of solute removal under drainage conditions established by the curve. Point V_b lies on the origin since the imbibition contains neither fibre nor brix.

Applying the third principle mentioned above to the mass balance equation (4) the position of point J may be established along the line $V_b L_a$. The same principle also establishes that V_a lies on the entercept of line $L_b J$ with the abscissa. Point V_a represents the concentration of the thick juice leaving the first leaching stage under ideal (complete mixing) conditions.

Operating Lines

In order to determine the number of ideal stages, operating lines must be constructed for each ideal stage. The graphical method used is analagous to the assumption of a fictitious mixer added to either end of the leaching system as shown in fig. 6 (*b*). From this diagram the following balances may be derived:

$$V_a = L_a + P, \; L_b + P = V_b, \; P = V_a - L_a = V_b - L_b \quad (6)$$

in which P is a mathematical quantity but does not actually exist as a physical stream.

Applying the third balance in equations (6) to fig. 5 it is clear that lines $L_b V_b$ and $L_a V_a$ must both project to meet at point P. Similarly all other operating lines $L_1 V_2$, $L_2 V_3$ . . . $L_b V_b$ radiate from point P.

Ideal Stages

Having constructed the lines $L_b V_b$ P and $L_a V_a$ P, the number of ideal stages may be determined by constructing the operating lines for the intermediate stages. For example, the overflow V_a from the first ideal stage will have the same concentration as the juice remaining in the underflow. From the first principle outlined above, the tie line is a vertical line projected from V_a to meet the underflow curve at L_1. The tie line $V_a L_1$ therefore establishes the conditions for the overflow and underflow of the first ideal stage. Similarly L_1 is projected to P and $V_2 L_2$ establishes the conditions for the second ideal stage. This procedure is repeated until a tie line is established to the left of or on point L_b. The number of tie lines thus constructed represents the number of ideal stages.

Since these stages are ideal they may be fractional. For example the number of stages in fig. 5 is approximately 2.8. Since there are 5 actual leaching stages in this case, the stage efficiency is (2.8/5) 100 = 57%.

An example of the construction based on figures from an existing milling tandem is given in the appendix.

Results of Analysis of Local Tandems

The author has recently analysed results submitted from most of the Natal sugar factories which carry out bagasse analyses for each unit in the milling tandem. These were analysed by means of the method described previously. Unfortunately space does not permit the reproduction of detailed calculations and constructions for each tandem. However, the stage efficiencies and other relevant data are tabulated in table 1. The author was able to obtain the necessary process data[1] from Fairymead factory in Queensland and similar results for this factory are compared in table 1.

In the latter table tandems are arranged in order of decreasing stage efficiency. Except where otherwise indicated, the data are generally averaged over the 1964 season up to August. The symbols in the right hand column denote the preparatory equipment preceding the leaching system, e.g. shredder (S), two roller crusher (C) and first mill (1).

TABLE 1

Tandem	Stage Efficiency %	No. Actual Stages	No. Ideal Stages	Imbibition % Fibre	Fibre/Juice Ratio in First Bagasse	Preparatory Equipment
FM*	39.5	4	1.58	228	0.548	S1
TS2	37.4	4	1.57	218	0.624	CS1
SZ2	35.2	4	1.41	214	0.798	S1
TS1	34.5	6	2.07	201	0.514	S1
SZ1	33.8	4	1.35	214	0.803	S1
UF1	31.3	6	1.88	279	0.538	S1
ZSM (1963–4)	30.6	5	1.53	282	0.566	S1
UF1 (1963–4)	29.6	6	1.78	274	0.423	1
UF2 (1963–4)	27.8	6	1.67	280	0.565	C
DL	24.6	5	1.23	377	0.669	S1
UF2	24.4	6	1.47	280	0.372	C

*Fairymead, Queensland.

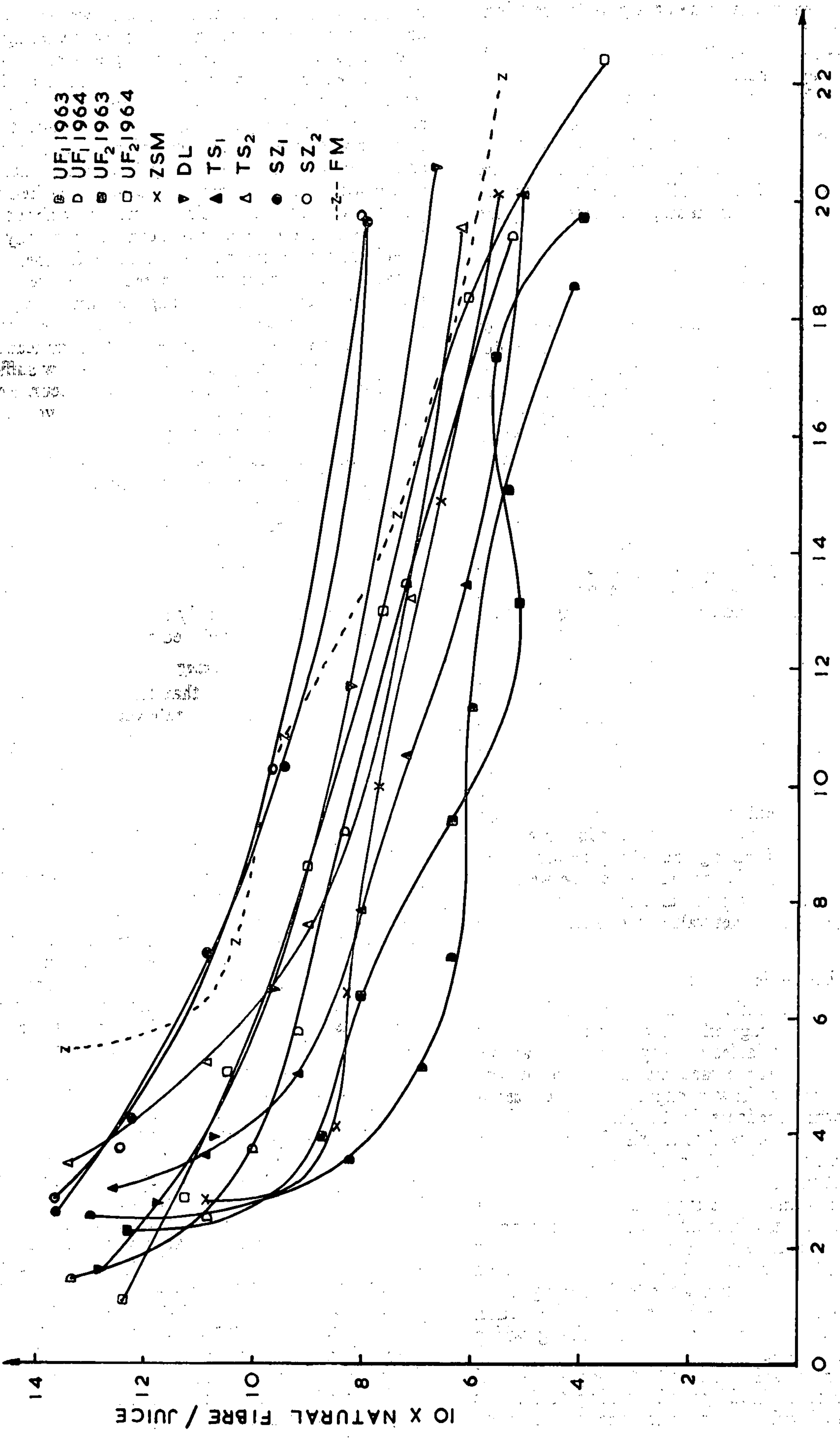

FIG. 7 - UNDERFLOW CURVES FOR MILLING TANDEMS

Regression analysis of these data gave the relationship in equation (7):

$$E' = 75 - 5.60\ I' - 2.75\ S' - 22.3\ F'_1 \quad . \quad . \quad (7)$$

where E' = stage efficiency
I' = imbibition/dry fibre ratio
S' = number of actual leaching stages
F'_1 = fibre/juice ratio in first mill bagasse

Underflow curves for the tandems in table 1 are reproduced in fig. 7 and indicate the progress of dilution and expression from stage to stage along the milling tandems.

Discussion

Stage Efficiencies

The results in table 1 show that stage efficiencies of milling tandems are rather low. The lowest is under 25% — this could be interpreted as only one quarter of the residual juice actually mixing with the imbibition juice at each stage before expression. The regression equation (7) shows that the stage efficiency variation from one tandem to another is mainly a function of (i) the imbibition to fibre ratio, (ii) the number of actual leaching stages and (iii) the fibre to juice ratio in bagasse entering the leaching system. This means in effect, that (i) additional amounts of imbibition applied to a milling tandem having a normal imbibition rate mix less efficiently with the residual juice, (ii) additional stages added to an existing average tandem will have a lower mixing efficiency than the preceding stage, (iii) the effect of improved milling will be to a certain extent subdued by the increased difficulty of efficiently diluting the residual juice.

Summarising, it appears that any attempt to increase the extraction of an existing tandem either by increasing the imbibition rate, the number of mills or the efficiency of milling (expression) will produce a diminishing increment in extraction. Hence the stage efficiency analyses provide a very clear interpretation of the limitations of milling and it may be concluded that a definite economic optimum exists between the cost of installed milling plant and operating costs on the one hand and the net value of extraction on the other.

Mixing Mechanism in a Tandem

The regression equation (7) above shows that most of the variance in stage efficiency may be accounted for by the three variables already mentioned above. One exception is that the tandems not equipped with shredders generally show a slightly lower efficiency than those with shredders. In the installations listed in table 1 a variety of positions exist for the location of the imbibition distributors. Hence it is logical to conclude that the location of the distributor is of little practical significance. This supports the opinion that mixing occurs mainly in front of the feed opening of the following mill. At this point a high-velocity countercurrent transport exists between the expressed juice and the bagasse entering the feed opening as the juice is forced through the bagasse bed. This action probably accounts for most of the mixing which occurs in each stage.

The results in table 1 show that the present final brix/fibre ratios attained by tandems of up to 6 stages could be achieved, under conditions of complete mixing, by less than 2 ideal stages. However, it would appear from the discussion in the previous paragraph, that a significant increase in mixing efficiency cannot be achieved in a conventional milling tandem. If the residual juice were simply absorbed on or near the surface of bagasse particles, then minor adjustments to the mixing process in present use would probably suffice. However, the difficulty lies in the fact that solute within microscopic cells is being leached from particles of macroscopic size. Fortunately about 90% or more of these cells have been mechanically ruptured[3], and thus the rate of solute diffusion to the surface of each particle is increased. However, the resistance to diffusion in the bagasse particle is greater than that from the surface to the bulk of the surrounding solution. Hence to achieve any significant improvement in mixing it is necessary to allow sufficient time for diffusion within the particles to occur. Reduction in particle size would also assist but would have to be considerable for any significant effect.

The above discussion infers that only by the inclusion of a diffuser between milling units could the mixing efficiency be increased to the extent necessary to reduce the number of milling stages. In other words the mixing efficiency of a normal milling tandem is so low that a large number of stages is essential for good extraction. However, the modern continuous cane diffuser is not the only solution to the problem of better mixing with reduced milling stages.

Milling with Efficient Mixing

In table 1 it is shown that for a tandem with an abnormally high imbibition rate such as Darnall, only 1.23 ideal leaching stages would be required to achieve the same extraction under the same milling conditions if ideal mixing were attainable. If only two stages were present, the leaching system would achieve the same result at 1.23/2 = 63% efficiency. This would require high-capacity mixers and intensive preparation of the first bagasse. The separation of the pulp would require additional equipment.

As an alternative, use could be made of short diffusion stages with an intervening mill. The advantage of such a multistage process is that mixing and countercurrent transport are conducted separately, whereas in continuous countercurrent apparatus, these operations are simultaneous. Experiments conducted by the author[4] have shown that 75% mixing efficiency can be attained after 10 minutes residence of first bagasse and cold water in a rotating flight-fitted leaching drum. On the other hand a well known continuous-contact diffuser has a bagasse residence time of 30 minutes.[2] For this reason it is probable that a two-stage diffuser with an intervening mill would require relatively smaller retention times and mixing efficiency than a single continuous unit hence considerably smaller and less elaborate equipment should suffice. The reduction in milling units and hence maintenance should compensate for the cost of two small diffusion units. This subject would provide the basis of an interesting pilot scale research project.

At this stage, however, the main conclusion to be drawn from this discussion is that owing to the inefficiency of mixing in normal milling, a relatively large number of imbibition stages is essential in order to achieve a good extraction, unless intermediate diffusion equipment is installed. Hence it may be anticipated that the future trend in milling of cane will be more in the direction of diffusion equipment than excessively long milling tandems, with elaborate feeding equipment requiring increasing maintenance, supervision and control.

Underflow Curves: Leaching vs. *Milling*

The underflow curves for the tandems listed in table 1 are compared in fig. 7. Bearing in mind that the slope of lines on this XY diagram is equal to the fibre/brix ratio of the bagasse, it is apparent that tandems with a high ratio of fibre/brix have a similarly high ratio in final bagasse except when the intermediate mills have a poor performance and long tandems achieve a better dilution than short tandems.

It is interesting to note that in many tandems only the last mill has a good expression, the intermediate mills performing little better than the first. These tandems generally achieve a lower dilution due to the greater residual juice remaining in the bagasse after each stage. This is particularly evident in the case of UF_1 (1963) showing that the pressure-fed last mill achieved a considerably higher fibre/juice ratio than the preceding mills. However, in the following year the curve for UF_1 (1964) shows that after improving mill settings the performance of intermediate mills increased and the difference between the last (pressure-fed) mill and the preceding mill performance decreased to a normal magnitude. Tandem UF_2 shows that a significant improvement in final dilution has been achieved by the improvement of intermediate mill performance. It is also clear that the milling (expression) of SZ_1 and SZ_2 tandems is more consistent and the performance higher than the other tandems considered. It is interesting to note that this is achieved by the combination of low speeds and high mill pressures without pressure feeders. However, the overall dilution performance is not as good as longer tandems and hence the final fibre/brix ratio is not higher than the longer tandems in spite of the good expression by SZ_1 and SZ_2.

From these observations it is clear that little is achieved in overall extraction by good final mill performance only. It is essential that first mills and intermediate mills be efficient and that sufficient imbibition stages are installed to achieve good dilution. It is also essential that both good leaching and good milling occur together.

In fig. 8 a typical XY underflow curve is shown through M_1 and M_2 which represent the conditions for typical first and last mills. Lines OA and OB have slopes equal to the fibre/brix ratio in first and last bagasses. Consider that an improvement in milling is required such that the fibre/brix ratios are increased to the values represented by OA^1 and OB^1. In the case of M_1 the improvement from OA to OA^1 could be achieved either by an increase in dilution of $\triangle X_1$ or an increase in mill expression of $\triangle Y_1$. Noting that $\triangle X_1$ is greater than $\triangle Y_1$, it is clear that in the initial milling stages good mill expression is more effective than good dilution. On the other hand for the last mill it is found that $\triangle Y_2$ is much greater than $\triangle X_2$. Hence for the latter stages, good dilution is more effective than good mill expression. Hence it is important to concentrate on attaining the highest possible mill expression on the earliest mills of a tandem and the highest possible dilution at the later mills. Thus we may conclude that, apart from fuel conservation, pressure feeders on final mills will achieve little improvement in extraction. Improvements in mill expression should more logically be directed at the earlier mills where the more concentrated juice is expressed. It follows that final bagasse moisture is a poor guide to overall performance and its use has attached an undeserved importance to the expression of the last unit (in terms of the effect of this unit on extraction). This is evident from the curve for Fairymead as well as many local tandems.

Conclusions

This paper has provided an example of how fundamental chemical engineering techniques may have a useful application in promoting a detailed analysis of unit operations in sugar manufacture. By the use of such methods the performance of plant units may be expressed on a more general basis. This could provide the means for an exchange of performance data not only within the sugar industry, but also from other industrial plants.

The calculation of stage efficiencies has shown that the efficiency of mixing in a milling tandem is low, particularly in long tandems with high imbibition rates. This indicates that the milling operation has limitations and it is concluded that diffusion is theoretically the most logical process to improve mixing efficiencies. Without diffusion, long tandems are necessary to promote the high degree of dilution necessary for good extraction. It is possible that two-stage diffusion may have advantages over continuous single-stage diffusion. In the former case, mixing and countercurrent transport between solid and liquid are conducted separately.

A regression analysis of the factors influencing stage efficiency has suggested that little significance should be attached to the location of imbibition distributors. It appears that in a normal tandem mixing occurs in front of the feeder opening of the following mill. The main resistance to mixing appears to be in the rate of diffusion of solute from within bagasse particles to the surface. Resistance to diffusion from the surface of particles into the surrounding liquid is relatively small. This again infers the necessity for diffusion.

A comparison of drainage *vs.* dilution diagrams for several tandems has indicated a number of useful conclusions regarding the operation of tandems. An important conclusion is that efficient mill expression is theoretically required in the initial milling stages and good dilution is necessary in later stages if good performance is to be achieved. Hence pressure feeders should theoretically be on the first unit for most benefit in extraction.

Finally, it is hoped that this paper will assist in promoting an increased interest in the application of chemical engineering techniques to the design and evaluation of unit operations in the manufacture of sugar.

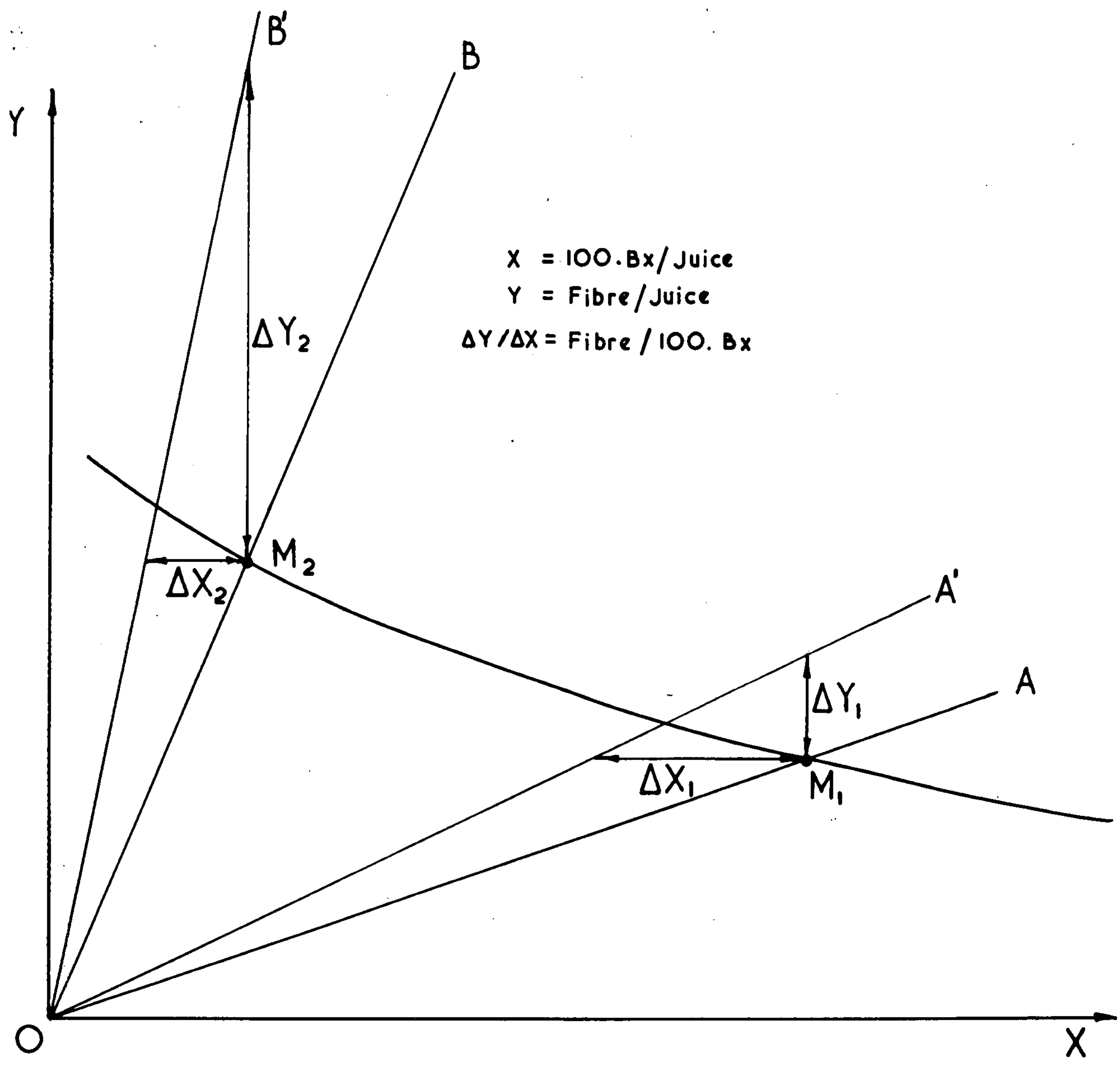

FIG.8 COMPARISON OF MILLING & LEACHING

Acknowledgments

The author is indebted to Dr. Allen, director of the Sugar Research Institute, Mackay and to the management of the factories listed in table 1 for providing the data necessary for calculations in this report.

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Appendix

Example of Stage Efficiency Calculation

The following data were furnished from Darnall milling tandem:

The figures in column (6) of table A were calculated from the equation:

$$F = 100 - (M + 100.S/P)$$

Solution

The number of ideal stages is determined using the modified Ponchon-Savarit construction outlined in the body of this paper.

The co-ordinates of the diagram are calculated as follows:

X = ratio of brix/juice in back roller juice = (brix of juice)/100

and Y = ratio of natural fibre/juice in bagasse = $1.25\ F_b/(100 - 1.25\ F_b)$

By substitution of the tabulated data above in these equations the co-ordinates of the XY diagram are calculated as in table B.

TABLE A

	(1)	(2)	(3)	(4)	(5)	(6)
Imbibition Stage No.	Mill No.	Back Roller Juice		Bagasse		
		Brix (b)	Purity (P)	% Sucrose (S)	% Moisture (M)	% Fibre (F_b)
-	1	20.52	87.88	9.72	56.88	32.06
1	2	11.66	84.95	7.10	55.41	36.23
2	3	6.52	82.97	5.02	54.65	39.30
3	4	3.87	81.40	3.56	54.37	41.26
4	5	2.75	78.47	2.70	53.15	43.41
5	6	1.55	72.42	1.90	52.47	44.91

Imbibition = 377% on dry fibre.

Hence the underflow curve $M_1\ M_6$ in fig. 9 may be plotted.

The overall balance is constructed graphically from the points L_a, L_b, V_b and J:

Basis 100 lb. first bagasse as in table A

First bagasse contains: 11.06 lb bx

1.25 x 32.06 = 40.08 lb. nat. fibre

100 — (11.06 + 40.08) = 48.86 lb free water

Point L_a: $X = \dfrac{11.06}{11.06 + 48.86} = 0.185$

$$Y = \frac{40.08}{11.06 + 48.86} = 0.669$$

Point V_b: $X = 0$ (since imbibition contains no $Y = 0$ brix)

These points are plotted on the graph (fig. 9) and the line $L_a\ V_b$ is drawn.

Point J: Imbibition % dry fibre = 377,

i.e., on 32.06 lb dry fibre we have $\dfrac{377 \times 32.06}{100}$ = 121 lb imbibition

TABLE B

Mill No.	X	Y	
1 . . .	0.205	0.669	x = concentration, lb brix/lb juice
2 . . .	0.117	0.828	
3 . . .	0.065	0.966	y = juice retained, lb fibre/lb juice
4 . . .	0.039	1.065	
5 . . .	0.028	1.186	
6 . . .	0.016	1.280	

The total juice input is 48.86 + 11.06 = 59.92 lb hence the total solution input is

59.92 + 121 = 180.92 lb

By the centre of gravity principle (fig. 4) point J is located on $L_a\ V_b$ at a distance from V_b of 59.92/180.92 = 0.331 the length of $L_a\ V_b$. (The full scale graph in fig. 9 gave $L_a\ V_b$ = 9.85 in. Hence the distance of J from V_b was 9.85 x 0.331 = 3.25 in). Hence point J is determined.

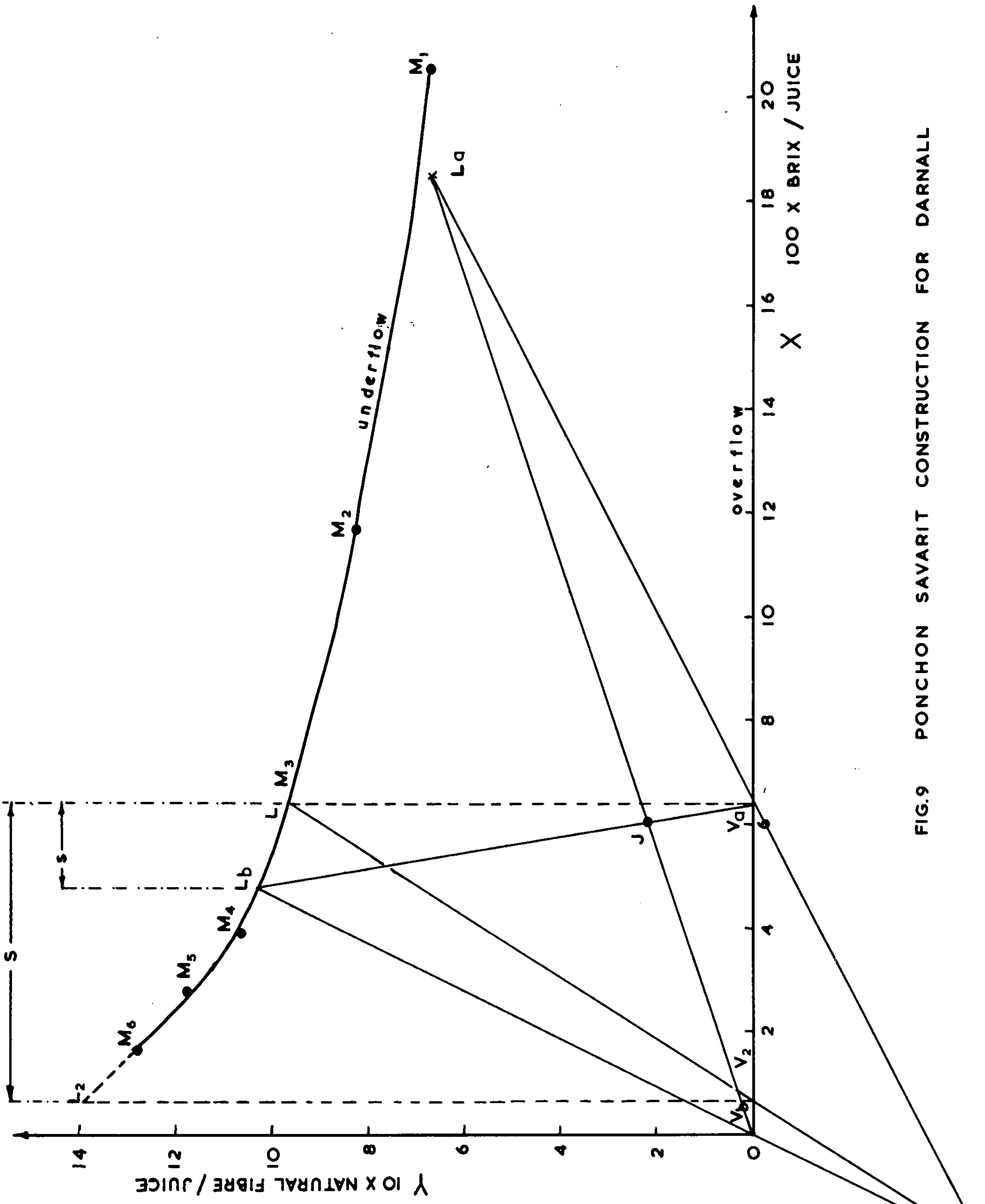

FIG.9 PONCHON SAVARIT CONSTRUCTION FOR DARNALL

Point L_b: This point represents the condition of final bagasse. It should lie on the underflow curve and is located as follows:

From table A, last bagasse contains 2.62% bx and $44.91 \times 1.25 = 56.14$% nat. fibre
fibre/brix ratio = 56.14/2.62 = 21.4

Hence L_b is fixed by the intersection of a line of slope 21.4 with the underflow curve. This line is $V_b L_b$ in fig. 9.

Point V_a: This represents the overflow from the first ideal stage. By mass balance

$$J = V_a + L_b$$

hence J, V_a and L_b lie on a straight line. The intercept of L_bJ produced, with the abscissa, fixes V_a.

Point P: The intersection of lines L_b V_b produced and L_a V_a produced locates point P.

Operating Lines: Operating lines are drawn to construct the number of ideal stages. The vertical (dotted) tie line through V_a fixes L_1 on the underflow curve. This represents the condition of the bagasse from the first ideal stage. The intersection of L_1P with the abscissa fixes point V_2 which represents the overflow from the second ideal stage. The tie line V_2 L_2 intersects the underflow curve at a point beyond L_b hence less than two ideal stages are required to achieve the bagasse condition represented by L_b. The fraction of the second ideal stage actually required is s/S as in fig. 9. In the full scale graph s = 0.78, and S = 2.90, hence s/S = 0.27.

Stage Efficiency: 1.27 ideal stages are equivalent to 5 actual imbibition stages hence the stage efficiency is 1.27/5 = 25.4%.

Summary

It is pointed out in this paper that in the rapid expansion of the sugar industry and sugar technology the application of general techniques of chemical engineering to plant design and performance rating should not be overlooked. This is particularly important considering that the process involves almost every unit operation of chemical engineering.

The application of the modified Ponchon-Savarit analysis, for leaching systems, to the determination of stage efficiencies in milling tandems is described. Several tandems in Natal as well as an Australian tandem are analysed using this method. Stage efficiencies are as low as 25% indicating poor mixing. It is shown that only by incorporating diffusion can the number of imbibition stages be reduced without increasing losses. Juice expression is most important in the first mill and dilution at the last. Hence pressure feeders are unlikely to reduce losses significantly when applied to last mills. Underflow curves plotted for imbibition stages indicate that in many Natal tandems losses are increased by neglecting the performance of intermediate mills.

There is a definite economic limit to the number of mills and imbibition rate since the increase of both reduces stage efficiency. A two-stage countercurrent diffuser with an intervening mill is suggested.

Mr. Gunn (in the chair): We have just seen how chemical engineering can assist in the design of plant in a sugar mill. The answer seems to be a small number of milling stages, with diffusion.

Dr. Douwes Dekker: The Ponchon Savarit diagram discussed in this report has been based upon the brix of the back roller juice at each stage. Is this correct, in view of the fact that a considerable difference exists between the condition of the back roller juice and the residual juice, for the purpose of stagewise extraction calculations?

Mr. Buchanan: The underflow curve is only used to express drainage conditions, not degree of extraction or anything else.

It indicates the dependence of the amount of juice retained in the bagasse upon the dilution of the juice.