THE RIVIÈRE JUICE EXTRACTOR: A NEW APPROACH TO THE EXTRACTION OF JUICE FROM CANE

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Abstract

A rapid continuous patented process is described for the extraction at ambient temperature of juice from shredded cane in three stages. In each stage air is displaced from the cane bed by upward flow of displacement juice ('Meichage') followed by downward displacement of the enriched juice in true plug flow by lower brix juice pumped from the succeeding stage. In the third (final) stage the displacement is by a mixture of presswater and imbibition water. Megasse from the final stage is conventionally dewatered. Total processing time including dewatering/drying is about two minutes. Pol extraction of 98% has been achieved in laboratory tests. The theory on which the design is based, a flow diagram, brix balance, typical layout drawing and comparative costings of a Rivière Juice Extractor and other methods of juice extraction are presented.

Introduction

The late Maxime Rivière during his lifetime registered many patents, mainly concerned with the extraction of juice from cane. The most important, in the author's opinion, was his final patent which covered improving the efficiency of the extraction process by:

- filling the voids in finely prepared cane with counter flow juice turning the shredded cane into a free flowing mixture of cane and juice
- replacing the thick juice in the cane by thinner juice in three stages in a true plug flow displacement process
- improving the efficiency of the solid/liquid separation between stages by increasing the hydrostatic head between the liquid mass in the extractor and the drained liquid receiving tank.

Displacement process

Maxwell (1930) wrote: "Mills in action are somewhat reminicent of the cave age; sheer brute force, huge wearing masses of metal, vast amounts of power and enormous pressures." and Hugot (1972) described a mill as "...a barbarous piece of equipment." The stage efficiency of mills is no more than 25 to 35%.

Cane diffusers now in use were developed from multi-stage counter current beet diffusers, not from scientific consideration of the desiderata. With an ever increasing processing rate, sugar factories are in danger of becoming mechanical monstrosities: a 10 000 tcd unit is 10 to 12 m wide x 60 m long. It has a mass of about 600 tons and has a headshaft weighing roughly 90 tons.

In both milling and conventional diffusers, the mixing/separation process is employed. The stage efficiency of cane diffusers is approximately equal to that of mills, viz. 30 to 35%.

The concept of 'displacement extraction' was patented by Matthey in 1889 under English Patent No. 21021 (Deere, 1921).

Payne (1963, 1969) pointed out the advantages of the displacement process. He wrote that having "...achieved the rupturing and stripping of the (juice) storage cells" "...what is now wanted is to isolate the rich juice from the fibre. Theoretically, this can be effected efficiently by displacement with water. Such a displacement is best achieved by a counter-current flow of water and fibre-juice in which the water flows as an advancing front similar to the phenomenon of saturated flow in porous media. The advancing front of water operates like pistons through the many ruptured cell modules replacing the juice. Any macro breaks in the bed lead to piping, channeling and by-pass of water from the displacement process. Any mixing in the system reduces the effective counter-current flow. Any pressing or squeezing will expel juice concurrently as well as counter-currently and cause mixing. *The ideal system therefore is an undisturbed bed of fibre and juice and a plug-type water-juice flow.*" This ideal is what is achieved in the Rivière Juice Extractor.

The advantages of displacement over mixing/separation are best demonstrated by the Ponchon–Savarit diagrams shown in Figures 1, 2 and 3.

- Figure 1 is the diagram for a conventional five mill tandem with imbibition rate of 200% on fibre. It shows that the brix of the extractable juice in bagasse leaving a given stage is much higher (five to seven points) than the juice separated from the same stage.
- Figure 2 is what the diagram would be like if there were 100% mixing efficiency on the five mill tandem with an imbibition rate of 200% on fibre. Number two mill bagasse would have the same brix of extractable juice as the juice (J2) coming out of the first stage. With only two stages the target brix of final bagasse composition is overshot.
- Figure 3 is the Ponchon-Savarit diagram applied to a fully efficient displacement process. The brix of the juice displaced in a given stage is always higher by at least two points than the brix of the extractable juice of the bagasse leaving the same stage as was achieved in the pilot plant on which Maxime Rivière's patent was based.

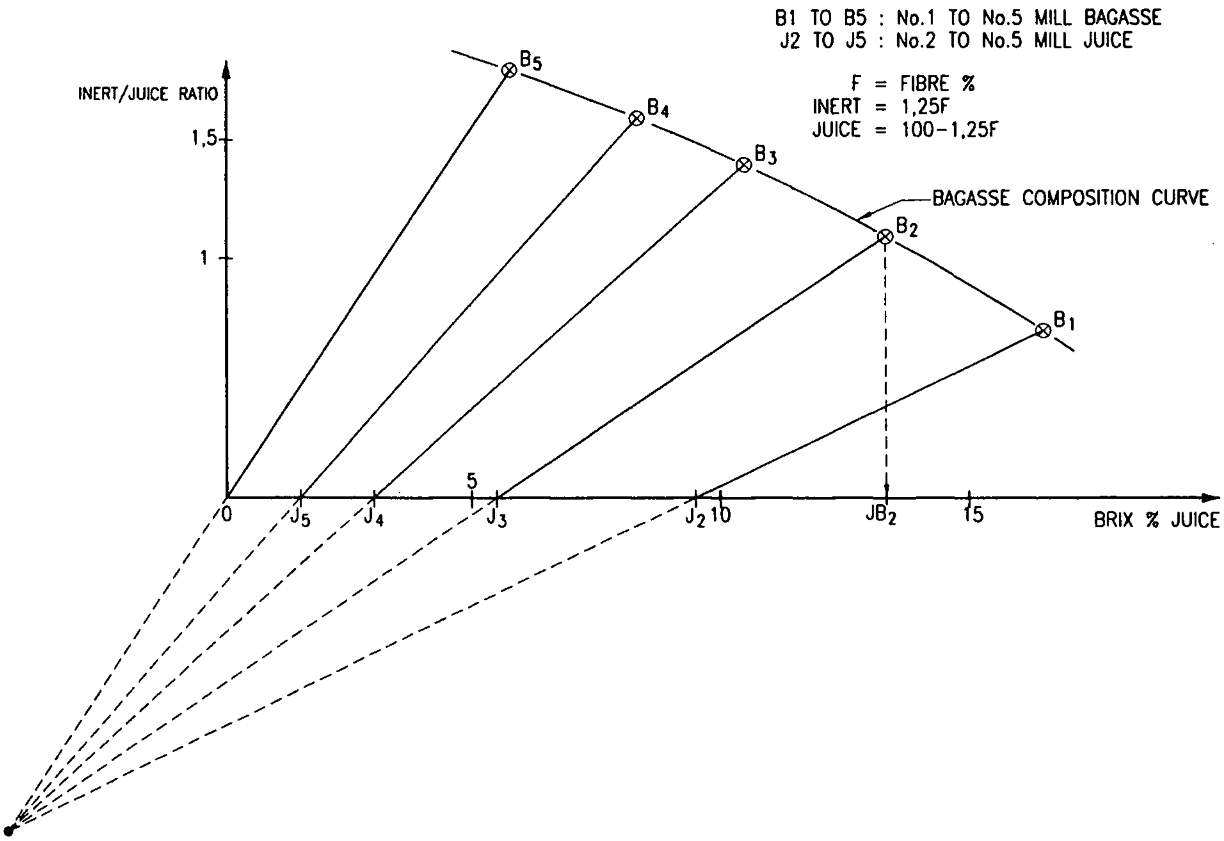

Figure 1. Ponchon-Savarit diagram for a tandem of five mills.

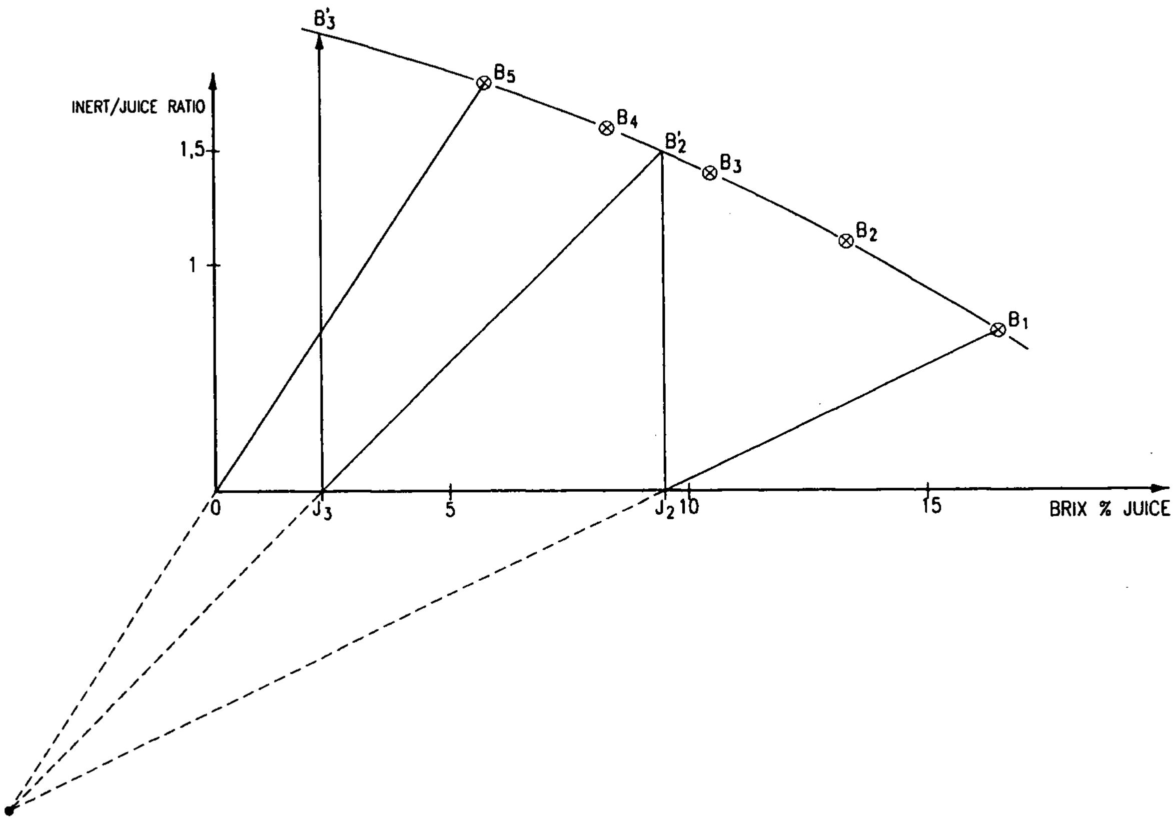

Figure 2. Ponchon-Savarit diagram with prediction of number of stages needed with 100% mixing efficiency.

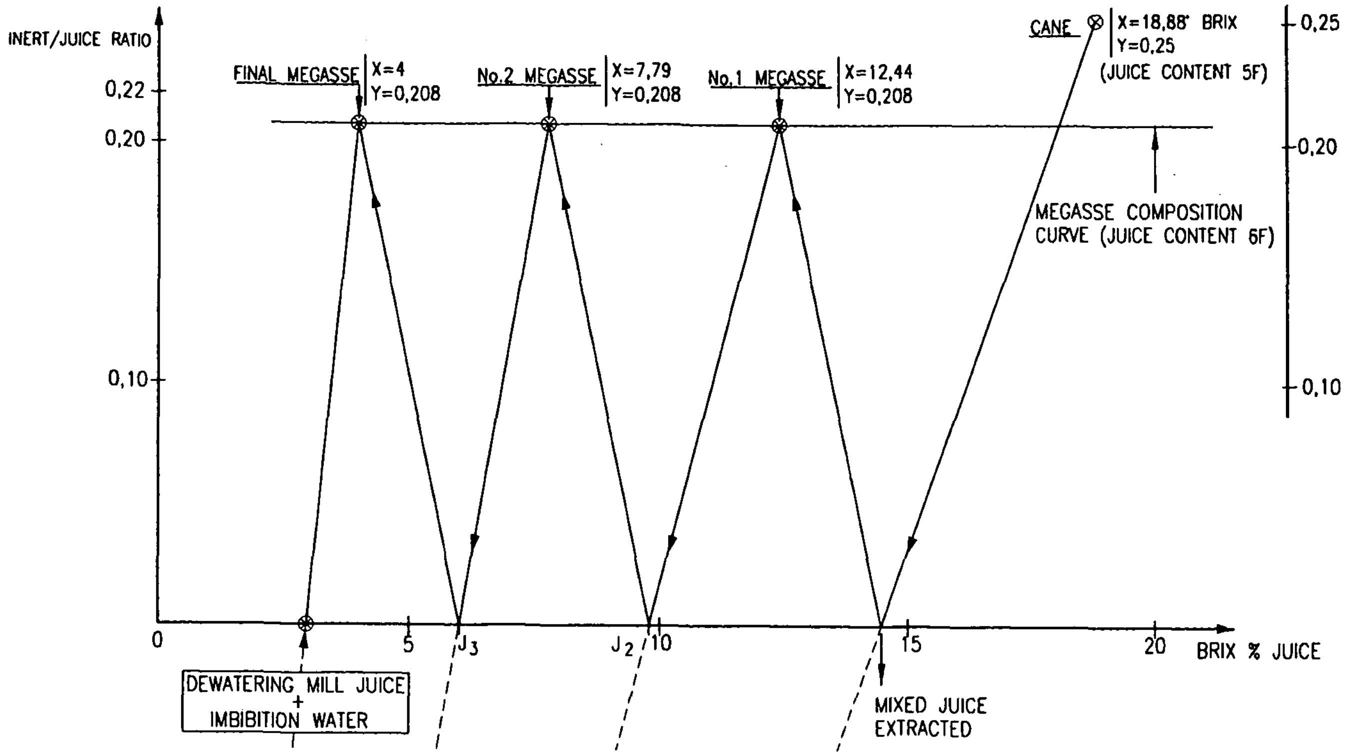

Figure 3. Ponchon-Savarit diagram for number of stages needed for displacement process.

If fully efficient displacement were taking place in a cane diffuser, only three stages would be enough to achieve 98% extraction using an imbibition rate of 200% on fibre. In practice, up to 18 stages are required. Buchanan (1968) calculated the ideal number of stages for a cane diffuser as 5,54, based on the stage residence time for interstage drainage determined from percolation tests and the mean particle size of prepared cane but concluded that, with a stage efficiency of 34%, 17 stages would be required. In the Rivière Juice Extractor, only three stages are required.

Development of the Rivière juice extraction process

This process has been developed as a result of a scientific approach by Maxime Rivière to the design of an extraction plant based on the displacement principle, the structure of the raw material and its volumetric composition, as set out below.

Bulk density of shredded cane depends on preparation and compaction and typically varies from 250 to 350 kg/m³ on a conveyor at up to 0,5 m depth. In this condition one ton of cane will occupy an apparent volume of 2,8 to 4,0 m³. The no void volume of cane being 0,89 m³/t, the void volume in the above described bed of shredded cane is between (2,8 – 0,89) = 1,91 m³/t of cane and (4 – 0,89) = 3,11 m³/t of cane.

Assuming a fibre content of 150 kg/t of cane (F=15), the amount of juice (of say, 1,05 density) necessary to fill the voids is between 1,91 x 1,05 = 2 and 3,11 x 1,05 = 3,27 t, or, expressed in terms of fibre, between 2000/150 = 13,33 F and 3270/150 = 21,8 F. (In the experiments conducted by Maxime Rivière on a pilot plant in Reunion, the amount of juice required to fill the voids was 15 to 20 F.)

In a conventional cane diffuser the 0,5 m upper layer of shredded cane has a similar density to that referred to above but, due to compaction, the density increases until, in the bottom layer of cane, the bulk density is probably two or three times higher. According to Hugot (1972), the average bulk density for cane in a diffuser is 500 to 600 kg/m³ which means that the average apparent volume occupied by one ton of cane is 1,67 to 2 m³. Deducting the no void volume of cane, this leaves a void volume of 0,78 to 1,11 m³. The filling of this void volume with 1,05 density juice will require 819 to 1 165 kg of juice.

According to the operation results published by Payne (1962) for a Silver diffuser in Hawaii, the maximum amount of juice that can be present without flooding was 5,6 F. For the average fibre content of cane in Hawaii of 13,5%, the weight of juice per ton of cane was 5,6 x 135 = 756 kg. The corresponding volume of juice was 0,720 m³/t which leaves, on average, a volume of air in the mat of cane of between 0,78 – 0,72 = 0,06 and 1,11 – 0,72 = 0,39 m³ air/t of cane. But in the upper layer of the bed, the volume of air is between 2 and 3 m³/t cane.

This is surely one of the reasons for the low stage efficiency of cane diffusers, the presence of air impairing the mixing efficiency.

However, the main disadvantage of the operation of a leaching or lixiviation process through a bed of cane of 1,5 to 2 metres high, as obtains in most commercial diffusers, is the low percolation rate of about 0,1 m/min, which results in cane retention times of 50 to 60 minutes. Stage efficiency is low because of channelling and the by-passing of stage circulation juice between the stages. Percolating angles ranging from 57 degrees from the horizontal in the first stage to 14,5 degrees in the last stages have been reported. Bed-disturbing screws have to be used to facilitate percolation.

The Rivière extraction process avoids these disadvantages, as it:

- uses cane beds of only 0,3 to 0,5 m depth
- completely removes the air between the cane particles and, aided by the increased hydrostatic head which the design provides, gives a percolation rate of *ca* 0,1 m/sec
- completes the displacement extraction process in *ca* one minute.

Meichage

Removal of air from the cells containing sliced beets was considered fundamental for efficient batch diffusion in the beet sugar industry before continuous diffusers were adopted. It was referred to by the ancient name 'meichage' in the north of France.

Meichage was also used in Egypt in the early 1930s in the Naudet multi-cell process of bagasse batch diffusion where, after filling each cell of the diffuser with bagasse, the cell was closed. Juice gravitated to the bottom of the cell and rose through the column of bagasse until it emerged from a cock on the lid of the cell, at which point the cock was closed. By this operation, the air contained in the bagasse was removed.

Of local interest is the fact that the first commercially successful extraction of juice by cane diffusion was in a plant constructed *ca* 1960 by the Durban firm of Patrick Murray (Pty) Ltd, with which the author was associated, at the factory of the Rhodesian Wattle Co. at Umtali when Trevor Boast was Manager. Prepared cane was processed in the multi-cell batch diffuser normally used to produce wattle bark extract.

Through combining the use of Meichage with the displacement process in a continuous cane juice extraction plant, Maxime Rivière has produced a breakthrough in juice extraction technology.

The validity of Maxime Rivière's juice extraction process has been demonstrated in pilot plant tests, conducted by the Sugar Research Institute (CERF) on Reunion Island and repeated independently by Copersucar in Brazil. These tests simulated the displacement of the extractable juice in cane in three stages, showing that an extraction rate of 98% can be achieved after dewatering the megasse in a hydraulic press to a moisture content similar to that which can be achieved by a conventional last mill.

It is interesting that the measure of the thoroughness of cane preparation formerly termed the 'leachability index' is now termed the 'displaceability index' in many cane sugar producing countries. The design of the Rivière Juice Extractor is based upon extracting all of the displaceable juice in three stages.

Description of process

Ponchon-Savarit diagram

From the results of the pilot plant experimentation, the number of stages to be used was determined by the Ponchon-Savarit diagram (Figure 3) assuming the following shredded cane analyses and operational conditions:

- preparation index 90%
- fibre 16%
- extractable juice content 80% (=5 F)
- brix of extractable juice 18,88
- an imbibition rate of 200% on fibre (2 F)
- final 'megasse' with extractable juice content equal to 6 F
- a brix of the extractable juice in the megasse, leaving a given stage, 2 points lower than the brix of the juice coming out of the same stage.

The target of 4° brix of juice in the final megasse is reached in three stages. This corresponds to a pol extraction of 98% when the purity of extractable juice in cane is 85 and the purity of extractable juice in bagasse is 60.

Flow diagram

With the above operational conditions, the flow diagram in Figure 4 has been drawn. In each stage, for a 100% efficient displacement process to take place, three operations have to be implemented.

(A) First stage

Meichage

Given an average typical shredded cane bulk density, the amount of Meichage juice needed to fill the voids between the cane particles completely is 15 F, giving an initial total juice content of the megasse in the first stage of 20 F at 15,55° brix, using as meichage 15 F of juice at the same brix 14,44° as in mixed juice leaving the first stage.

Displacement

Displacement is performed using the juice (7,36 F, brix 9,79°) coming out of the second stage to replace the same amount (7,36 F) of juice at 15,55° brix contained in the megasse, which is thus extracted by displacement.

Drainage

Before leaving the first stage the juice content of the megasse which, after displacement contains 20 F of juice at an average brix of 13,43°, is drained by gravity into a receiving tank resulting in a juice content of 6 F in the megasse leaving the first stage.

The amount of drainage juice will be 14 F at a brix of 13,85°. This juice is mixed with displaced juice (7,36 F at 15,55° brix) giving a mixed juice with brix of 14,44°. From this mixed juice, 15 F is recirculated as Meichage juice and 6,36 F leaves as extracted juice to maintain the overall balance, which is:

- juice in: 5 F from the cane + 2 F as imbibition water = 7 F
- juice out: extracted juice (mixed juice) 6,36 F + 0,64 F as extractable juice in the final bagasse = 7 F.

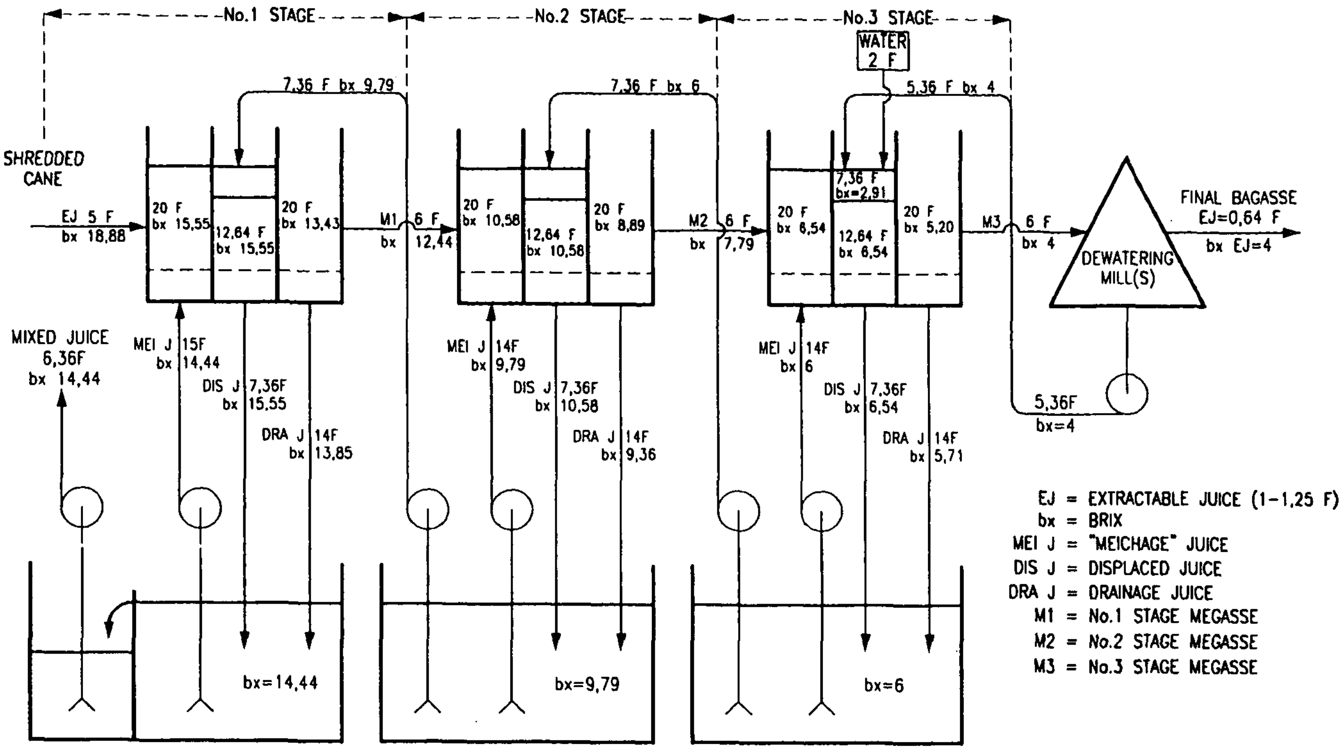

Figure 4. Flow diagram for Rivière juice extractor.

(B) Second stage

Meichage

As the megasse will have the same juice content (6 F), in and out of the stage, the quantity of Meichage juice will be 14 F in this case (instead of 15 F in the first stage).

Displacement

Juice (7,36 F) coming from the third stage at a brix of 6° will displace the same amount (7,36 F) of juice at 10,58° brix.

Drainage

Juice (14 F) at 9,36° brix will leave 6 F as juice content of the megasse feeding the third stage.

(C) Third stage

Meichage

As in the second stage the Meichage juice (14 F) will be supplied by the drainage and displaced juice with a brix of 6°.

Displacement

The dewatering mill juice (5,36 F) will be used as displacement juice, followed by imbibition water 2 F. The brix of the displaced juice (7,36 F) will be 6,54°.

Drainage

Juice (14 F) at 5,71° brix will be drained from the third and last stage, giving:

- a juice content (6 F) in the final megasse at the target brix of 4°
- a mixed juice (displaced + drained juice) of 21,36 F at 6° brix which supplies the
- Meichage juice (14 F) for the third stage and the displacement juice for the second stage (7,36 F).

Design of industrial unit

Two configurations of the Rivière Juice Extractor have been proposed for industrial application:

Horizontal drag conveyor type

This comprises a conventional type horizontal double chain and slat conveyor to transport the prepared cane delivered from the shredder to the dewatering mill(s) and having a suitably perforated deck at the Meichage, displacement and drainage sections. An industrial prototype installed by Copersucar at a sugar factory in Brazil is described in more detail under the following section.

Induced flow paddle blade type

This comprises three stages, each with a paddle bladed rotor operating in a casing, semicircular in section, suitably perforated at the Meichage, displacement and drainage sections.

A typical horizontal drag conveyor type of industrial unit is shown in Figure 5.

In considering the operation of both types, it is important to note that, as stated previously, the displacement process can only be performed efficiently when the air has been expelled from the megasse under which condition the juice content of the megasse is at least 20 times the fibre content of the cane. This means that the fibre content of the megasse must be less than 5%.

In this condition, megasse has the hydrodynamic characteristics of a liquid. In fact, a slurry containing up to 7% fibre content can be pumped. With a juice content of 20 F, megasse will flow freely, by gravity, in an open trough. Because of this, mechanical transportation of megasse in a displacement process is not needed during Meichage and displacement. Only when drainage is taking place will the relatively drier material need to be transported mechanically.

The flow diagrams for both types of unit are the same and are shown in Figure 4.

Description of industrial prototype

A proportion of the cane used for the tests conducted by Copersucar was taken from near the top of a chute feeding the first mill of an existing tandem at the São Luiz AA factory in the state of São Paulo, Brazil, and was conveyed via a slat-type cross carrier to the prototype Rivière Juice Extractor. An opening in the deck of the cross carrier allowed the cane to fall into the extractor.

The extractor incorporates a narrow steel trough 350 mm deep x *ca* 16 m effective length. The bottom of the trough is perforated where necessary to allow the passage of juice in the sections of the three stages where upward or downward juice flow takes place.

Two endless driven chains running on either side and just above the trough carry steel plate slats which effectively compartmentalise the trough into a series of boxes preventing cross-flow of juice between the sections and between the stages. The pitch of the slats is *ca* 400 mm.

A frequency inverter is used to set the speed of the extractor drive motor. At a speed of *ca* 13 m/min the calculated capacity of the unit is 25 tons cane/hour based on a cane bulk density of 250 to 300 kg/m³. The processing time is 1,25 minutes. The unit would preferably be operated at a higher speed than 13 m/min but this would have made the dimensions too small for practical operation, particularly in regard to the ease of filling the individual compartments.

Each of the three stages consists of the three individual operations described above:

- Meichage, which is effected by pumping juice upwards through the perforated bottom of the trough at a controlled rate such that the juice level is automatically maintained at the height of the top of the juice-fibre bed.
- Displacement, in which the juice in the bed is displaced downwards through the perforated bottom of the trough by a stream of lower brix juice which is pumped onto the top of the bed from the succeeding stage. In the case of the third (last) stage this displacing stream is a mixture of press water from the dewatering mill and imbibition water. In the displacement section, the juice level is automatically maintained at the top of the juice-fibre bed by controlling a valve on the displacement drain line.
- Drainage, where the juice in the bed is allowed to drain through the perforated bottom.

The maintenance of an unbroken column of liquid of *ca* 4 m is necessary to give the high liquid displacement and drainage rates on which the design is based.

The two streams from each of the three stages of the extractor, viz the displaced juice and the drainage juice, are fed from the extractor trough to a tank situated about 4 metres below the extractor trough.

The Meichage juice is pumped from this tank with:

- first Meichage juice coming from the first tank
- second Meichage juice from the second tank
- third Meichage juice from the third tank.

Mixed juice to processing overflows from the first tank. Displacement juice for the first stage is pumped from the second tank, that for the second stage is pumped from the third tank while that for the third stage is pumped from the press water plus imbibition water tank. The individual air displacement (Meichage), juice displacement and drainage sections of the extractor have perforated bottom plates but between the three sections of each stage and between the three stages, the bottom deck of the extractor trough is not perforated to avoid cross mixing.

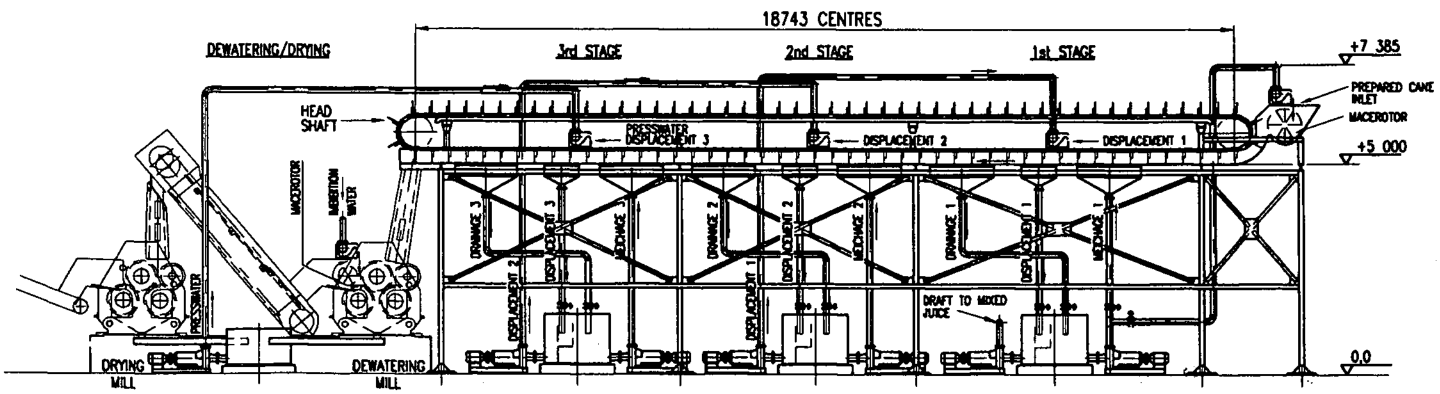

Figure 5. Rivière juice extractor – plant layout.

Megasse from the third stage is fed through a vertical chute to a six roller mill. The bagasse is sent to the boilers while the unscreened press water flows to the tank where it is mixed with the imbibition water. The quantity of imbibition water is measured by a magnetic flow meter and set manually to the required flow rate.

If two mills are used in tandem for dewatering/drying, imbibition may be applied between the mills, as is the case in many conventional diffuser installations, to reduce further the pol in bagasse.

At the time of preparation of this paper, the industrial prototype had been erected and cold commissioned but no process tests had been conducted. These were to commence at the beginning of the 1998 crop.

In an alternative form of feed, the prepared cane falls into a casing, semicircular in section, in which a multi-bladed macerotor thoroughly mixes it with part of the Meichage juice, allowing the fibre-juice mixture to flow into the extractor.

The first production units are likely to be of the horizontal drag conveyor type and will almost certainly follow the configuration of this industrial prototype. The width of the trough will vary with the capacity. Based on a 350 mm juice-fibre depth in the trough and a speed of 25 m/min, the width of the trough will be 650 mm per 100 tch. Speeds of up to 30 m/min are contemplated. Conventional diffusers with a width of bed in the order of 2,5 m per 100 tch, and a length of 60 m, are some four times the width and four times the length of an equivalent Rivière Juice Extractor.

Typical trough widths of Rivière Juice Extractors will be:

100 tch	650 mm
200 tch	1 300 mm
300 tch	1 950 mm
400 tch	2 600 mm.

These dimensions may be reduced by increasing the operating level in the trough above 350 mm and increasing the effective length proportionately. It is envisaged that, in most instances, a Rivière Juice Extractor will be capable of being installed in an existing mill house, in the space normally occupied by three or four mills in a tandem, where it would receive prepared cane directly from the existing feed system and discharge spent megasse directly into the dewatering/drying mills(s) feed chute.

Sand removal

An unexpected negative effect resulting from the introduction of cane diffusion in place of milling has been the retention in the cane bed of sand brought in with the cane which, in milling, was largely removed in the mill juice. This has been evident in the reduced quantity of clarifier muds in diffusion factories but, more expensively, in the increased wear and tear in boiler plants which have led to the introduction of single pass boilers with 'membrane' walls. The destructive effect of sand brought in with the cane has been exacerbated by the increasing introduction of mechanical loading of cane in the fields, particularly push-piled windrowed cane.

Since the cane/juice mixture is in the liquid phase in each of the Meichage and displacement stages, it can be expected that much of the sand carried in with the cane will be decanted in the displacement stage and be carried out with the juice in the drainage stage.

It would be prudent therefore to provide for sand trapping and removal in the juice tanks beneath the extractor. The cost of such arrangements will be justified by the saving in boiler maintenance costs and in reduced capital costs of boilers on new installations.

Heating in the Rivière Juice Extractor

Indications are that the operating temperature has little bearing on the extraction results. In conventional diffusers the temperature is kept high enough to prevent micro-organism growth but in the Rivière Juice Extractor the retention time of *ca* one minute versus 50 to 60 minutes in a conventional diffuser eliminates this requirement.

In a conventional diffuser, the high temperature is also intended to assist in the dialysis process. The question is, just how much juice is extracted by lixiviation and how much by dialysis in a conventional diffuser? Not much appears to be extracted by dialysis, judging by the test results of the Rivière Juice Extractor.

It is generally accepted that starch extraction is substantially reduced by lower temperature operation. Presswater returned from the dewatering/drying mills need not be clarified or heated as in conventional diffusers. There have been many reports of difficulties experienced in feeding dewatering/drying mills with hot megasse of 80 to 85% moisture content so that the cold process employed in the Rivière Juice Extractor will be advantageous in this respect.

Capital cost

For comparative purposes, the March 1998 cost of three alternative juice extracting systems, commencing after the cane preparation system which is assumed to be common to all of them, *viz:* a new five mill tandem, a new cane diffusion plant with dewatering/drying mills and a Rivière Juice Extractor with dewatering/drying mills, all rated for 250 tch, including civil works and installation in South Africa, together with other significant differences, e.g. draft juice % cane, power consumption and estimated annual maintenance costs, are set out in Table 1. Power savings and reduced load on the evaporator station are significant, especially with the increasing importance of co-generation in the sugar industry.

Acknowledgements

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Table 1. Comparative costs of three juice extraction systems.

Plant	Milling plant	Cane diffusion plant	Rivière Juice Extractor
Description	Five 1 067 x 2 134 four-roller mills with 750 kW variable speed electric drives, intercarriers, Donnelly chutes, juice screens, pumps and piping. NOTE: no allowance for additional power generating plant.	6,5 m wide cane diffuser with dry feed conveyor, scalding juice heating, pumps and piping, draft juice screen, two 1067 x 2 134 four-roller mills with 750 kW V.S. electric drives, intercarrier, presswater screens, pumps and presswater heater	1 676 m wide juice extractor with macerotor feed, pumps, tanks and piping, draft juice screen two 1 067 x 2 134 four roller mills with 750 kW V.S. electric drives, intercarrier and pump.
Cost of extraction plant	N/A	R26 250 000	R6 250 000
Cost of dewatering drying mills	N/A	R23 000 000	R23 000 000
Total cost including civil works and erection	R57 000 000	R49 250 000	R29 250 000
Power consumption	3 600 kW	1 800 kW	1 300 kW
Estimated annual operating and maintenance cost for processing 1 000 000 tons of cane per annum (labour and materials)	R4 710 000	R2 185 000	R1 475 000
Draft juice % cane	115	122,5	100
Predicted Pol extraction %	96,5	98	98

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