COMPARISON OF DIFFUSION AND MILLING AT A CANE SUGAR PLANT

By

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Low Operation and Maintenance Cost, Exportable Electricity.

Abstract

WITH THE advent of the diffusion technology and its improvement, diffusers have replaced mills for juice extraction at a few cane sugar plants due to their better extraction efficiency, lower manpower needs, lower power consumption, low operating and maintenance cost, increase in exportable electricity, and better operation flexibility. The performance of a cane diffuser at The Andhra Sugars Limited, Sugar Unit – II at Taduvai has been elucidated and a comparison done between diffusion and milling. Taduvai achieves a reduced milling extraction (RME)[1] of 98.4% and pol in bagasse (%) of 0.84 and has 51% lower manpower, 18% lower power consumption and 60% lower operation and maintenance costs compared to a milling tandem. The vacuum filter station has been eliminated. With a cane diffuser, 2616 kW more electricity can be exported than with a milling tandem.

Introduction

'In the sugar factory, diffusion is therefore the phenomenon by which the cells of the beet or the cane, immersed in water or a solution of lower concentration than the juice which they contain, give up to that water or to that solution a part or all of the sugar forming the excess of concentration of their juices', quoted Hugot (1986).

In diffusion, sugar extraction from cane is effected by rupturing the cane cells and then washing the ruptured cells with water or juice. So it is necessary that the preparatory index of around 90% be achieved to obtain a RME of 98% or higher. This process of extraction of sugar from cane offers several advantages over milling.

Percolation type diffusers are widely used in the cane sugar industry. There are two types of percolation diffusers in use – the fixed screen and the moving screen.

The cane sugar industry has used milling for juice extraction. With the advent of diffusion technology and its improvement, this process has replaced mills at the juice extraction station in a few cane sugar plants; particularly due to its better extraction efficiency, lower manpower needs, lower power consumption, lower operating and maintenance costs, increase in exportable electricity and better operating flexibility.

In 1969, a moving screen percolation type bagasse diffuser was installed at The Andhra Sugars Limited, Sugar Unit – I, at Tanuku in Southern India. Satisfied with its performance, a second moving screen percolation type bagasse diffuser was installed in 1977 and a moving screen percolation type cane diffuser was installed in 1997 at Sugar Unit – II at Taduvai.

This is the only cane sugar company with diffusers, producing direct consumption plantation white sugar of around 30 IU colour. All information presented in this paper is from the Taduvai plant (see Table 1).

[1] Reduced to common basis of 12.5% fibre on cane; details in Annex 2

Table 1—Test results of direct white plantation sugar produced at Taduvai.

Grade – Grain size	Colour[2] IU	Ash %	Turbidity IU	SO_2 ppm
S-31 > 600 Microns	30	0.028	23	10.56
M-31 > 1180 Microns	34	0.025	20	10.24

Cane diffusion

Cane is prepared by a fiberiser or a shredder to a preparatory index of 90% or higher and passed through the diffuser with no mills before the diffuser and only one dewatering mill after the diffuser; see Figure 1.

Initially diffusers at most cane sugar plants were bagasse diffusers, where the existing mills were used as primary and dewatering mills.

With the advent of improved fiberisers and shredders that achieve 90% and higher preparatory index, cane diffusion became popular, doing away with the primary mill, resulting in multiple savings as mentioned in the abstract and introduction.

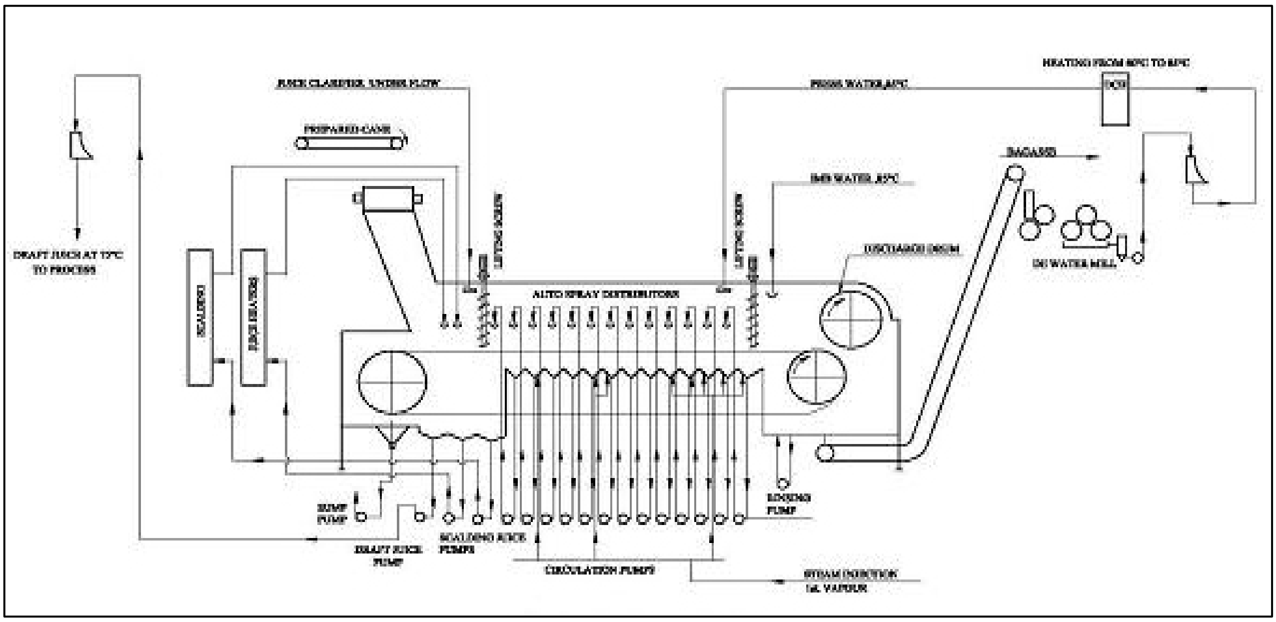

Fig. 1—A diffuser.

There are a few aspects to be borne in mind when considering the use of diffusion at a cane sugar plant:

- Compared to milling, diffusion requires 2 to 3% more low pressure steam**,** to heat the prepared cane to the operating temperature of 80°C, using vapour bled from the 2nd effect evaporator. This extra 3% steam is first used to generate electricity and then used to heat the prepared cane.
- Imbibition of 45% on cane is given at the diffuser, requiring slightly more evaporator capacity.
- Experience shows that addition of the clarifier underflow (mud) into the diffuser made a minor difference in quantity of ash or on the calorific value of the bagasse.

[2] ICUMSA Method GS2/3-10

Operation of a cane diffuser at the Taduvai Sugar Plant

The cane diffusion process has three major operations:

Cane preparation

A heavy duty swing hammer type horizontal fiberiser with 144 hammers (each weighing 17.5 kg) driven by a 1865 kW steam turbine is being used at Taduvai. An auto-feed arrangement is used to have a uniform bagasse mat feeding the diffuser. The power consumed for cane preparation is 1790 kW though 2242 kW is installed.

Juice extraction

Juice extraction is by a moving screen, percolation type cane diffuser of 5000 t/d capacity. It is like a long rail box wagon, with its bottom having a horizontally moving screen running the full length of the diffuser. Below the moving screen are 15 recirculation trays, 2 scalding juice tanks and 1 draft juice tank. At the top, fixed just below the roof of the diffuser are 15 distributors located throughout the length of the diffuser at the centre of the recirculation trays. The screen moves slowly from the feed to the discharge end, carrying a bagasse mat of uniform thickness. Imbibition at 45% on cane is added on to this mat at the discharge end of the diffuser. Press juice is added on to the mat at the second last compartment from the discharge end of the diffuser. This press juice is heated from 60 to 85°C, using 3rd vapour in a direct contact heater.

Pumps at the recirculation trays pump the percolated liquid through the distributor above the preceding tray. The liquid percolates through the bagasse mat and collects in the recirculation trays below. The liquid moves from the discharge end to the feed end of the diffuser gradually increasing its concentration by taking up the soluble matter, resulting in a counter current extraction. It takes 60 minutes for the bagasse mat to traverse the length of the diffuser, while the liquid takes 20 minutes. The juice goes to the process house, with the flow being controlled by the level of the juice in the scalding juice tank. The juice from the diffuser passes through a screen before being sent to the process house. This quantity is around 110 to 115% on cane.

At the discharge end of the diffuser, the bagasse drops on to a rake carrier, which transports it to the dewatering mill. To avoid blocking of the bagasse mat by fine particles, 2 sets of lifting screws are provided, one after the feed end and the other before the discharge end of the diffuser, facilitating proper drainage of the liquid.

The liquid distribution system automatically adjusts (Rein *et al.,* 1992) by sensing the liquid level in the bed using a differential pressure transmitter through a DCS (distributed control system) to have better percolation of liquid through the bagasse mat. With this arrangement, the point of application of the liquid moves forward or backward, adjusted by means of a pneumatic cylinder. The power used at the diffuser is 448 kW though 574 kW is installed. Table 2 shows the diffuser performance data.

To have a better extraction and to minimise microbial activity in the diffuser, the temperature inside the diffuser is maintained at around 80°C. To achieve this, a fully automated and controlled injection of 1st vapour is provided. To raise the temperature of the bagasse to the operating temperature, the juice from the scalding juice compartment is heated in two multi-pass vertical juice heaters and spread over the bagasse mat at the feed end of the diffuser.

At this stage, milk of lime is added to maintain the pH between 5.8 and 6.0. As the temperature of the juice in the diffuser is maintained at around 80°C, inversion is minimal. Figure 2 shows the concentration (°Brix), pH, temperature (°C) and reducing sugar (RS) per 100°Brix of the juice at the various compartments of the diffuser at Taduvai indicating that there is minimal inversion in the diffuser. The clarifier underflow (mud) is pumped into the diffuser near the first row of lifting screws, at a point of matching concentration, eliminating the vacuum filter station and the need for disposal of the filter cake. The mat of bagasse acts as a filter, removing the mud particles in the underflow (mud) of the clarifier and the suspended particles in the diffuser juice

(Meadows *et al.*, 1998; Bentley *et al.*. 2003)**.** Addition of the clarifier underflow (mud) into the diffuser has not negatively affected the boiler. It has in fact resulted in**:**

- Power saving of 112 kW.
- Increase in recovery by 0.06% on cane.
- Steam saving of 1%, as there is no cake washing.

Performance data for the diffuser at Taduvi are presented in Table 2.

Table 2—Diffuser performance data at Taduvai.

Cane processed (t/d)	4050	Fibre (% on cane)	14.22
Mill extraction (%)	98.15	Added water (% on cane)	45.06
Reduced mill extraction (%)	98.41	Bagasse (% on cane)	29.97
Recovery (% on cane)	12.49	Net draft Juice (% on cane)	115.02
Sugar (% on cane)	14.07		

Particulars/time		12:00–13:00	14:00–15:00	16:00–17:00	18:00–19:00
Crushing rate (t/h)		188	170	170	170
Diffuser screen speed (m/min)		0.744	0.744	0.744	0.744
Diffuser mat thickness (mm)		1600	1600	1600	1600
Scalding juice No.1	Flow (m^3/h)	170	174	172	170
	Temp. (°C)	86	90	84	84
Scalding juice No.2	Flow (m^3/h)	173	175	176	175
	Temp. (°C)	86	90	84	84
Scalding juice	Concentration (°Brix)	13.98		14.42	
	Pol (%)	11.54		12.00	
	Purity (%)	82.55		83.22	
Imbibition water	Flow (m^3/h)	78	79	76	77
	Temp. (°C)	84	88	82	82
Draft juice	Flow (m^3/h)	192	199	202	203
	Temp. (°C)	64	68	72	70
	Concentration (°Brix)	14.32		14.96	
	Pol (%)	11.88		12.50	
	Purity (%)	82.96		83.56	
Press juice	Flow (m^3/h)	137	136	124	137
	Temp. (°C)	72	66	80	80
	Concentration (°Brix)	1.64		1.36	
	Pol (%)	1.14		0.99	
	Purity (%)	69.51		72.79	
Temp. of circulation juice (°C)	Stage 1	82	83	82	82
	2	90	88	84	88
	3	82	80	86	84
	4	88	87	87	88
	5	87	88	87	88
	6	86	86	86	87
	7	87	86	86	87
	8	86	86	85	87
	9	85	85	84	85
	10	86	85	86	86
	11	88	90	88	88
	12	86	87	86	86
	13	92	92	90	90
Diffuser injection steam flow (t/h)		4.57			
Steam to scalding juice heaters (t/h)		5.22			
Diffuser outlet bagasse	Pol (%)	1.05		1.04	
	Moist. (%)	81.50		80.50	
Final bagasse	Pol (%)	0.89		0.79	
	Moist. (%)	50.50		51.00	
Preparatory Index (%)		89.85		89.31	

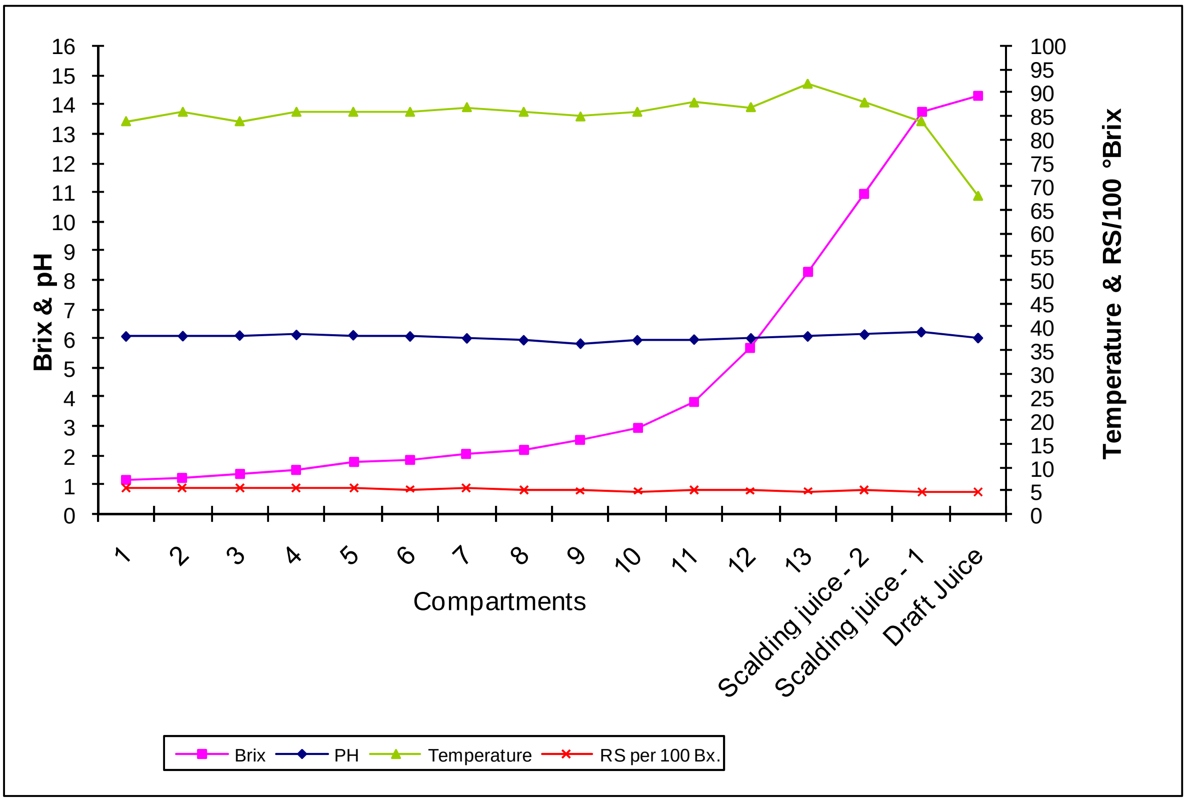

Fig. 2—Graph of concentration (°Brix), pH, Temperature and RS/100°Brix at various compartments of the cane diffuser at Taduvai.

Dewatering of bagasse

The moisture content of the bagasse discharged from the diffuser is around 80%. It passes through a 991 mm × 1982 mm mill with a TRPF (toothed roller pressure feeder). The moisture content of bagasse at the outlet of the dewatering mill is around 50.5%. This bagasse is passed through a flash dryer bringing the moisture down to 42%, thus improving the efficiency of the boiler. This has enabled each of the 40 t steam/h boilers to produce 5 t/h more steam. The power consumed at the dewatering mill is 507 kW, though 1082 kW is installed.

Advantages of cane diffusion over milling (5000 t/d capacity, and a 150 day season)

Better extraction efficiency

While the RME at many mills is about 96% and pol in bagasse (%) is about 2, at Taduvai the RME is around 98.4% and pol in bagasse (%) is 0.84, gaining 0.374 in recovery (% on cane), while elimination of the vacuum filter station contributes 0.06 (% on cane) to the recovery. The sugar so gained is approximately US$1.95 per tonne of cane processed. Recovery gains for diffusion and milling are presented in Table 3.

Table 3—Calculated recovery gain with a diffuser.

Particulars	Diffusion (RME of 98.4%)	Milling (RME of 96%)
Pol in cane (%)	14.0	14.0
Pol in mixed juice (% on cane)	13.744	13.415
Pol in bagasse (% on cane)	0.256	0.585
Pol in filter cake (% on cane)	–	0.060
Filter cake (% cane)	–	2.30
Pol in Molasses (% on cane)	1.219	1.134
Molasses yield (% on cane)	4.3	4.0
Unknown losses (% on cane)	0.06	0.19
Pol yield (% on cane)	12.465	12.031

Sugar recovery at a cane diffusion plant is 0.434% points on cane higher than at a similar capacity milling plant.

Lower manpower

The manpower engaged at the extraction station at Taduvai and a comparative milling tandem is presented in Table 4.

Table 4—Manpower.

Description	Diffusion	Milling
Manpower	21	43

Lower power consumption

The installed and consumed power (kW) at a diffuser and a milling tandem (4 sets of mills) is shown in Table 5.

Table 5—Power for cane preparation and juice extraction.

Description	Diffusion		Milling	
	Installed kW	Consumed kW	Installed kW	Consumed kW
Cane preparation	2242	1790	1839	1469
Juice extraction	1716	1165	2701	2145
Total power (kW)	3958	2955	4540	3614

There is a saving of 659 kW power with a diffuser. With the elimination of the vacuum filter station this saving increases to 749 kW. While a RME of 98% and higher is achieved with a diffuser, to achieve this RME with a milling tandem, two more sets of mills are needed, requiring an additional installed power of 1268 kW.

Lower operation and maintenance costs

The operation and maintenance cost at a diffuser and a milling tandem for a 150 day operation is shown in Table 6.

Table 6—Operating and maintenance cost details.

Diffusion		Milling	
Particulars	$US	Particulars	$US
Out of 3 rollers, 1 unit reshelling/year	5130	Out of 12 rollers, 4 units reshellings/year	20 520
For 1 trash plate @ $1500/piece	1500	For 4 Trash plates @ $1500/piece	6000
For mill rollers arcing @ $720 per mill	720	For mill rollers, arcing @ $720 per mill	2880
Out of 2 mill scrappers, 1 unit per year @ $ 515/piece	515	Out of 8 mill scrapers, 4 units per year @ $ 515/piece	2060
Out of 3 mill roller pinions 1 unit per year @ $ 310/piece (rebuilding only)	310	Out of 12 mill pinions, 4 units per year @ $ 310 (rebuilding only)	1240
For maintenance of 1 pumps @ $180/pump	180	For maintenance of 5 pumps @ $180/pump	900
For maintenance of 1 inter carriers @ $2488 for 4 years	622	For maintenance of inter carriers 4 units @ $2488 for 4 years	2488
For maintenance of 8 mill bearings @ $620 for 6 years	826	For maintenance of 32 mill bearings @ $620 for 6 years	3304
Spares for 1 prime mover and reduction gear @ $4500/piece	4500	Spares for 4 prime movers and reduction gears @ $4500/unit	18 000
Lubricants for mill bearings 12 litres/8h/mill @ $1.65 per litre.	8910	Lubricants for mill bearings 12 litres/8h/mill @ $1.65 per litre.	35 640
Lubricants for prime mover & reduction gears 800 litres /mill @ $2.80/litre, for one set of mill for 2 years	1120	Lubricants for prime mover & reduction gears 800 litres /mill @ $2.80/litre, for 4 sets of mills for 2 years	4480
Other Lubricants	370	Not Applicable	0
Labour cost for off-season overhauling of one set of mills 720 man-days @ $7.2/man-day	5184	Labour costs for off-season overhauling of 4 sets of mills and inter carriers etc. 2,880 man-days @ $7.2/man-day	20 736
Labour cost for overhauling of a diffuser 1260 man-days @ $7.2/man-day	9072	Not Applicable	0
Spares and off-season maintenance for a diffuser: runner flats 2 t @ $1130 – 3 years life; main chain @ $50 × 244 links for 6 years life	2786	Not Applicable	0
Spares for 8 lifting screws 4 years life @ $750	1500	Not Applicable	0
Spares for 21 circulation and scalding pumps @ $130/pump	2730	Not Applicable	0
Painting cost	1200	Painting cost	235
Total rounded off to:	47 500	Total rounded off to:	119 000

Lower Capital, Foundation and Construction Costs

The price of a diffuser and a milling tandem of 5,000 t/d capacity is shown in Table 7.

Table 7(a)—Capital cost.

Currency	Diffusion	Milling
US$	2990 000	3 958 000

The foundation and construction costs for a diffuser are much lower than for a milling tandem, as a diffuser can be installed outdoors while a milling tandem requires a complete roof cover.

Table 7(b)—Foundation and construction costs.

Description	US $	
	Diffusion	Milling
Foundation cost for diffuser	12 320	
Foundation cost for one dewatering mill	92 400	
Cost of construction for dewatering mill building	118 000	
Foundation cost for 4 sets of mills, 4 intermediate carriers and 4 pumps @ $92 400/set		369 600
Cost of construction for milling tandem building		295 700
Total cost	222 720	665 300

Clarification and filtration

The bagasse mat in a diffuser acts as a filter for the juice. The suspended solids in the draft juice from the diffuser are around 80 ppm, while it is about 2000 ppm with a milling tandem. With the addition of the clarifier underflow (mud) into the diffuser, the pol loss in the filter cake is ‘0’. ‘No’ recirculation of filtrate to draft juice results in lower suspended impurities in the draft juice, better floc formation and better clear juice transmittance, as seen in Figure 3.

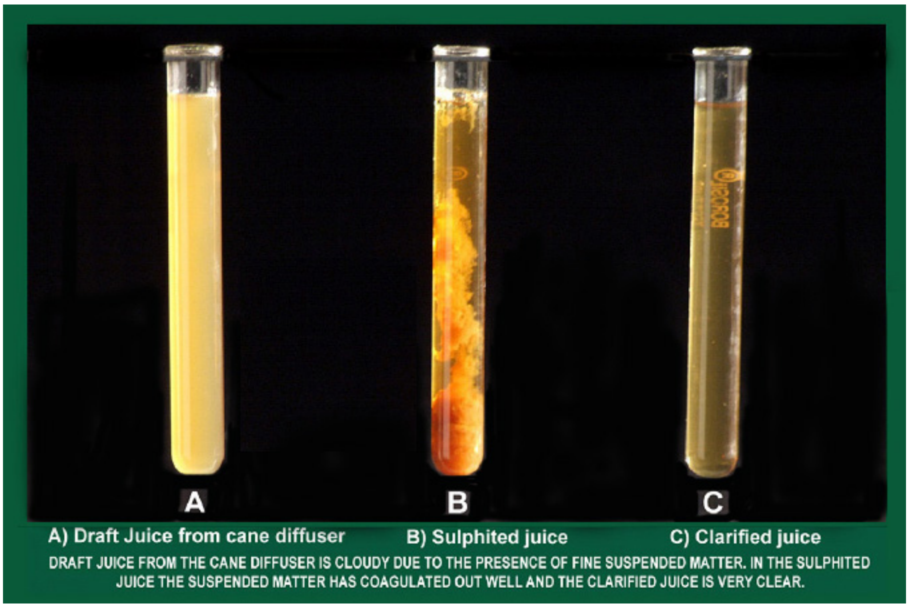

Fig. 3—Colour of draft, sulphited and clarified juice at Taduvai.

There is a notion that as the diffuser draft juice is higher in colour, use of a diffuser is not conducive to produce direct white sugar. Figure 3 shows the juice colour achieved at the cane diffuser, while Table 1 and Annex 1 show the quality of sugar produced at Taduvai.

Lower unknown losses

As diffusion takes place in enclosed equipment, at a temperature of 80 to 85°C, microbial activity is minimal. In milling, extraction is done in the open, at ambient temperature, so most of the unknown loss is due to microbial activity, loosing eight parts of sucrose to one part of lactic acid, while it is only two parts of sucrose to one part of lactic acid in a diffuser (Mackrory *et al.,* 1984).

Increase in Exportable electricity

A cane sugar plant with a boiler at 4.5 Mpa and 420°C and a diffuser would export about 2616 kW more electricity than with a milling tandem as seen in Table 8.

Table 8—Comparison of energy requirement.

Description	Diffusion	Milling
Cane crushing rate (t/d)	5000	5000
Bagasse yield (% on cane)	30.50	29.28
Bagasse production (t/h)	70.15	67.34
Bagacillo used for filter cake (t/h) @ 3 (% on cane)	0.00	2.3
Bagasse available (t/h)	70.15	65.06
Exhaust steam (% on cane)	48	45
Exhaust steam requirement (t/h)	110.4	103.5
De-super heated water required (t/h)	3.62	3.39
High pressure steam required to produce the required exhaust (t/h)	106.78	100.11
HP steam required for miscellaneous uses (t/h) at 3.5(% on cane)	8.05	8.05
Total high pressure steam to be generated (t/h)	114.83	108.16
Power generated while producing the required exhaust (kW)	13 350	12 510
Power used for cane preparation (kW)	1790	1469
Power used for juice extraction (kW)	1165	2145
Power used for other plant load (kW)	4031	4216
Total power utilised (kW)	6986	7830
Surplus power (kW)	6364	4680
Bagasse consumed (t/h)	51.5	48.5
Surplus bagasse (t/h)	18.65	16.56
Steam equivalent to surplus bagasse (t/h)	41.58	36.92
Power generated from the surplus bagasse with a condensing turbine (kW)	8316	7384
Net exportable power (kW)	14 680	12 064
Additional exportable power (kW)	2616	

Better operating flexibility

A diffuser can be operated from 20 to 100% of its rated capacity without significant loss in efficiency by merely varying the thickness of the bagasse mat and the screen speed.

Conclusion

Diffusion has a definite advantage over milling due to higher extraction, lower manpower needs, lower power consumption, lower operating and maintenance costs, increase in exportable electricity and better operating flexibility. For a cane sugar company considering setting up a new sugar plant, it would be advantageous in the interest of a better bottom line to use diffusion for juice extraction.

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ANNEXES

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Andrha Pradesh

TANUKU 534216
Indien

Project No.	: 5 7 8 6 6 0 0
Date	: 2.02.2004
Our Code	: MR / KS

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T E S T   R E P O R T

Examination of	: Sugar
sample reception	: 15.01.2004
number of samples	: 1
Your order dated	: 15.01.2004
Labelling	: see attached fotocopy
Packaging	: plastic bag
- condition	: o.k.

THE ANDHRA SUGARS LIMITED
SUGAR UNIT-II, TADUVAI
SUGAR SAMPLE
Grade : M31 Date : 09-12-03
Season : 2003-04

TESTING RESULTS

Start of examination	: 20.01.2004	
Total plate count mesophylic aerobic (standard agar) method ME188	: 42	cfu/10g
Yeast (wort agar) method ME192	: 0	/10g
Moulds (wort agar) method ME192	: 1	/10g
Colour (ICUMSA) (photometric, 420 nm) method ME179	: 39.0	I.U.
- points	: 5.2	
Ashes (ICUMSA) method ME294	: 0.019	%
- points	: 10.6	

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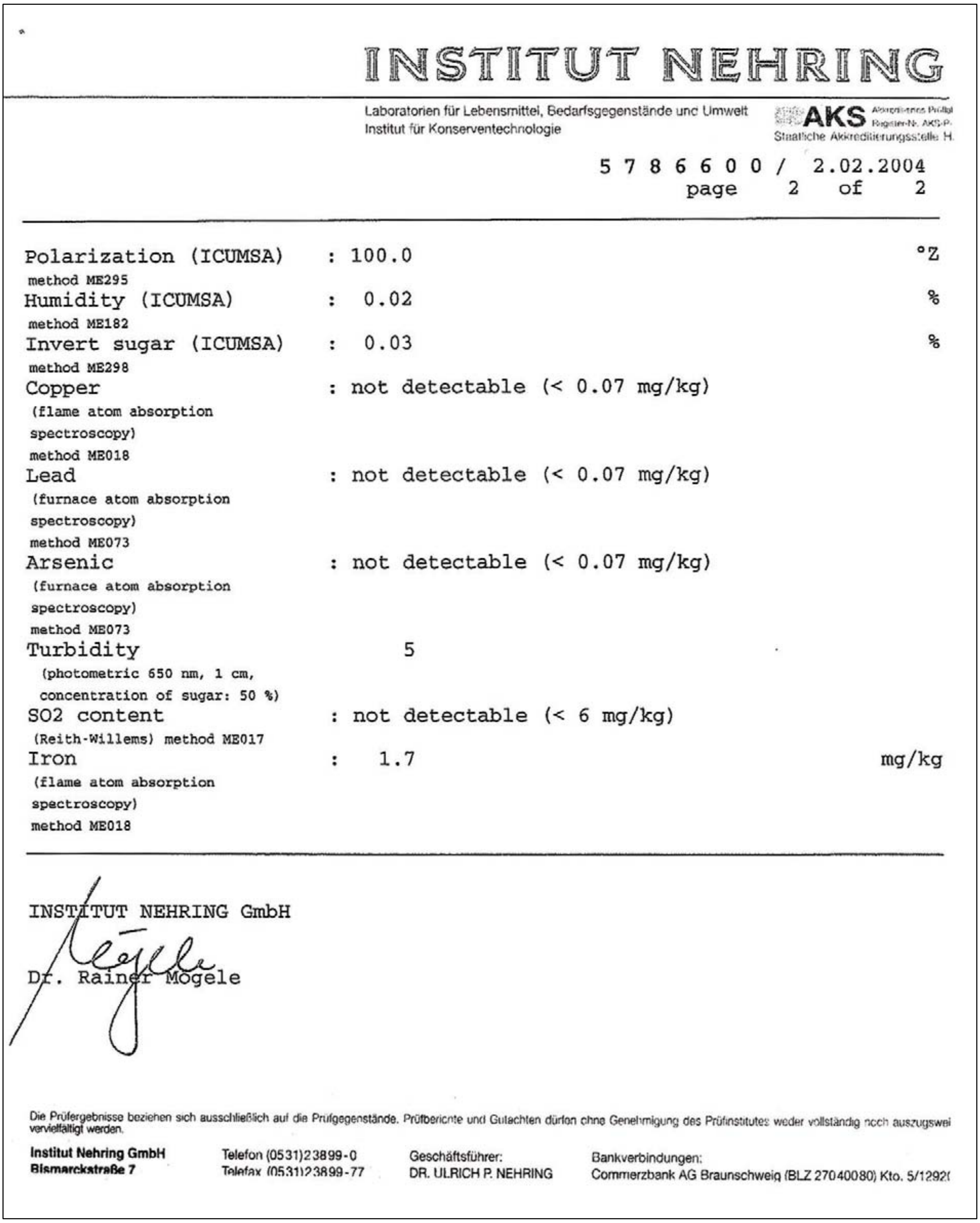
Annex 1: Taduvai sugar compliance to EC-2 grade requirements.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Polarization (ICUMSA) method ME295	:	100.0	°Z
Humidity (ICUMSA) method ME182	:	0.02	%
Invert sugar (ICUMSA) method ME298	:	0.03	%
Copper (flame atom absorption spectroscopy) method ME018	:	not detectable (< 0.07 mg/kg)	
Lead (furnace atom absorption spectroscopy) method ME073	:	not detectable (< 0.07 mg/kg)	
Arsenic (furnace atom absorption spectroscopy) method ME073	:	not detectable (< 0.07 mg/kg)	
Turbidity (photometric 650 nm, 1 cm, concentration of sugar: 50 %)		5	
SO2 content (Reith-Willems) method ME017	:	not detectable (< 6 mg/kg)	
Iron (flame atom absorption spectroscopy) method ME018	:	1.7	mg/kg

INSTITUT NEHRING GmbH

Dr. Rainer Mögele

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Annex 2: Reduced (mill) extraction.

Recorded extraction reduced to a common basis of 12.5 % fiber in cane, Noel Deere

$$E_{12.5} = (7 - V)/7 * 100$$

Where $V = ((1 - e)(1 - f))/f$

$E_{12.5}$ Reduced (mill) extraction (%)

V Lost juice % fiber

e Recorded (mill) extraction

f Fiber % cane

COMPARAISON DE LA DIFFUSION ET DES MOULINS DANS UNE SUCRERIE

Par

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MOTS-CLEFS: Diffusion, Energie et Extraction, Coûts de l'Opération et de la Maintenance, Exportation d'électricité.

Résume

AVEC l'avènement de la technologie de diffusion et de son amélioration, les diffuseurs ont remplacés les moulins pour l'extraction du jus dans des sucreries. Comparée aux moulins la diffusion donne une meilleure efficacité d'extraction, demande moins de main d'œuvre, et consomme moins d'énergie; les coûts de maintenance et de l'opération sont plus faibles. Elle permet aussi d'exporter plus d'électricité et donne une opération plus flexible. Les performances d'un diffuseur de canne à The Andhra Sugars Limited, Unit Sugar-II à Taduvai ont été élucidées et une comparaison effectuée entre la diffusion et les moulins. Taduvai réalise une extraction réduite (RME) de 98.4%, un pol % bagasse de 0.84, une maintenance réduite de 51%, une consommation d'énergie réduite de 18%, et 60% de réduction pour les coûts d'opération et d'entretien par rapport à un tandem. La station de filtre a été éliminée. Avec un diffuseur on a augmente l'exportation de l'électricité par 2616 kW, compare aux moulins.

COMPARACIÓN ENTRE DIFUSIÓN Y MOLIENDA EN UNA PLANTA DE AZÚCAR DE CAÑA

Por

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Resumen

CON la aparición de la tecnología de difusión y su mejoramiento, los difusores han reemplazado los molinos para la extracción de jugo en algunas fábricas debido a su mejor eficiencia de extracción, menores requerimientos de mano de obra, menor consume de energía, menores de operación y mantenimiento, incremento en cogeneración y mayor flexibilidad de operación. El desempeño del difusor en la Unidad II de Andhra Sugars Limited, en Taduvai ha sido evaluado y se comparado con la tecnología de molienda. Taduvai alcanza una extracción reducida de 98.4% y pol en bagazo (%) de 0.84 y tiene 51% menos mano de obra, 18% menos consumo de potencia, y costos de operación y mantenimiento 60% menores si se lo compara con un tren de molinos. La estación de filtración fue eliminada y con este difusor pueden exportarse 2616 Kw más que con un tándem de molinos.