WHY DO WE CONTINUE TO BURN SO MUCH COAL?

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Abstract

Several sugar mills in southern Africa have adverse fuel balances for various reasons, and end up burning enormous amounts of coal. Some of the reasons for this are discussed, and two in particular are analysed in detail: time efficiency and imbibition.

The variables that are directly related to the energy efficiency of a sugar mill are listed and their relative effects are discussed.

The effect of time efficiency is evaluated, and some guidelines are provided that may help in reducing this factor.

The use of a very high rate of imbibition to achieve good extraction has almost become the norm in southern Africa. In some circumstances, the cost of this practice in increased fuel consumption can outweigh the gains achieved through high extraction.

A theoretical exercise has been carried out that explores the effect of changes in imbibition on extraction and on the fuel balance. Equations are derived, using historical performance figures, for the relationship between imbibition and extraction, and allowances for other effects are discussed.

A hypothetical sugar mill which relies on coal to provide sufficient steam is used as the basis of calculations. These calculations compare the relative cost of reduction in extraction with a saving in coal used, and show that in certain conditions, reduction of imbibition can result in a net saving in costs.

Keywords: imbibition, extraction, fuel, steam balance, energy, time efficiency

Introduction

Cane sugar mills have traditionally been self-contained in their consumption of energy. All the bagasse is used as fuel to produce sufficient steam to satisfy the electrical and prime mover power requirement, and the heating demand of the whole process. With time, however, several supplementary processes have been introduced that have reduced the available bagasse and increased the demand for either high pressure or process steam, or both.

At present the South African sugar industry consumes about 250 000 tons of coal per season, which is costing the industry nearly R90 million. The first impression from this information is that the traditional energy economy has not been able to be maintained in all cases. However, the situation has developed because the returns from the supplementary processes such as the sale of bagasse for by-products, steam used in refineries, and energy sales have been high enough to more than justify the expenditure on the additional coal.

Figure 1 is a plot of the total coal consumption per 1000 tons of cane, for South Africa, as reported to the Sugar Milling Research Institute (SMRI). Not all sugar mills report their coal consumed in a uniform manner. A few mills that export their fibre report only coal for which the value is not recovered by the sale of fibre, or do not report coal consumption at all. This graph indicates that coal consumption is far from consistent from year to year. The variation may be attributed to many factors that change continuously, such as the weather, or any of the parameters that are discussed below.

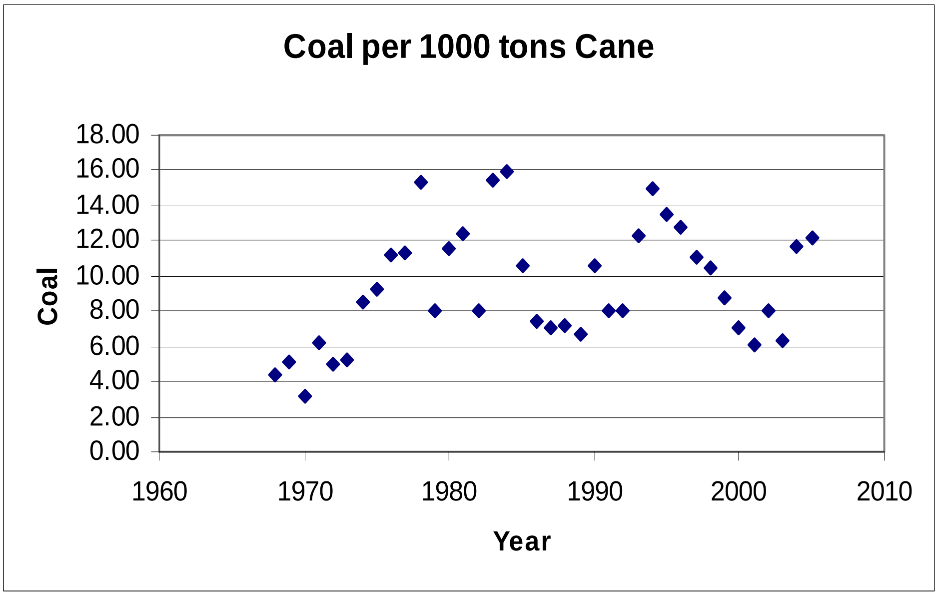

Figure 1. Annual coal consumption.

This paper analyses the causes of the high consumption of coal, and examines in some detail two of these: time efficiency and imbibition.

Most sugar mills could reduce their process energy demand considerably, as demonstrated by many successful cases in which the sugar mill generates the maximum amount of electric power for sale to the national electricity supplier. Examples can be found in Hawaii, Reunion, Mauritius and many other places in the cane sugar world. Factory process steam consumption at exhaust pressure can be as low as 350 kg per ton cane. This aspect of efficiency improvement is beyond the scope of this paper.

Causes of burning coal

The following list gives the reasons why supplementary fuel is consumed by sugar mills in South Africa.

Bagasse export

This is the most significant reason for the consumption of coal. Some sugar mills, notably Felixton and Gledhow, which export fibre for paper, and Sezela, where bagasse (which suffers a mass loss in the process) and steam are used to manufacture furfural, have established a steady supply of bagasse for by-products. Several other sugar mills use smaller amounts of bagasse for cattle feed plants and fibre board production.

Time efficiency

Whenever the extraction plant stops, bagasse supply ceases, but the factory cannot immediately stop using steam. This consumes any surplus bagasse, and eventually coal. A detailed analysis and discussion of this parameter follows below.

Refinery attached to raw sugar mill

The steam and power used by the equipment of a 'back-end's refinery is quite significant in relation to the fuel balance. In round figures, the high pressure steam consumption attributable to an efficient refining operation is 1 ton per ton of refined sugar output (RSO). Thus, for an hourly capacity of 25 t RSO, the best marginal coal consumption, at about 7 tons steam per ton coal, would be at least 3.5 t/h, or roughly 14 000 tons in a normal season. Usually the income from refining is more than sufficient to compensate the miller for this additional expenditure, but it should be remembered that where the efficiency is increased to reduce coal consumption, it will increase the income to the miller.

Pan movement water

It is usually necessary to add water to a vacuum pan to maintain control of the growth of crystals. When the syrup quality is poor, such as from cane of poor quality, this water use may have to increase. Any additional water in the system requires steam for its evaporation.

Some successful energy saving has been achieved at a few sugar mills by replacing water for pan dilution with clear juice, hence by-passing the evaporator and reducing exhaust steam consumption.

Pan movement water is usually expressed as a percentage of the minimum quantity to be evaporated from the syrup to crystallise the sugar. With modern pan control systems it is possible to maintain movement water at levels down to 10%.

Filter wash water

Water is used to dissolve sucrose from the filtercake in the vacuum filters. The pol loss in filtercake can be reduced by increasing the water, but this can also reduce the effectiveness of the filters.

Imbibition % fibre

The addition of water to the diffuser or mills is an important contributor to good extraction. This must be weighed against the cost of fuel required for evaporation. A detailed analysis and discussion of this parameter follows below.

Fibre % cane

The fibre content of the cane determines the amount of bagasse produced, which in turn affects the fuel balance. This is largely outside the miller's control.

Boiler efficiency

The efficiency of a boiler has three main controllable components:

- *Dry flue gas loss*, which is affected by the air to fuel ratio, air temperature, furnace pressure control and performance of the economiser (where fitted). In a modern automated boiler these functions are determined by the computer control system, as long as the operator does not switch to manual control. The functions would normally be held at optimum settings.

- *Unburned carbon in ash loss*. This is a function of the fuel quality (moisture and ash content, fixed carbon, volatiles) and feeder and grate settings.
- *Steady operation*. Erratic steam demand and variability in fuel quality compromise the ability of the control system, whether manual or automatic, to maintain all variables at levels that will result in high efficiency. Also, when variations in casing temperature occur, the radiation losses increase significantly.

Good boiler design, operation and maintenance will maximise efficiency and hence keep the wastage of coal on this account to a minimum.

Steam and heat losses

Faulty steam traps, negligent operation and leaks in the steam system can waste a significant amount of energy. In a badly maintained system, these would be obvious to the eye and noisy. Heat losses are caused by damaged or non-existent insulation and cladding.

Bagasse quality

The quality of bagasse seriously affects the calorific value and combustion efficiency of the bagasse. Moisture is the more serious, and depends on the condition and operation of the dewatering mills. Bagasse with moisture in excess of 55% cannot be burned in most sugar mill boilers and may require adding some coal to stabilise combustion. Ash (soil in cane) also seriously affects the calorific value of the bagasse, and this depends on the weather, and on harvesting technique. Again, if this is higher than about 5%, coal will have to be supplemented to maintain combustion. Fines content can also have a serious effect on the combustion efficiency and on the danger of furnace explosions, but the effect is difficult to quantify.

Coal calorific value

This varies with coal type, area and seam being mined, and many other factors. Coal that is high in CV will cost more, but will burn better.

There are other reasons why South Africa uses more energy than some other countries, one of which is the relatively poor energy efficiency of the typical boiling scheme used in this country. The magnitude of these causes is small, and they are not discussed in this paper.

Using a spreadsheet-based steam balance program, a sensitivity analysis of the above parameters in which the relative effect on weekly coal consumption of each was calculated. A hypothetical sugar mill was used as a basis, with the configuration of a single diffuser, quin evaporator, back-end refining of 70% of the raw sugar produced, and no export of bagasse. The main input variables were as follows:

Tons cane per hour	260
Imbibition % fibre	400
Fibre % cane	13.8
Sucrose % cane	14.6
Cane purity (DAC)	87.0
Suspended solids % mixed juice	0.15
Extraction %	97.4
Bagasse moisture %	50.0
Ash % bagasse	2.0
Syrup brix	65.0
Overall time efficiency %	85.0

The results of this analysis are given in Table 1.

Table 1. Sensitivity analysis of parameters that affect coal consumption.

Parameter	Usual range	For change in level	Coal per week (t)
Bagasse export	Up to 60%	From 0 to 50%	1600.00
Time efficiency	50 to 100%	Decrease 10%	160.00
Back end refinery	Up to 120% of raws	From 0 to 70%	447.00
Pan movement water	5 to 30%	From 12 to 24%	330.00
Filter wash water	0.5 to 3.0 t/h	Increase 2 t/h	8.50
Imbibition % fibre	200 to 400%	Increase 50%	110.00
Fibre % cane	10 to 15%	Decrease 1%	196.00
Boiler efficiency	60 to 85%	Decrease 5%	47.00
Steam losses	1 to 5%	Increase 1%	34.00
Heat loss from bare surfaces	Up to 2 kW/m^2	Increase $20m^2$	5.00
Bagasse moisture	45 to 55%	Increase 1%	16.00
Bagasse ash (sand in cane)	1 to 10%	Increase 1%	76.00
Coal calorific value	24 to 30 MJ/kg	Decrease 1 MJ/kg	10.00

Time efficiency

In an ideal sugar mill, as soon as the extraction plant and hence the production of fuel stops, the fuel requirement can be drawn from the bagasse store during the entire duration of the stop. The bagasse store shortfall can then be made up as soon as fuel becomes available.

However, when the fuel balance is unfavourable and coal needs to be burned continuously, whenever the extraction plant stops the consumption of coal increases either immediately or later to conserve stored bagasse, or to keep the raw and refined sugar production going until stock in progress is reduced.

It is possible to quantify this effect. One method is to gather steam flow data and overall time efficiency (OTE) over a long period. This is illustrated by the graph in Figure 2, in which daily coal consumption corrected for fibre sales credit, was plotted against daily OTE for part of last season at Gledhow. Although the relationship is clearly not linear, a straight line fitted to the data yields the formula:

$$\text{Coal, tons} = 2.25 * \text{OTE} - 209$$

The break-even OTE for zero coal, based on this equation, is 93%.

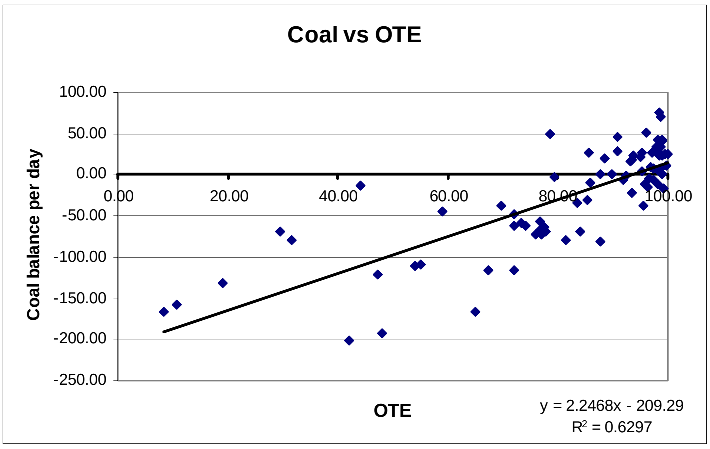

Figure 2. Gledhow weekly overall time efficiency vs coal balance.

Another method is to plot the steam demand of a sugar mill from a time just before a mill stop, until the mill starts again, for various lengths of mill stops. This can conveniently be done using modern computer controls. Figure 3 is a smoothed plot of a typical steam demand curve during a short stop and followed by a long stop. If this data is analysed it may be seen that the steam consumption reduces as the stop lengthens, but would only go to zero if a decision was made to shut everything down.

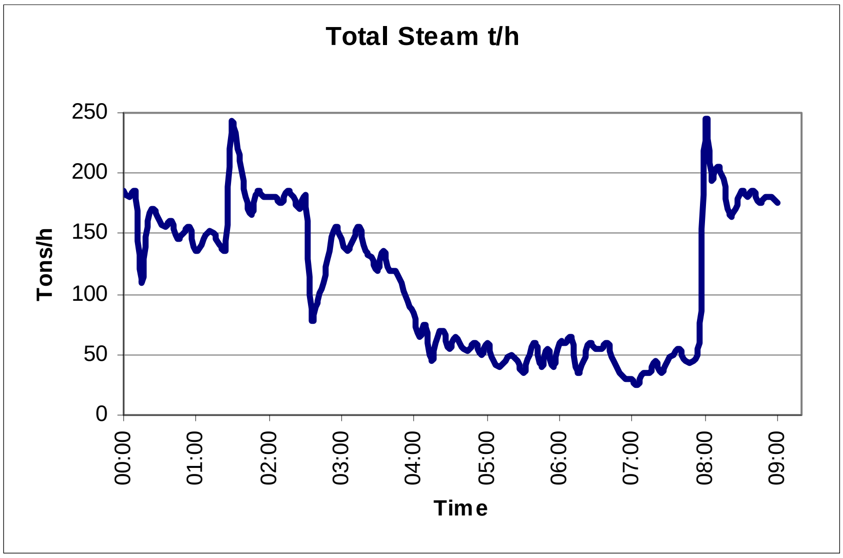

Figure 3. Hourly steam flow during stops.

The data from Figure 3 is summarised in Table 2. This indicates that the steam flow can vary considerably during stops.

Table 2. Average steam flow during different conditions.

Time periods and consumers		Times	Average steam (t/h)
Crushing period 1:	Whole factory	0:00 to 0:10	183.33
Stop period 1:	Raw house and refinery	0:15 to 1:25	147.67
Crushing period 2:	Whole factory	1:30 to 2:30	185.38
Stop period 2:	Raw house and refinery	2:35 to 3:55	124.71
Stop period 3:	Refinery only	4:00 to 7:55	50.42
Crushing period 3:	Whole factory	8:00 to 9:00	186.92

It should be remembered that the steam flow during the stop periods must be produced from supplementary fuel, whether it be recovered bagasse from the bagasse store, or coal brought in at high cost.

The great effect that OTE has on the fuel balance could be reduced if the sugar mill could vigorously campaign to prevent unplanned stops. All other stops should be carefully planned with a view to conserving fuel, e.g. by endeavouring to shut down the process and the boilers as soon as possible after the front end stops.

Imbibition versus extraction

One of the most significant variables that affect the energy balance and also extraction is the amount of imbibition water used on the extraction plant. Generally, as the tonnage of imbibition is raised, extraction increases and more sugar is produced. However, an increase in imbibition raises the consumption of fuel because of the greater quantity of water that needs to be evaporated.

Wienese (1994) carried out a theoretical exercise at Mount Edgecombe, in which it was found that the break-even imbibition level at which the revenue from the additional sugar just balanced the cost of additional coal was 470% on fibre. This was clearly a level higher than the mill at that time would ever have been expected to use, thus indicating that it was best to apply much imbibition.

Some work has now been done to quantify this effect once again, with up-to-date financial figures and also with the knowledge that there are many factors other than imbibition that can influence extraction. It is known from previous work and from basic chemistry, that the relationship between these two variables follows an asymptotic curve, i.e. the relative increase in extraction diminishes as the imbibition increases. For example, Rein (1975) derived a formula for corrected reduced extraction, and in the course of the investigation showed that the dependence of extraction on imbibition % fibre was exponential, which at the levels investigated, was asymptotic. However, there are many other factors that can influence extraction, and this fact must always be borne in mind. These factors include:

- Cane quality
- Cane preparation
- Cane throughput
- Feeding efficiency
- Roll surface condition
- Hydraulics and roll lift
- Uniform feeding.

The typical scatter of extraction plotted against imbibition is illustrated by Figure 4.

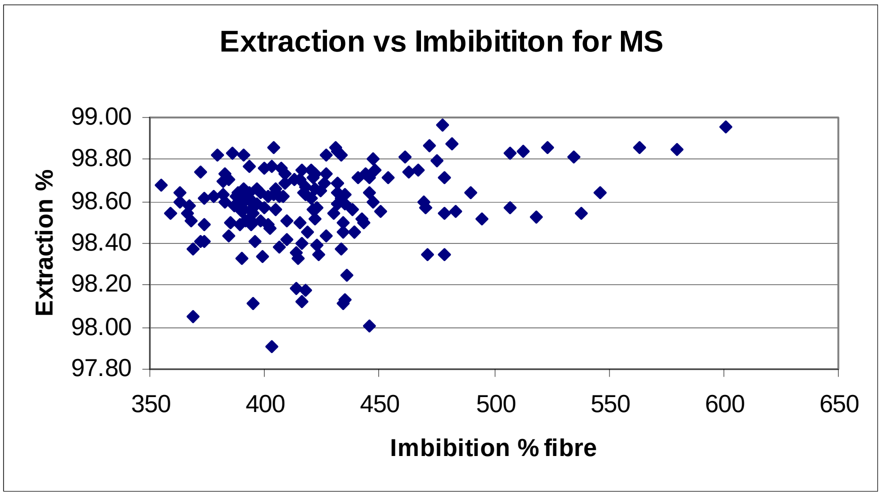

Figure 4. Weekly extraction vs imbibition over five seasons for Maidstone mill.

It has been assumed that if sufficient data relating extraction to imbibition are used, statistical curve fitting would tend to eliminate these other factors and valid results would be obtained.

After analysing different asymptotic curves, it was concluded that the best fit between the limiting values is given by a double exponent formula. The limiting values are given by: (a) the expected extraction with zero imbibition at the lower end, which is equivalent to dry milling, or first mill extraction, and (b) 100% for infinite imbibition at the top end. The formula would have the form:

$$\text{Extraction} = 100\text{-}Pe^{(Qe(-I/J))}$$

Where P, Q and J are constants, and I = Imbibition % fibre in cane.

The figures for imbibition and extraction were provided by the SMRI for all sugar mills in South Africa, for every week of the past five crushing seasons. Exponential trend lines were obtained for plots of ($EXP^{(-I/J)}$) versus (100-Extraction%) and equations of the above form were derived for each sugar mill from these trend lines. The value of J was tested and found to make little difference to results. J = 400 was therefore used in the final calculations. Table 3 gives the constants and regression coefficients for all mills. Figure 5 is a graph of the derived asymptotic curves, using the constants in the table, for selected sugar mills.

Table 3. Summary of extraction equations for all mills.

Mill	Multiplier P	Constant Q	Regression coefficient
ML	0.9808	1.8674	0.2022
KM	1.1288	0.9002	0.0943
PG	1.3457	1.3922	0.1452
UF	1.1423	1.8134	0.2690
FX	0.3578	4.0591	0.3139
AK	0.6996	2.7764	0.4445
DL	1.0827	2.1983	0.0730
MS	0.9832	1.0189	0.0809
GH	1.4863	0.9382	0.0296
NB	0.9663	2.0866	0.1505
UC	2.3181	0.1074	0.0007
ES	0.9589	2.7264	0.6856
SZ	0.9519	1.5679	0.0787
UK	0.6824	2.9088	0.3117

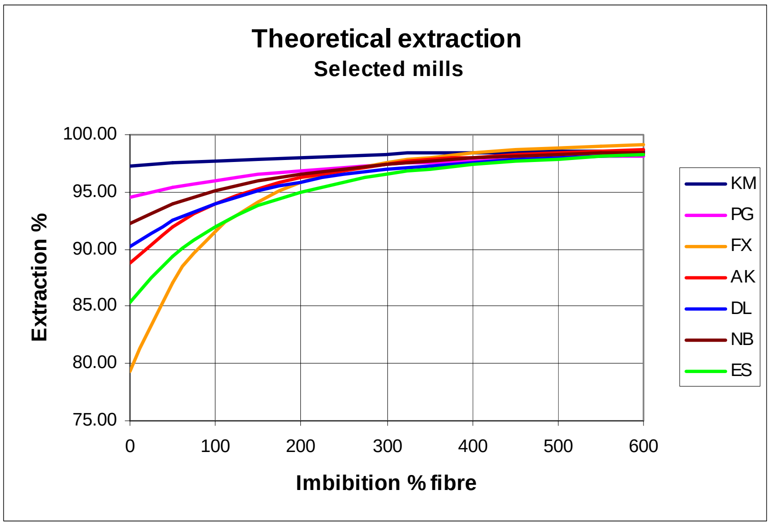

Figure 5. Extraction curves for selected mills.

The scatter in the data was greater than expected. In some cases, e.g. Union-Co-op mill, the regression coefficient obtained by fitting the appropriate curve was far too low to indicate any degree of confidence. The best regression coefficient was obtained for the Eston data, at 0.68. The constants for this equation were therefore used in the analysis which follows.

The same steam balance program mentioned under the previous exercise was used to calculate conditions for five cases, in which the imbibition was varied from 300 to 500% on fibre.

The possible effect of variations in extraction on boiling house recovery has not been considered in this exercise. Lionnet (1981) has shown that the mixed juice purity decreases relative to the DAC purity with higher extraction. The conclusion was that the increased revenue from the additional sugar outweighs any possible costs of achieving the increased extraction. It has been previously reported that an increase in extraction will add to the mixed juice some undesirable compounds that interfere with clarification and crystallisation (Lionnet, 1985). Rather than introduce effects that are dependent on many other factors, particularly as affected by cane quality, it was felt expedient to ignore it.

The formula used to calculate extraction, based on the ES data which gave the highest regression coefficient, is:

$$\text{Extraction} = 100\text{-}0.96e^{(2.73e(-I/400))}$$

These five cases are summarised in Table 4, and Figure 5 shows the variation in extraction and coal burned against imbibition.

Table 4. Summary of imbibition effects on coal and costs.

Assumptions						
Season length (h)						4200
Overall time efficiency (%)						85
Base case sugar made in season (tons)						103530
Boiling house recovery (%)						87.5
Marginal sugar revenue per ton (R)						2200
Cost of coal per ton (R)						375
Imbibition % fibre	Extraction (%)	Coal/h (t)	Sugar/h (t)	Marginal revenue (R)	Coal cost/season (R)	Cost of increased Imbibition
300	96.51	0.00	29.00	0	0	0
350	97.00	0.92	29.15	1,156,750	1,449,000	292,250
400	97.38	1.74	29.26	2,041,703	2,740,500	698,797
450	97.67	2.51	29.35	2,730,194	3,953,250	1,223,056
500	97.90	3.26	29.42	3,273,840	5,134,500	1,860,660

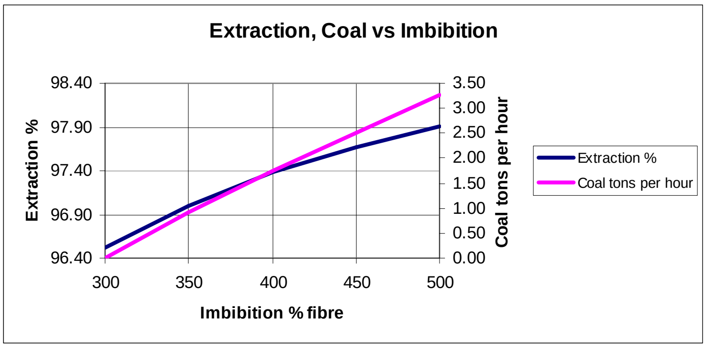

Figure 6. Extraction and coal consumption vs imbibition.

Discussion

When imbibition is reduced, the clear juice is more concentrated and the exhaust consumed in the evaporator decreases. This results in less high pressure steam being let down through the reducing valve to make up into the exhaust range.

However, in many sugar mills the exhaust range balance is finely tuned, with only a small let down being required in normal operation. Thus, reducing exhaust consumption often results in the exhaust supply from turbines becoming excessive, and the surplus is blown off to atmosphere through the relief valves. This is clearly wasteful of energy, and would place a limit, in these circumstances, on the extent to which imbibition can be reduced.

The solution to this problem would be to improve the efficiency of turbines, by replacing low efficiency turbines with electric motors, or by reducing the electrical load on the power house. The cost of these measures would have to be compared with the gains resulting from coal saving.

Problems may be encountered in juice preparation, particularly in clarification, if the juice brix runs at too high a level caused by a low imbibition rate. It has been reported that if the brix of mixed juice is higher than about 15.0, the solids settling rate may be unacceptable. In the example used to show the effect of lowering imbibition, the brix may be on the limit at 300% imbibition on fibre. This is the level at which the normal coal consumption is zero. However, if the circumstances were to change and it were feasible to reduce imbibition more, it should be possible to run at a higher brix than 15.0 with careful attention to detail in the clarifier.

Another problem may arise in Kestner first effects, in which a juice with too high a brix may cause excessive fouling in the tubes, because the climbing film velocity may be too low. However, it is felt that this problem is unlikely, or could easily be overcome. There are several sugar mills using Kestners as second effects, and the high brix juice does not seem to present any problems.

The above conclusions depend very much on the revenue from sugar and the landed cost of coal. An additional series of calculations were done to find the break-even point imbibition level for various sugar revenue figures while keeping the coal cost constant at R375 per ton. These are given in Table 5. An increase in sugar revenue from the base assumption of R2200 to R3450 per ton, about 57%, will raise the BEP to 500% imbibition on fibre.

Table 5. Effect of sugar revenue on imbibition break-even point.

Marginal sugar revenue per ton (R)	BEP Imbibition
2756	350
2953	400
3185	450
3450	500

Conclusion

In these circumstances, at the assumed cost of coal and sugar revenue, there would appear to be a strong incentive to reduce imbibition by a significant amount, and benefit from the resultant reduction in the consumption of coal. At sugar mills where coal is consumed on a continuous basis, it would be advisable to confirm the relationship between extraction and imbibition, and use this to monitor the relative cost of increasing imbibition compared to the cost of coal.

It is hoped that this paper will have helped to focus attention once again on the issue of energy efficiency and its wider ramifications.

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