# A REVIEW OF THE TRIANGLE ETHANOL PLANT AND ITS EFFECTS ON THE SUGAR MILL

By C. M. WENMAN and H. B. MORAR

*Triangle Limited, Triangle, Zimbabwe*

## Abstract

The performance of the Triangle ethanol plant since its commissioning in 1980 is reviewed. The rationale for its building at that time is discussed with particular reference to the current situation. Plant performance as well as operating changes that have been introduced over the years and their effect on the plant are described. The paper also comments on the operation of the sugar mill with a two-boiling system in conjunction with the ethanol plant.

## Introduction

As Zimbabwe is a land-locked country all sugar exports and all fuel imports have to be transported through neighbouring territories. This need is currently, and has been for many years, exacerbated by security problems in Mocambique requiring even longer and more expensive routes to be used.

In the 1970s, low sugar prices and the threat of oil shortages caused Triangle Management to look into the possibility of building a plant to produce fuel grade alcohol from molasses and a proportion of potential crystal sugar.

The final go-ahead to build this plant was given in November 1978 and the original cost of construction was Z$4 million. The plant is designed to produce 40 million litres per annum of anhydrous ethyl alcohol of minimum 99,6° quality in a fifty week season at 96% overall time efficiency. Daily rated capacity is 120 000 litres.

The plant is closely integrated with the existing sugar mill, utilising exhaust steam at 110 kPa gauge for distillation and is able to take feedstock from the sugar mill ranging from raw or mixed juice to B-molasses. Bought-in C-molasses can also be utilised.

In the design of the plant it was decided that a certain minimum proportion of crystallisable sugar would always be committed to ethanol production and as a result, the C-station was eliminated and Triangle currently operates only with A- and B-boilings.

During the first years of operation, juice as well as A- and B-molasses were used as feedstocks. After two years of operation the use of juice was discontinued and only A-and B-molasses were utilised. Again, more recently, the use of A-molasses has been discontinued and currently only B-molasses is used as a feedstock. These moves are all designed to reduce the amount of crystallisable sugar being consumed for ethanol production.

## Ethanol plant operations

### *Conversion efficiency*

One of the most important factors in assessing the efficiency or economic viability of the plant is the conversion ratio from sugar to ethanol. This can be expressed in several different ways and the most commonly used method is probably as litres of ethanol produced per ton of molasses. However, this does not take into account the quality of the molasses, particularly in the Triangle case where B-molasses is used. A more accurate measure, therefore, is to analyse the molasses for total sugars and to express the ethanol yield in terms of litres per ton of sugars. Often these sugars are expressed as invert sugars or monosaccharides but at Triangle sugars are expressed as sucrose since this can be directly related to the crystal sugar which otherwise would be produced. The expression of yield as outlined above appears straightforward.

The determination of sugars, however, is a minefield. An easy, quick and accurate analysis for reducing substances is available in the form of a Lane & Eynon titration and fairly closely approximates total sugars. However, the lower the purity of the molasses or juice, the more inaccurate this estimation becomes. Converted to equivalent sucrose, this analysis gives Total Reducing Substances as Sucrose (TRSAS).

Over a number of years, Triangle has utilised HPLC to determine total sugars and this gives a result much closer to true total sugars. Nevertheless, there are still a number of inaccuracies in this procedure and the equipment has not proved reliable. The most accurate determination is considered to be GC but this requires a high degree of expertise and is not really practical as a plant control parameter.

Over the last few years, in conjunction with the Technical Management Department (TMD) of Tongaat-Hulett Sugar Limited, Triangle has developed an alternate, more practical analysis to determine what is termed Total Fermentables as Sucrose (TF). This procedure consists of:

(a) undertaking a Lane & Eynon titration on unfermented material to determine Total Reducing Substances;

(b) carrying out a laboratory fermentation;

(c) determining Unfermentable Reducing Substances on this fermented sample.

**Table 1**

**Overall plant Ethanol yields**

| | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Yield of total alcohol: | | | | | | | | | | | | |
| Litres/ton TRSAS | 568 | 540 | 536 | 528 | 506 | 567 | 544 | 527 | 561 | 543 | 557 | 555 |
| Litres/ton GCTSAS | - | - | - | - | - | - | - | 606 | 589 | 569 | 589 | 593 |

(d) subtracting the Unfermentable Reducing Substances from Total Reducing Substances to give Total Fermentables.

Over the years this has shown the most consistent agreement of all methods with GC and is currently used at Triangle for weekly control purposes.

Bearing the above limitations in mind, yields achieved are tabulated, showing litres alcohol produced per ton TRSAS and per ton sugar measured by GC (GCTSAS), for the years that GC analyses have been done by TMD.

The accuracy of the figures in the first few years is open to question due to inaccuracies of measurement of both molasses and final product. The accuracy of molasses measurement since 1985 has been improved with the installation of a Servo Balans to weigh physically all molasses into the plant.

Measurement of fermented beer quality can be reasonably accurately determined. The quantity is measured using a magnetic flowmeter and cross-checked by tank dips, which leaves a fair margin for error in volume determination. Final product volumes are measured using a positive displacement meter and cross-checked using an accurate dip tape. These figures are considered acceptable.

Overall plant yields, therefore, can be determined accurately but fermentation and distillation efficiencies are prone to measurement errors.

*Molasses storage*

In order to achieve the annual design output, the ethanol plant is run during offcrop and to enable this to be achieved, molasses storage of some 38 000 tons has been built.

In the first few years of operation, it was discovered that loss of fermentability occurred during storage at levels as high as 5% on all material handled. Investigations by TMD (Smith and Cazalet, 1987) indicated that losses were adversely affected by high storage temperatures and coolers were installed to cool down the molasses to below 40° prior to storage. This has reduced storage losses to levels below 1%.

Molasses storage over extended periods, particularly during the hot summer months, is aggravated by foaming within the molasses. This foaming inevitably leads to losses in storage whilst making the measurement of stock very difficult.

The stock measurement problem has been reduced by fitting external pipes on the molasses tanks with an isolating and drain valve on them. These pipes are normally kept empty but when a level measurement is to be taken, the inter-y connecting valve is opened allowing non-foaming molasses from the bottom of the tank to enter the pipe and provide a depth measurement. The pipe is subsequently drained into buckets and left empty until a further measurement is required.

To reduce the foaming, product is continually circulated within the tanks and low and high pressure air is blown into the tanks at various levels. This air serves the dual purpose of assisting in circulation as well as breaking up any foam.

*Fermentation nutrients*

When the plant was designed and built a wide range of feedstocks was specified ranging from juice to C-molasses. This full range has been fermented and characteristically the higher the purity of the material the faster and easier the fermentation process. Conversely, low purity C-molasses results in slow fermentations with increased possibilities of infection or presence of residual sugars after fermentation is judged to be complete.

During one offcrop, crystal sugar was melted for fermentation but it was discovered that this fermented extremely poorly - contrary to expectations. To assist with the fermentation of this sugar, additional nutrients in the form of diammonium phosphate and urea were added to provide nitrogen and phosphorus. A similar effect was achieved by adding low purity molasses or by recycling stillage which provides these elements naturally.

This led management to question the amounts of nutrient that were being added as a result of the initial design recommendations. Marked reductions have been achieved in nutrients usage, considerably reducing operating costs and foreign currency expenditure. This reduction has also been assisted by the fact that for the last four years stillage has been routinely recycled at between 25% and 50% of mash volume depending on the purity of fermentable materials. This has the added advantage of increasing stillage brix and reducing its volume.

*Fermentation pH*

Sulphuric acid is used to reduce the pH of mash during the initial yeast growth phase to suppress bacteria development. During 1989, when it was found that the yeast was being poisoned by the presence of copper, it was suspected that this contamination may have originated in the acid.

As a result pH values were raised from 3,5 to 4,5 and significant reductions in acid consumption were achieved. No adverse effect in the form of increased bacterial infection was noticed and the plant has since continued to run at the higher pH values. Faster fermentations and higher yeast populations were found to result from this policy.

*Benzene usage*

Benzene was specified in the design of the plant as an entrainer in the final dehydration phase of distillation and benzene was produced within Zimbabwe at the Wankie Colliery, Hwange, by fractional distillation of raw benzol. Raw benzol from both Wankie Colliery and ZISCO (Zimbabwe Iron and Steel Company) coke ovens is also sent to Triangle for blending with the final product to denature it and render it unfit for human consumption.

Early on in the history of the plant, the possibility of carrying out a fractional distillation of raw benzol within the dehydration column was conceived. An experiment utilising benzol instead of benzene as an entrainer was run and this was found to be completely successful. As a result, the much cheaper benzol has been used in this role for many years.

Originally, consumption of benzol as a dehydrating agent was considered to be acceptable at about 0,5% of final product produced. Towards the end of 1988, however, it appeared that the benzene recovery column was not functioning adequately and with closer attention to the operation of this minor component of the plant, benzol consumption has since been reduced to less than 0,1%.

*Management*

When the plant was built, its operation fell under the control of an Assistant Process Manager, reporting to the Process Manager. In addition, the Assistant Process Manager still retained sugar production responsibilities.

This mode of operation proved acceptable for the first six years of operation but due to staff changes, it was felt that perhaps more direct management was required on the ethanol plant. As a result, in 1986 an Ethanol Manager with sole responsibility for operating the ethanol and carbon dioxide plants was appointed. Greater attention was also paid to yeast quality and quantity and a semi-skilled microbiologist was trained under the guidance of Tongaat-Hulett Sugar Limited's Technical Management Department staff.

The presence of these two persons led to the early discovery of fermentation problems in 1989 which were subsequently tracked down to the presence of copper in fermentation (Madaree *et al.*, 1990). Yeast counts, yeast viability examinations and checks for the presence of bacteria are now an integral and routine part of the plant operation.

When the plant was first commissioned, it was seen by most staff as being a convenient and ready safety valve or disposal outlet for sugar mill mistakes or inefficiencies. As a result, attention to inversion within the sugar mill and factory was allowed to lapse in the belief that any product which did not come out as crystallisable sugar would end up as molasses and hence ethanol. Over the years this way of thinking has been completely reversed and the slogan WHAT IS GOOD FOR SUGAR IS GOOD FOR ETHANOL has been adopted. Attention to housekeeping throughout the mill, as well as the ethanol plant, is now considered to be of utmost importance.

## Sugar mill operations

The sugar mill at Triangle is responsible for providing the ethanol plant with both feedstock and services, in the form of steam, raw and filtered water and maintenance.

Though autonomous in its management, the ethanol plant is an extension of the production process in the sugar mill. Decisions made in the mill have a direct bearing on ethanol or carbon dioxide production and hence close and constant communication is necessary. Contact between the plants is maintained via handheld radios.

Process monitoring and control in the sugar factory is done by analysing for both pol and TRSAS. The Factory Balance (including losses and recoveries) is calculated on a TRSAS as well as a pol basis. If there is any movement from pol to TRSAS, the particular station is investigated and corrective action is taken.

In addition to standard sugar factory monitoring, overall plant efficiencies are monitored in the following ways:

- TRSAS % mixed juice to sugar;
- B-massecuite exhaustion;
- TRSAS % B-molasses;
- TRSAS recovery based on cane;
- TRSAS boiling house recovery.

The traditional sugar factory attention to detail is not discarded and every effort is made to produce final product sugar of acceptable quality for the specific market as well as molasses of fermentable quality for ethanol production.

Over the past few years, it has been apparent that revenue to Triangle could be increased by maximising crystal sugar production and minimising potential (or deemed sugar) sent in molasses to ethanol. To this end, redundant C-centrifugals, crystallisers and pans have been re-deployed to enable A- and B-exhaustion to be maximised. Automatic controls have also been installed on batch pans to assist in optimising performance.

*Services*

Amongst the services provided to the ethanol plant, the major component is steam at a constant pressure and desuperheated temperature. This is essential for the maintenance of steady-state conditions in the distillery columns. Over the years, the power station has learnt that priority exhaust or back-pressure steam should be provided to the ethanol plant with the sugar mill having to take the fluctuations in the event of a steam shortage or pressure drop for whatever reason.

With the recent drought, strict water conservation methods were introduced in both factories. All sweet condensates not required in the sugar process are used at the ethanol plant for molasses dilution. The sugar mill laboratory provides a laboratory sampling and analytical service for the fermentation and distillation section.

## Economic review

When the plant was built, the main rationale for its construction was:

(a) From a national point of view, to decrease the nett outflow of foreign currency by sacrificing sugar exports for reduced fuel imports;

(b) From a Company point of view, to increase revenue over an extended period by reducing low price sugar exports and enhancing the value of molasses.

*National viewpoint*

With reference to Table 2 an estimate of the total foreign currency saving that has accrued to the country from 1980 to 1991 has been made. This has been done in two stages.

**Table 2**

**Nett national foreign currency earnings/losses as a result of producing ethanol from sugar**

| | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ave. world price of sugar USc/lb | 25 | 15 | 9 | 9 | 5 | 4 | 7 | 6 | 10 | 12 | 12 | 8 |
| Tonnes sugar used | 29 216 | 40 785 | 39 899 | 37 887 | 48 580 | 31 841 | 43 929 | 21 345 | 22 632 | 19 032 | 13 212 | 9 133 |
| Nett value/tonne Z$ | 305 | 192 | 134 | 169 | 111 | 69 | 198 | 157 | 352 | 512 | 528 | 726 |
| Nett loss of sugar revenue M$ | 8,91 | 7,83 | 5,35 | 6,40 | 5,39 | 2,83 | 8,70 | 3,35 | 7,97 | 9,74 | 6,98 | 6,65 |
| Litres EtOH produced x 1 000 | 30 186 | 38 517 | 39 289 | 36 703 | 38 463 | 36 161 | 41 582 | 37 122 | 34 129 | 30 864 | 29 795 | 22 888 |
| Delivered price of petrol Z$/litre | 0,34 | 0,29 | 0,30 | 0,32 | 0,37 | 0,39 | 0,25 | 0,26 | 0,29 | 0,41 | 0,55 | 0,84 |
| Nett reduction of fuel imports M$ | 10,26 | 11,17 | 11,77 | 11,74 | 14,23 | 14,88 | 10,40 | 9,85 | 9,90 | 12,45 | 16,39 | 19,23 |
| Cost of imported chemicals M$ | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,20 | 0,10 | 0,10 | 0,10 | 0,05 | 0,05 |
| Nett (cost) saving to Zimbabwe M$ | 1,15 | 3,14 | 6,23 | 5,14 | 8,64 | 11,85 | 1,50 | 6,20 | 1,83 | 2,60 | 9,36 | 12,53 |

Total saving over 12 years = Z$70 170 000

(a) Regarding sugar, average world prices and ruling exchange rates have been ascribed to each year. This has given a gross value per ton sugar. From this has been subtracted transport and harbour costs as well as transit losses which have been of significant magnitude over the last four years. This has given a nett value per ton of sugar, for each of the years under consideration, if that sugar had been produced and sold on the world market. The tonnage that was used in the ethanol plant has been estimated with reference to Hippo Valley's performance in the same year and assuming Triangle would have achieved a similar recovery. By multiplying the tonnage by unit cost, a nett loss of sugar revenue is estimated.

(b) From a fuel point of view, the landed price of petrol in each year was determined by the National Oil Company of Zimbabwe and multiplied by the volume of ethanol produced to give a nett reduction in fuel imports.

Finally, an allowance is made for imported chemicals used on the plant which have been reduced considerably in recent years.

The difference between lost sugar revenue and reduced fuel imports, with allowances being made for chemical imports, gives the nett cost or saving to Zimbabwe. Over the twelve years under consideration, this amounts to Z$62,28 million.

*Triangle viewpoint*

In trying to assess the benefit to Triangle of the ethanol plant, an initial estimate needs to be made as to what revenue would have been earned had the plant not been built. To do this, an estimate is made of the additional sugar that would have been produced and this is given in Table 2 as well as the price to be obtained for it at the Mill Door. This price and the tonnage are then included in the total pool of distributable proceeds earned by the industry, to give a new average Mill Door price. Multiplying by the new tonnage gives an expected annual sugar revenue.

To this needs to be added the revenue that would have been earned from molasses. To obtain this, an estimate of the annual unit cost of the molasses had the ethanol plant not inflated its value, has been made. The tonnage is again calculated using Hippo Valley's performance as a standard. Utilising these two sources of revenue only, the expected total revenue is calculated. The actual situation is shown in Table 4.

The cost of bought-in molasses is subtracted from the revenue earned from sugar and ethanol to give the nett actual revenue. When comparing this with the base case shown in Table 3, it can be seen that for nine of the twelve years there has been an increase in revenue over the base case. The three years in which losses were incurred were years during which world sugar prices were either high (1980) or significant quantities of sugar were in fact consumed for ethanol production (1986 and 1987). The total increase in revenue over the base case over the last twelve years is Z$43,5 million which includes two back-payments of Z$10,4 million received for ethanol but not included in annual totals in Table 4.

Finally, for interest, a second theoretical exercise was undertaken using a similar approach to the previous two cases, but in this instance, trying to assess what could have been achieved had the ethanol plant been built and the C-station been left intact. This shows a very much more favourable situation, again highlighting the benefit to Triangle of revenue earned from sugar production when this is calculated on an average pool price. This illustrates the particular benefit to a sugar mill of making ethanol from final molasses only.

**Table 3**

**Estimated revenue without ethanol**

| | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| World sugar price USc/lb | 25 | 15 | 9 | 9 | 5 | 4 | 7 | 5 | 10 | 12 | 12 | 6 |
| Probable molasses price Z$/tonne | 20 | 22 | 25 | 27 | 30 | 32 | 35 | 37 | 40 | 42 | 45 | 50 |
| Expected sugar revenue MZ$ | 43,74 | 30,14 | 33,98 | 46,12 | 58,66 | 58,04 | 76,43 | 79,45 | 96,97 | 126,21 | 148,15 | 131,06 |
| Expected molasses revenue MZ$ | 0,91 | 1,08 | 1,35 | 1,74 | 2,06 | 1,96 | 2,42 | 2,55 | 2,54 | 2,95 | 3,03 | 2,26 |
| Expected total revenue MZ$ | 44,65 | 31,22 | 35,33 | 47,85 | 60,72 | 60,00 | 78,85 | 82,01 | 99,50 | 131,16 | 151,16 | 133,36 |

**Table 4**

**Actual revenue with ethanol**

| | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Actual sugar revenue MZ$ | 35,35 | 22,41 | 27,26 | 38,33 | 49,36 | 51,97 | 65,23 | 73,48 | 88,03 | 118,22 | 140,02 | 123,51 |
| Actual ethanol revenue MZ$ | 7,19 | 10,14 | 12,15 | 13,12 | 16,86 | 16,14 | 17,50 | 17,69 | 16,08 | 19,69 | 22,70 | 20,83 |
| Cost of bought-in molasses MZ$ | 0,20 | 0,62 | 0,98 | 1,20 | 1,65 | 2,54 | 2,15 | 2,17 | 1,92 | 2,40 | 3,01 | 2,17 |
| Actual total revenue MZ$ | 42,33 | 31,93 | 38,43 | 50,25 | 64,57 | 65,56 | 80,58 | 89,00 | 102,19 | 135,51 | 159,71 | 142,17 |
| Increase (decrease) in revenue | (2,32) | 0,70 | 3,10 | 2,40 | 3,85 | 5,56 | 1,73 | 6,99 | 2,69 | 4,35 | 8,54 | 8,81 |

Total increase in revenue over last twelve years with the ethanol plant = MZ$57,79

**Table 5**

**Potential revenue with C-station and ethanol**

| | 1980 | 1981 | 1982 | 1983 | 1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990 | 1991 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ethanol revenue MZ$ | 3,24 | 4,66 | 6,06 | 9,95 | 9,60 | 9,87 | 10,09 | 10,81 | 14,55 | 14,72 | 17,14 | 14,01 |
| Expected sugar revenue MZ$ | 43,74 | 30,14 | 33,98 | 46,12 | 58,66 | 58,04 | 76,43 | 79,45 | 96,97 | 128,21 | 148,15 | 131,06 |
| Cost of bought-in molasses MZ$ | 0,20 | 0,62 | 0,98 | 1,20 | 1,65 | 2,54 | 2,15 | 2,17 | 1,92 | 2,40 | 3,01 | 2,17 |
| Expected total revenue MZ$ | 46,78 | 34,18 | 39,07 | 54,87 | 66,62 | 65,37 | 84,37 | 88,10 | 109,60 | 140,53 | 162,27 | 142,92 |
| Increase (decrease) in revenue | 2,13 | 2,96 | 3,74 | 7,01 | 5,89 | 5,37 | 5,52 | 6,09 | 10,10 | 9,37 | 11,09 | 9,56 |

Total potential increase in revenue over last twelve years with a C-station and ethanol plant = MZ$76,83

## Conclusions

From the above the following conclusions can be drawn.

(a) From a national point of view, the plant - in every year except one - has shown a saving in nett foreign currency expenditure. However, with more flexibility between sugar and ethanol production, this could have been improved even further.

(b) From a Triangle point of view, the plant has more than fulfilled its objectives in earning more than ten times its capital cost in the last twelve years. However, again with more awareness and ability to shift between ethanol and sugar production, this could have been at least double that shown.

### REFERENCES

Madaree, SJ, Rein, PW and Wenman, CM (1991). Investigations into problem ethanol fermentations. *Proc S Afr Sug Technol Ass* 65: 129-132.

Smith, IA and Cazalet, JS (1987). Estimation of sugars loss in stored high-grade molasses. *Proc S Afr Sug Technol Ass* 61: 18-21.