

PERSPECTIVES ON ETHANOL MANUFACTURE

By A. B. RAVNÖ

Sugar Milling Research Institute

Abstract

Recent trends in market demand and oil refinery yield patterns in South Africa are discussed. Reasons for the growing diesel/oline imbalance are noted, with particular reference to the impact which the coal-based SASOL plants will have on the fuel pool in the 1980's. Against this background the potential role which ethanol could play as an extender in the country's automotive fuel pool is discussed. A brief review of the technology for the production of ethanol from sugarcane is given together with a current cost estimate for this operation. Various options for the disposal of distillery effluent are discussed.

Introduction

Relative to many other countries in the world, South Africa is in the fortunate position that about 75% of its total energy needs are furnished by coal.¹ The fuels market may conveniently be divided into two principal categories, namely the stationary and the transport (or automotive) sectors.

Electric power generation constitutes the bulk of the stationary users and the primary energy needs in this sector are derived predominantly from coal. The automotive sector is overwhelmingly the preserve of the oil industry and the internal combustion engine.

In recent years a lot of attention has been focused on the need to develop a substitute for petroleum-based automotive fuels. This has been brought about by the steep cost escalation in fuel prices since 1973, the growing realisation that crude oil is a non-renewable resource and — in South Africa — the urgent need to find an indigenous fuel not subject to the threat of international boycotts.

The whole question of alternative transport fuels is one which has exercised the minds of scientists, economists and planners in many countries during recent years. It has been the central theme for numerous conferences and the coverage in the scientific literature on the relative merits of methanol, ethanol, hydrogen, battery power and oil-from-coal is formidable.

Of all the possible substitute fuels, ethanol is of most interest to the sugar technologist, since it can readily be manufactured from either sugarcane or molasses. The discussion in this paper has been confined to two specific areas. Firstly the recent processing trends in the oil industry in relation to market demand are reviewed in an attempt to place into perspective the potential role which ethanol could play in the overall automotive fuel pool. Secondly a brief outline is given of the technology and approximate costs involved in the manufacture of ethanol from sugarcane. Although it is beyond the scope of this paper to consider the relative roles of the other potential alternative fuels, it is almost certain that the long term solution of the energy problem is going to involve the utilisation of all these energy resources.

The oil industry

Refinery processing

Crude oil is refined into a number of product blending components by means of a variety of physical (e.g. distillation) and chemical (e.g. catalytic cracking) processing steps. These blending components are then mixed in the proportions required to meet the final product specifications. The task of the oil refinery

is to match its product out-turn to the market demand spectrum which it must supply. In consequence product yield patterns from crude oil refining vary significantly around the world.

Traditionally the refining scene in the U.S.A. has been affected by the availability of cheap, indigenous natural gas, thereby reducing the demand for fuel oil. This fact coupled with the American motorists' predilection for large, fuel-hungry vehicles has exaggerated the light distillate requirements.

The picture in Western Europe, on the other hand, differs considerably, where the limited availability of natural gas has permitted fuel oil to dominate the power and heating market. These contrasting yield patterns are illustrated in Table 1, based upon information published for 1973 by Wheatley.²

TABLE 1
Typical refining patterns

Component	Percentage by Mass	
	U.S.A.	Western Europe
Gasolines	42	17
Middle Distillates	29	33
Fuel Oil	7	37
Other Products (including Refinery Fuel and Loss)	22	13

There are two ways in which the oil refiner can match the product yield pattern to the market demand. The first of these concerns the effect which crude oil type has on refining yield. Typical distillation yields² for a light (Qatar) and a heavy (Iranian heavy) Middle Eastern crude are listed in Table 2. However other considerations such as purchase costs, freight, political circumstances and long term supply arrangements very often predominate and limit the flexibility of the crude slate. Another variation on this theme, which was used at one stage in this country, was the practice of spiking a crude oil with some imported naphtha to enhance light distillation yields. The economics of doing this are, of course, highly dependent upon the world-wide supply/demand position for naphtha as a chemical feedstock.

TABLE 2
Crude distillation yields

Component	Percentage by Volume	
	ME Light	ME Heavy
Gas	3	2
Gasolines	21	15
Middle Distillates	38	31
Fuel Oil	38	52

The other more flexible method of adjusting yield patterns is through the choice of refining configuration. Various plant combinations can be postulated depending upon the extent of conversion needed. By the progressive installation of more extensive catalytic cracking, then visbreaking and finally deasphalting followed by either heavy oil cracking or hydro

cracking, the net fuel oil yield can be reduced to as low as 13% by mass on crude. However the costs, both capital and operating, for the more complex configurations increase almost exponentially with reduction in fuel oil yield.²

The Dieseline Problem

The general refining pattern in South Africa lies somewhere between those of the U.S.A. and Western Europe shown in Table 1. Although accurate figures on the current market demand situation are not available, some data published a few years ago giving estimated projections² serve to illustrate the point, even if the figures are a little out of date. These data are reproduced in Table 3 and reflect the forecasted market demand in refinery yield terms assuming a fixed 8% refinery fuel and loss.

TABLE 3
Local product demand projections

Component	Percentage by Mass		
	1973	1980	1985
Gas	2,2	3,2	3,0
Gasolines	31,1	33,0	32,2
Middle Distillates	30,6	35,3	37,7
Fuel Oil	24,0	15,9	14,5
Other Products	4,1	4,6	4,6
Refinery Fuel/Loss	8,0	8,0	8,0

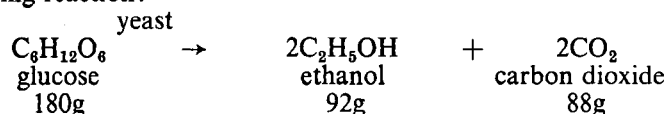
These figures indicate a progressive reduction in fuel oil demand coupled with a growing middle distillate bulge. Whilst a refinery can fairly readily reduce fuel oil output by the installation of more extensive cracking facilities, there is much less flexibility in the achievable gasoline/middle distillate (or dieseline) ratio. This projected gasoline/dieseline imbalance is largely due to a reduction in growth rate for gasoline sales following the rapid price increases, the general speed restrictions and the reduced selling hours, particularly over weekends. This problem will be compounded in the near future with the commissioning of SASOL II. Unfortunately the manufacture of oil-from-coal via the Synthol route tends to produce considerably more gasoline than dieseline, to the extent that, on paper, there could be a surplus of gasoline production in the country by the mid 1980's.

The above factors are of considerable importance in any discussion on the potential supplementary role for ethanol in the automotive fuel pool. Fortunately ethanol is capable of being blended with both gasoline and dieseline, which enhances its flexibility as a fuel extender. However it is beyond the scope of the present paper to look at the properties of ethanol in relation to both gasoline and dieseline blends, as this topic is to be covered elsewhere.

Ethanol production

Stoichiometry and Yields

Ethanol is produced from the fermentation of invert sugar by the yeast, *Saccharomyces cerevisiae*, according to the following reaction:



Where sucrose is utilised as the substrate the above reaction is preceded by the conventional hydrolysis of sucrose to invert sugar. The stoichiometric yield of ethanol from glucose is 51,11% on a weight basis.

Normally the efficiency of fermentation is expressed in terms of actual ethanol yield as a percentage of the theoretical stoichiometric yield, assuming only ethanol and carbon dioxide are formed. In practice a number of other products are also formed and Pasteur, in a series of classic experiments,³ concluded that the maximum attainable yield under ideal laboratory conditions was 94,5% of theoretical. In practice yields of 85-90% of theoretical are achieved.

A recent paper by Chenu⁴ discussed the optimum point in the process at which crystallisable sugar should be diverted to the distillery, in order that the overall steam/energy balances are not adversely affected. However no mention is made of the effect which this position can have on alcohol yields. A recent study has indicated that, while laboratory fermentation yields of 94,5% of theoretical were achievable on A-molasses, these fell to 92,3% on B-molasses and as low as 86,6% on C-molasses.⁵ This indicates that during the boiling process some fermentable sugars are degraded and converted to unfermentable reducing substances.

Processing Routes

Most distilleries still operate a batch process with fermentation times varying between 20 and 72 hours. In the manufacture of potable spirit, extreme care is exercised over the fermentation step to ensure that the production of undesirable components is minimised. To achieve this, many distillers utilise a fresh batch of yeast each cycle. However for the manufacture of fuel alcohol in Brazil, extensive use is made of the Melle-Boinet discontinuous process, which involves the recovery and recycling of yeast cells. This permits the use of much higher yeast concentrations in the fermenters and hence a substantial reduction in the required fermentation times. It is claimed in certain quarters that some form of molasses pretreatment to remove calcium salts and suspended matter is a prerequisite, if yeast recycling is being contemplated. However this does not appear to be essential, especially where juice feeds are being used.

The fermentation process itself is sensitive to both temperature and alcohol concentration. Temperatures should be kept as constant as possible in the range 32-36° C. Below 32° C the kinetics of the reaction are severely retarded, whilst above 36° C the yeast activity is adversely affected. High alcohol concentrations also inhibit yeast activity, which places a limitation on the initial sugar concentrations that may be used. It is seldom that alcohol concentrations of 10-11% v/v are exceeded, whilst many distillers operate in the 8-9% range.

In Europe there is a move towards the installation of continuous fermentation systems. These require very close process and microbiological control but are reputed to result in a substantial reduction in both capital and operating costs. A recent innovation is the concept of vacuum fermentation^{6, 7} whereby ethanol is continuously stripped from the fermenter under reduced operating pressures. This obviates the problem of alcohol inhibition and should permit the use of more concentrated feed solutions. However the major drawback at present appears to be the relatively high capital and operating costs for maintaining the required vacuum conditions.

A three stage distillation process is normally used to separate the ethanol from the fermented beer and concentrate it into absolute (or anhydrous) alcohol. A simplified flowsheet of the distillation process is given in Figure 1.

In the first tower the ethanol is steam stripped from the stillage (or distillery effluent). This column is prone to severe scaling, especially when final molasses is used as the distillery feedstock. The second (or rectifying) column concentrates the ethanol up to the constant boiling (96,5° GL) ethanol-water azeotropic mixture. However for the production of fuel alcohol

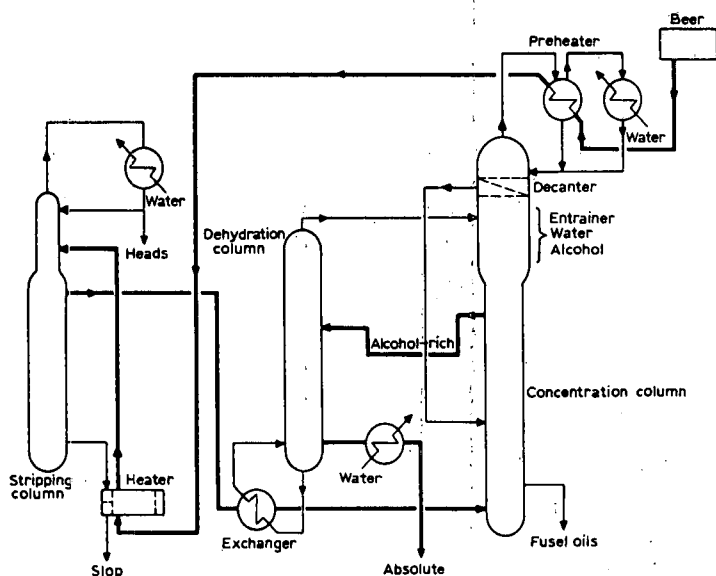


FIGURE 1 Typical flow scheme for the distillation of anhydrous ethanol.

it is necessary to remove the last few percent of water and since this cannot be achieved by simple, two-component distillation, it is necessary to introduce a third phase into the system, usually benzene. This forms the ternary benzene-water-ethanol azeotrope having a lower boiling point than rectified spirit and hence facilitates the final removal of water. The benzene and some ethanol are recovered in a small fourth tower and recycled back to the process. Traditionally alcohol distilleries have made extensive use of bubble cap towers, although some of the recent installations feature both valve and sieve tray designs, as well as double effect distillation for improved steam economy.

Cost of ethanol manufacture

Much has been said and written about the cost of ethanol manufacture from a variety of substrates.^{3, 8, 9, 10, 11, 12} Whilst it is generally accepted that the cost of producing ethanol is somewhat higher than the cost of the equivalent petroleum based fuels, there is much speculation that the ever increasing price of crude oil will progressively render ethanol more attractive.

A historical review of the "in bond" price of regular gasoline at the coast (net of all excise duty and levies) over the past 60 years is depicted in Figure 2. On the same graph the raw material costs for ethanol from sugarcane are shown over the past 50 years.

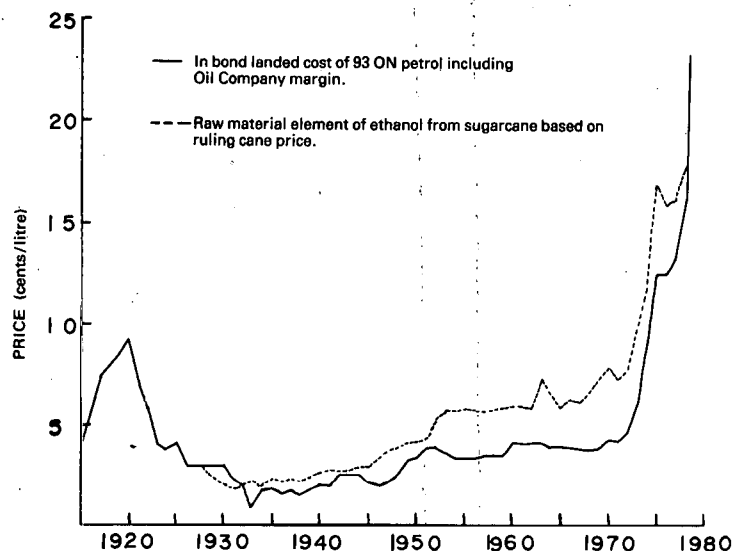


FIGURE 2 Trends in the fuel and cane prices with respect to ethonal manufacture.

It is readily apparent that over most of the period under review the raw material element on its own has been higher than the net petrol price. Although the figures presented have not been converted into real terms, the effect of inflation, especially in recent times, is clearly evident.

It has been estimated that the current cost of producing ethanol from sugarcane is in the region of 36 cents/litre. A detailed breakdown of this cost is given in Table 4.

TABLE 4
Estimated costs for ethanol from sugarcane

Cost element (see note 1)	Cents/litre	Comment
Raw material	18,0	See note 2
Juice extraction	9,2	See note 3
Process chemicals	0,4	
Utilities (water/steam/power)	0,2	
Salaries and wages	0,4	
Maintenance materials	0,5	See note 4
Depreciation	1,8	See note 5
General expenses	0,1	
Industrial levy	1,4	See note 6
Return on capital	3,8	See note 7
TOTAL	35,8	

- NOTE: (1) Basis — 220 000 litres/day module
fixed capital R9 million
working capital R2 million
- (2) Basis — cane price R13,50 per ton
ethanol yield 75 litres/ton cane
- (3) Based on the assumption that two-thirds of the total Millers cost claim (including transport) is associated with processing up to the juice scales; to this figure is added the full "return on capital" element for both the extraction plant and the boiling house equipment rendered redundant due to the diversion of juice to the distillery.
- (4) Basis — 3% per annum on fixed capital cost.
- (5) Basis — 10% per annum on plant and machinery.
5% per annum on buildings.
- (6) Based on assumption that 30% of full industrial levy of R1,50 per ton cane is associated exclusively with export sugar and can be deducted from levy applicable to alcohol production.
- (7) Basis — 14% return p.a. on full (undepreciated) fixed + working capital over 10 year period.

Distillery Effluent

No discussion on ethanol manufacture is complete without a word about distillery effluent. The very nature of the fermentation process and the limits to which yeasts can tolerate alcohol means that a large water load must be transported through the process system to emerge as an effluent stream. The magnitude of the disposal problem will be appreciated when it is realised that distillery effluent, or stillage, is typically produced at a rate of 10-15 litres/litre of ethanol. The polluting load of stillage varies widely depending upon the substrate used, the fermentation efficiency and the processing system, but levels of BOD₅ between 10 000 and 60 000 ppm have been recorded.¹³ It has been estimated that the stillage from a 100 000 litres/day distillery is equivalent to the pollution load from a population of about 1,7 million people.¹⁴ Some typical compositions for stillage are given in Table 5.¹⁵

The topic of stillage disposal has been comprehensively covered in the literature in a number of excellent reviews.^{13, 14} Some of the methods discussed are mentioned briefly below:

- Irrigation — this is the simplest method of disposal provided sufficient suitable land is available. It has been estimated that an initial application rate of 60m³ per hectare per annum could be used in the South African industry.¹⁶
- Evaporation — this method can be used either to reduce the volume for removal by road transport or to produce a concentrated syrup for use as a binder in animal feed

TABLE 5
Stillage composition from Molasses and Juice

Component	Percentage Weight	
	Molasses	Juice
Total solids	6,47	6,69
Organic matter	4,63	5,14
Mineral matter	1,95	1,50
Nitrogen	0,04	0,01
Calcium	0,07	0,04
Magnesium	0,02	0,01
Phosphorous	0,01	0,007
Potassium	0,48	0,17
pH	4,8	4,6

formulations. This tends to be an expensive process requiring quadruple or quintuple effect evaporation in stainless steel vessels, which will need frequent cleaning, either chemical or mechanical, to remove heavy scale deposits.

- (c) Spray drying — this system is used extensively by NCP in South Africa to produce their ethyl concentrate feed, which is sold both here and abroad as an animal feed component.
- (d) Incineration — this method permits the utilisation of the organic fuel value to generate heat whilst a crude form of potash is recovered. Special furnace designs are required for this process. A fluid bed incinerator was installed at the Bacardi plant in the Bahamas but has allegedly been closed down, whilst Ahlström type furnaces are reported to be operating at the Bols distillery in Schiedam (Holland) and the Bacardi plant at Malaga (Spain).
- (e) Fermentation — anaerobic fermentation to produce methane gas or aerobic fermentation to yield single cell protein are proven processes. Considerable work on the production of fungal biomass from stillage has been undertaken in Taiwan¹⁷ and extensive use of this process is made at their new Hsinyin plant to produce Torula yeast.

Conclusion

The technology for ethanol manufacture from sugarcane is well established and proven. It has also been shown that ethanol could play a significant supplementary role in the short/medium

term as an extender in both the gasoline and diesel fuel pools. However since the State has now committed itself to massive expenditure on the coal-based SASOL route, the competitive position of ethanol, and other potential substitute fuels, will not be determined solely by market forces in a free enterprise system. That ethanol will inevitably have a role to play is beyond dispute, but it is probable that the State, and not industry, will decide upon the timing of this step.

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