

The Potential for Bio-Ethanol Fuel from Molasses in the Southern African Sugar Industry

J. F. Agwa-Ejon, C. Mbohwa

Department of Quality and Operations Management, University of Johannesburg, Johannesburg, South Africa

Abstract-This paper investigates the technical advancement in the production of ethanol in Southern Africa and examines the utilisation of ethanol and of the by-products derived from its production process. Although numerous studies have identified the use of ethanol as an alternative energy source especially in Brazil and the USA, very little data and analytical attention has been given to Southern Africa. This paper therefore builds on that and on the study done on alternative energy in Southern Africa such as the coal to liquids processes by Sasol. The paper demonstrates that the expansion of bio-ethanol as an alternative fuel would result in the reduction of Greenhouse gasses emissions and an increase in the rural economic development in the Southern African region. In conclusion the paper emphasises the need for a speedy upgrading of the ethanol technological methods in order to expand the use of bio-ethanol as an alternative energy. In addition the paper strongly recommends the supplementation of coal for the generation of electricity, as well as the progressive replacement of petroleum fuelled vehicles with the ethanol blend or the complete replacement with ethanol-fuelled ones.

and reasons for the construction of the Triangle ethanol plant are discussed. In 1951 the British Commonwealth sugar agreement guaranteed fixed prices to the historical sugar producers, and encouraged the South African Sugar Company Hulett, and the mining giant Anglo-America to invest in Swaziland and then Southern Rhodesia, now Zimbabwe [4]. This led to large investments in sugarcane farming, which was short-lived following the withdrawal of South Africa from the British Commonwealth and the increased Isolation, as well as a sustained period of low world sugar prices in the 1960s, which discouraged further investments in the sugar industry. Tongaat Hulett Sugar Company emanated from the above investments and now comprises the wholly owned Hippo Valley and Triangle sugar estates, and the Triangle ethanol plant situated in the South low-veld of Zimbabwe approximately 450 kilometres from Harare. Fig.1 shows the exact location of the plant. The ethanol plant at Triangle provides a useful means of disposing of large quantities of molasses produced by the sugar factory.

I. INTRODUCTION

This section gives a background history of the sugar estates in the Southern low-veld region of Zimbabwe, the Triangle, and Hippo Valley estates and plants. The history

The production of ethanol therefore has proven to be an economically attractive aspect of the Triangle operations by utilising the molasses from both the Triangle and Hippo sugar estates, which could have otherwise been transported elsewhere at considerable cost [1].

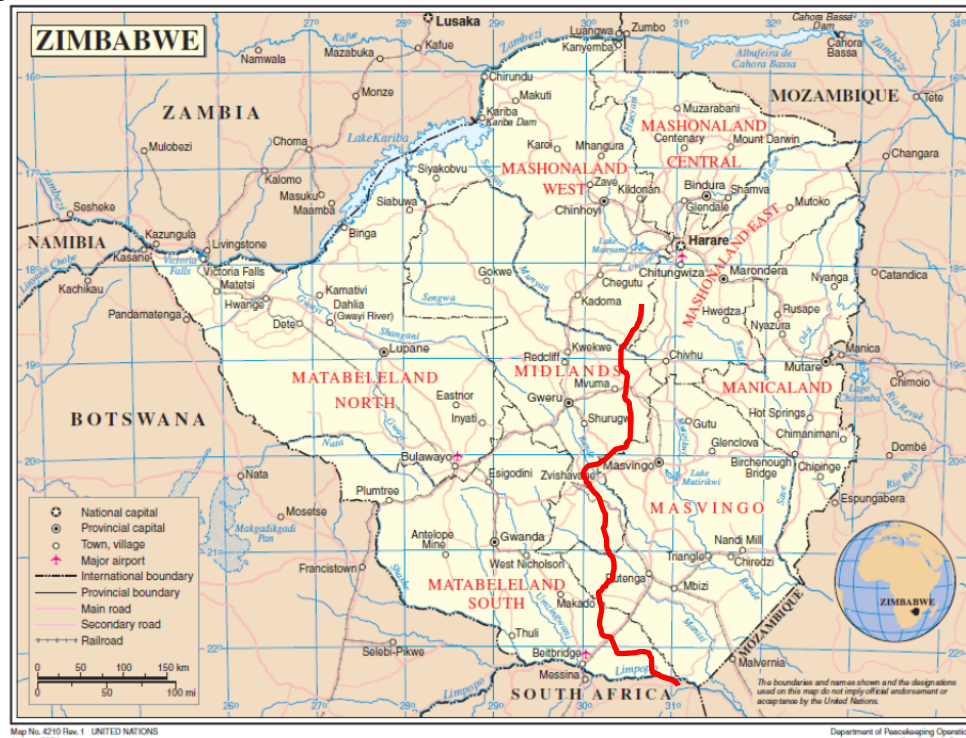


Fig. 1: The position of Triangle ethanol plant traced by a red marked road from Harare the capital city (U.N 2004, Zimbabwe Map No. 4210 Rev 1) [12].

The ethanol plant at the Triangle Limited was built partly because of political reasons, since this was approved at the time when Zimbabwe was at war and was under international sanctions, hence the need to be more independent in terms of fuel supplies. As reported by Dominic Dhanah [2], the export of sugar via Mozambique became impossible. This country had gained independence in 1975 and was now a political enemy, forcing a decision to construct the ethanol plant in order to convert over 30,000 tons of sugar molasses produced into motor fuel. Dominic further explained that much later between 1999 and 2000 the country experienced serious fuel shortages and had to blend petrol in-order to produce an affordable fuel. This enabled Zimbabwe to save the needed foreign currency at the time. At the moment most of the ethanol produced is industrial and not anhydrous ethanol usable for fuel blending. It is exported through the South African port of Durban to Europe and the Middle-East since the domestic market for industrial ethanol in Africa is anticipated to remain much lower compared to its export market.

In this paper, the current methods used in the production and improving of the ethanol yields are discussed, as well as the factory capacities of the plant. The paper outlines the basic operations in the production of ethanol by examining each stage of the operation, with particular emphasis on both the input and outputs during the production process. Details of how these processes are carried out and the capacity constraints are mentioned. Discussions are also extended to the efficiency and the effectiveness of each stage. The paper concludes by noting the growth in the ethanol industry especially in the Triangle, the ethanol contribution to the economy of Zimbabwe, and the potential economic benefits derived from rural developments based on both the direct and in-direct support.

II. LITERATURE REVIEW

According to Richardson [11], Southern Africa is considered the hottest spot in the sugar industry and even could be the Middle East of biofuels in the future. Over the last decade, foreign companies have earmarked around \$3bn for investment in the sugar cane industries of some of southern Africa's poorest countries to produce sugar and ethanol for export. The African-grown biofuels would have a small effect on total global carbon emissions, and it is unlikely that they will begin to substitute for domestic oil demand any time soon. The purported link to rural development will therefore be the most relevant reason for poor African countries to pursue investment in these biofuels. The investment in the export of sugar and ethanol can increase on-farm and off-farm employment and revenue. According to the International Energy Agency, African demand for biofuels will reach two billion litres by 2030, which will almost exclusively be concentrated in Nigeria and South Africa the major oil users at present. Naturally there are food versus energy issues that need to be resolved so that

the efforts do not result in hunger at all. Richardson further explained that the Climate Change Package adopted in 2008 by member states of EU requires the use of renewable energy for 10% of its transport energy by 2020. Since the EU is unlikely to produce enough biofuels domestically, it will have to import. Due to its low cost and higher greenhouse gas savings, sugarcane is promoted as one of the best options for meeting this demand in the EU and other developed countries. The trade agreements such as the EU's includes everything But Arms Agreement (signed in 2001), which allows least developed countries (LDCs) to export most products to the EU without restrictions, and provides the opportunity for Southern African sugar producers to meet this EU demand. The availability of plenty of sunshine and access to irrigated fresh water make the sugar production in the Southern African LDCs globally competitive. A Zambian sugar industry, known as Zambia Sugar, produces between 50,000 and 80,000 tonnes of molasses per year, which translates to 15m to 24m litres of biofuel at a rate of 300 litres/tonne. This amount of biofuel will replace around 6% of the country's petrol demand.

In his writings on Ethanol production, Peter [10] explains how sugar crops have a clear advantage compared to that from other crops. Sugar cane and sugar beet can potentially yield between 6 - 8,000 litres of ethanol per hectare, compared to only 3 - 4,000 litres from cassava and corn and only 1,000 litres from wheat. What adds to the competitive edge of ethanol from sugar cane is the fact that it produces eight times as much energy as it uses, compared to 1.2 times if the feedstock is wheat, and around 1.5 times if the feedstock is corn. Also production costs are lowest when using cane juice or molasses. The production cost of ethanol from molasses is about \$0.3 - \$0.4 per liter, compared to \$0.5 per liter from corn. This production cost of \$0.5/liter of corn/ethanol also includes subsidies provided by the government.

Dufey and Greig-Gran [3] discuss the small volumes of bioethanol which are already being manufactured in South Africa by fermenting the molasses produced as a by-product of the sugar industry. This product is primarily used as portable alcohol, in paints and inks and by the pharmaceutical industry. About 40,000 tons of bioethanol is manufactured from sugarcane molasses, and another 115,000 tons of industrial ethanol is manufactured by Sasol as a by-product of its Fischer-Tropsch process. More than 50% of this ethanol is exported to African countries and Europe. The yield from molasses in South Africa has been estimated to have the capacity to substitute 0.91% of the region's petrol by 2015. To blend 8% of bioethanol with petrol, South Africa would require a more than ten-fold increase in the country's bioethanol fermentation capacity. It will require about ZAR 1.4 billion to build new infrastructure to process sugar cane to produce this amount of bioethanol. Sugar processing mills in South Africa currently operate at between one fifth and half of their capacity, and these mills could easily convert existing processing capacity so as to manufacture bioethanol. To

compete with imported fuels, it is estimated that South African bioethanol is required to be produced at US\$0.46 per liter. The production cost of South African dry land sugar cane can be very low at US\$20 per ton. The cost of producing bioethanol is estimated to range between US\$0.41 – US\$0.52 per liter. Considering no or little feedstock price inflation, the processing cost can be reduced over time as in the case of Brazil, where the bioethanol production cost has dropped by around 10% per year over the last several years as a result of efficiency and scale enhancements. Additional revenue can be generated through potential sale of bioethanol by-products, and emissions reduction certificates from the Clean Development Mechanism (CDM). According to the Biofuels Task Team estimates, sugar cane bioethanol could generate additional carbon revenue of US\$0.15 per liter. Thus, by-products generated from the production of sugar cane bioethanol for E8 blends would generate US\$14 million. The scenarios by the Cane Resources Network for Southern Africa (CARENSA) [14] indicate a potential for the production of bioethanol from sugar crops in Southern Africa in magnitudes that could meet domestic demands and export markets in the region as shown by Fig. 2 below.

A report by Deenanath, Iyuke and Rumbold [1] discusses the establishment of ethanol plants in SADC countries. The research began by examining, the Triangle Ethanol Plant constructed in 1980 in Zimbabwe which began producing approx. 40 million litres of bioethanol annually (120,000 litres per day) using sugar cane molasses available from local sugar cane processing mills as feedstock. However, the plant was compelled to shut down due to drought conditions, which resulted in a severe reduction in sugar cane production. Likewise, the Kenyan Muhoroni Plant which produced

45,000 litres of bioethanol per day from sugar cane molasses closed in 1993 due to a financial crisis and lack of support from the government and oil companies. Deenanath, Iyuke and Rumbold [1] also reported on the Malawian Dwangwa Estate Plant built in 1982, and which began producing 15 to 20 million litres of bioethanol annually from sugar cane molasses and is still in operation. Another plant in Malawi, the Nchalo Plant, began bioethanol production in 2004, and produces approx. 12 million litres per annum.

In Sub-Saharan Africa, crops are major sources of food for human consumption. For instance, almost 95% of maize cultivated in Zambia is consumed as the staple food. This makes corn a bad energy crop, since it would affect food supplies. Sugar cane and bagasse are utilized for the generation of electricity and heat in Mauritius. There is a strong believe that Bioethanol production from sugar cane might threaten electricity production in the sugar cane industry as better innovative technology gets introduced. It is also noted that sugar cane and sweet sorghum have the highest potential for bioethanol production with lesser food security issues. Due to favourable climatic conditions, sugar cane cultivation is dominant in Zimbabwe, South Africa and Mauritius. Van Zyl, Chimphango, den Haan, Gorgens and Chirwa [13] gave a detailed explanation of Ethanol production from molasses which currently has a very high unexploited potential in Africa (Table 1). For instance, only 30% of the molasses produced from the sugar industry in Tanzania is exported and used as animal feed, while the remaining 70% goes to waste. Hence, sugar cane molasses offers a viable option to mitigate the potential negative impact of increasing biofuel production on food security in the region.

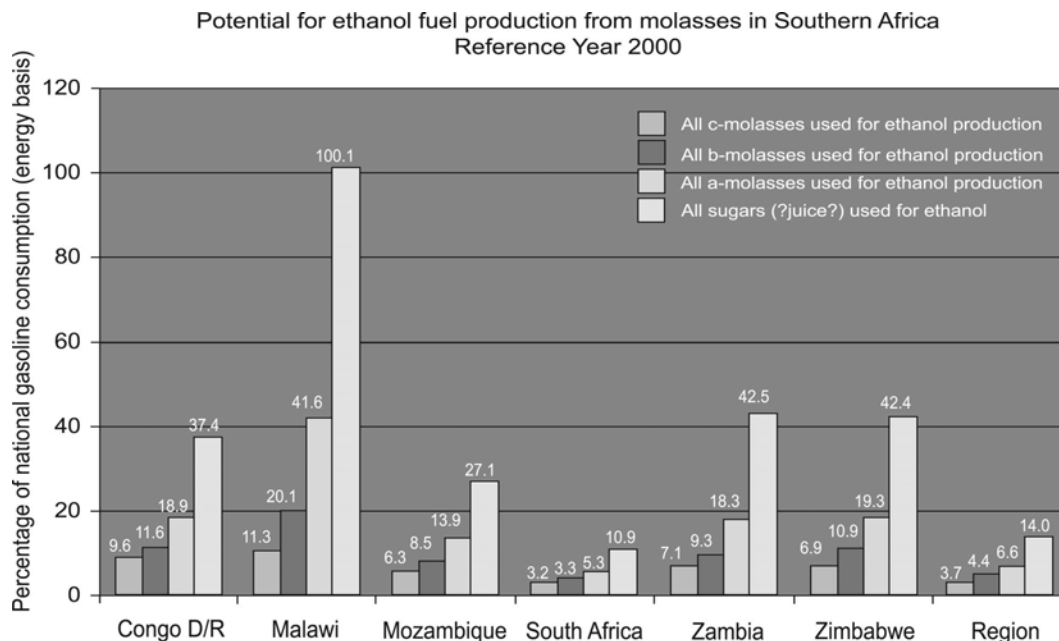


Fig. 2: Potential for ethanol fuel production from molasses in Southern Africa. (Source: Based on CARENSA scenarios, J. Woods and G Brown., 2005.)

TABLE 1. POTENTIAL OF ETHANOL PRODUCTION FROM SUGAR CANE MOLASSES IN SELECTED AFRICA COUNTRIES IN MEGALITRES (ML)

Country	Ethanol (ML)
Ivory Coast	20
Mali	20
Malawi	146
Kenya	413
Ethiopia	80
Sudan	408
Swaziland	480
Senegal	15
Tanzania	254
Uganda	119

A recent study by Mwithiga [8] has further established that besides molasses being composed of sucrose and invert sugars (40% to 60%) as well as other crop nutrients including vitamins. The yield of molasses per unit mass of sugar cane ranges from 3.5 to 4.5% depending on the variety of sugar cane, or on the process. The fermentation of molasses can yield 0.45 litres of ethanol per kg. The potential bioethanol yield from molasses in South Africa is estimated to be 672 litres per hectare. The importance of an ethanol plant is strengthened by an argument by Felix, E., Cardona, C. A., and J. A. Quintero [5] who stated that the integration of ethanol distilleries in existing sugar mills ensures profitability for the sugar industry by shifting production between ethanol and sugar in response to world market sugar prices. The integrated facilities eliminate the cost associated with the transportation of molasses which lowers the production cost for molasses-based ethanol.

III. RESEARCH METHODOLOGY

The methodology used in this study is based on a single case study conducted by the researcher, who visited the plant site and carried out a detailed extensive tour of the plant in conjunction with the factory officials. An extensive document review was also done in order to capture existing data based on earlier academic studies, and on secondary data sources on the sugarcane and bioethanol industry in Southern Africa. Secondary data from the national press, and in-depth reports from the Triangle ethanol plant, as well as documents from both Government and Non-Governmental organisations were also used in this study and the findings triangulated by observation. The study was mainly focussed on the technical feasibility only due to data challenges as plant officials could not give credible cost figures. As explained by O'Brien J.A. and Marakas G.M. [9], technical feasibility assessment focusses on gaining an understanding of the current technical resources of an organisation and their applicability to the expected needs of the existing plant. It is an evaluation of the hardware or software and how it meets the need of the plant operations. The criteria use in this study is to assess the

details of how ethanol is produced and delivered as a product. The study outlines how ethanol is evolved and moved through the plant to physically reach the market.

IV. INITIAL MOLASSES PROCESSES

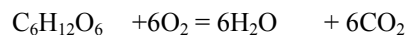
In this section of the paper, a brief description is given of the observation and data gathered from the discussions conducted with all levels of employees at the shop floor of the Triangle ethanol plant. A description of the seven stages of production observed at the plant is discussed. Critical information and data were collected from the Plant Engineer; the Production Engineer; the Chief Safety officer and four other technicians involved in the production process. The process starts at the two molasses coolers each with twelve passes. The molasses is introduced through pipes connected to a mono positive displacement pump. Originating from the sugar plants the molasses is between 50 to 60 degrees centigrade and has to be cooled to around 30 degrees centigrade. The molasses passes from the coolers into seven molasses tanks where it is emptied on a first-in first-out basis. These tanks are fitted with an air supply and a recirculating pump to control both temperature and excessive foam. The molasses is then channelled through a manifold called a mash mixer. This is a very important requirement for molasses before being introduced for fermentation, as it has to be diluted with water to a mash mixture. Two control flow meters regulate the flow in this system.

V. FERMENTATION

The Fermentation of the sugars into alcohol is achieved through two stages namely pre-fermentation and the main fermentation. The process is biological and involves the fermentation of the sugars using yeast. The inputs and outputs derived from this process are shown in the Fig. 3.

Pre-fermentation involves the biological aerobic propagation of yeast cells. During this process molasses is mixed with water through a mash mixture, and air is sparged in-order to make the process to be more efficient. During this process the level of brix purity and pH reading is controlled very closely to avoid contamination of the culture. The layout of the process equipment is shown in Fig. 4.

The equation of the process is generally given by:



When the desired yeast cell concentration is attained the mixture is emptied into the main fermenter, and the pre-ferment equipment is sterilised before introducing the next batch. This is done by supplying exhaust steam at a temperature of 100⁰ C for at least one hour under a constant pressure of 115 kPa.

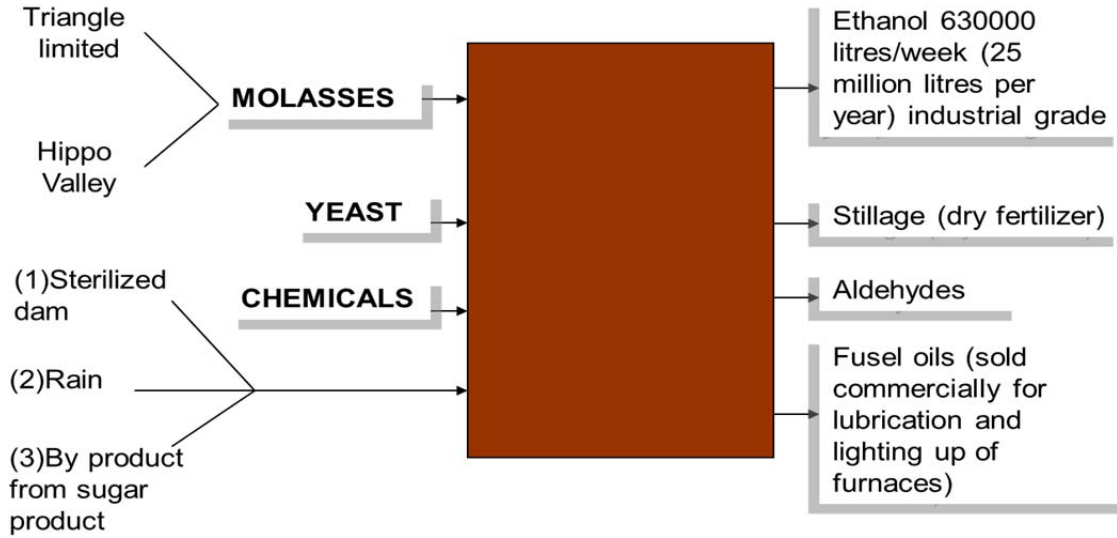


Fig. 3: The input and outputs materials observed and recorded during ethanol production process.

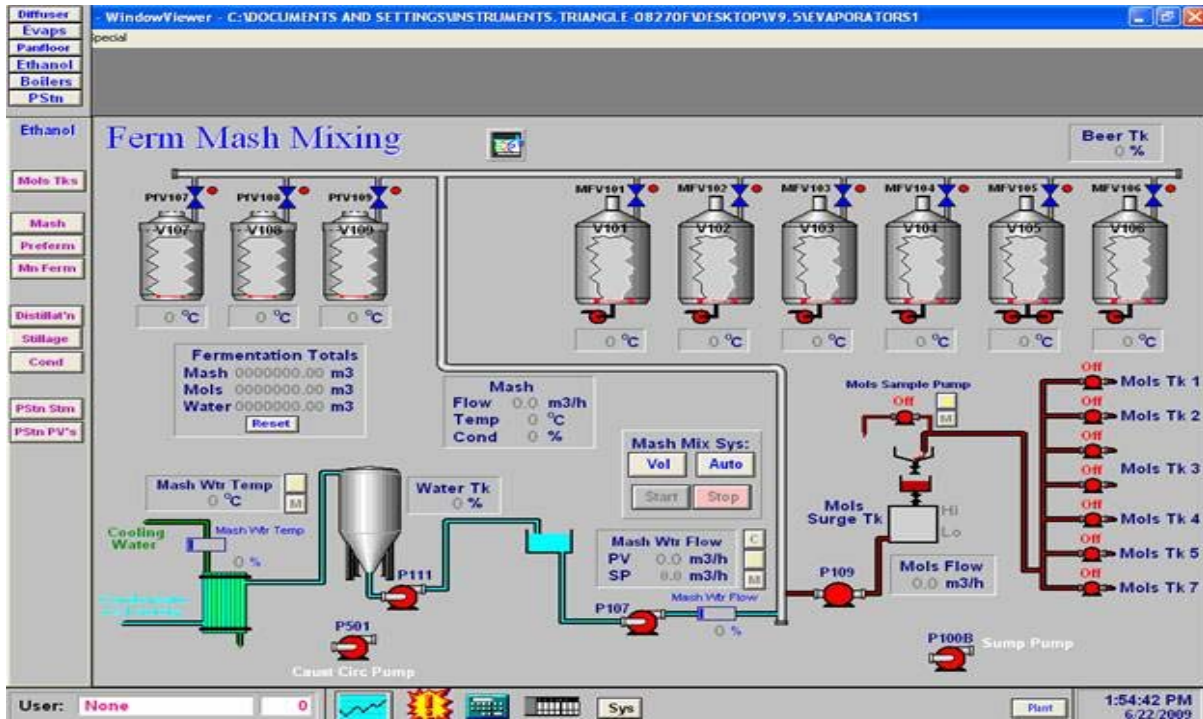


Fig. 4: The pre-fermentation process layout at the Triangle plant.

VI. MAIN FERMENTATION

In total there are six main fermenters at the Triangle plant, each with a capacity of 750 m³, constructed mainly from stainless steel. Fig. 5 shows the layout of the fermentation equipment. The process in the main fermentation is the conversion of sugar to ethanol. Mash is pumped into the fermentation tank along with large amounts of yeast. While in the fermentation tank, yeast cells efficiently convert the sugars into ethanol, CO₂ and heat. Fermentation is considered

a batch process because the tanks are filled, held, emptied and cleaned. Filling takes between 8 and 9 hours; holding takes place for between 42 to 48 hours; and emptying normally takes only 2 hours, after which the tank is cleaned for a further 2 hours. The whole process therefore takes a cycle of 55 hours per batch. In-order to optimise the fermentation process, the activity of the yeast is enhanced through a very strict control of temperature, the pH and a good mash mixture. The resultant effect is that 51% of the glucose gets converted to ethanol and the remaining 49% is converted to CO₂.

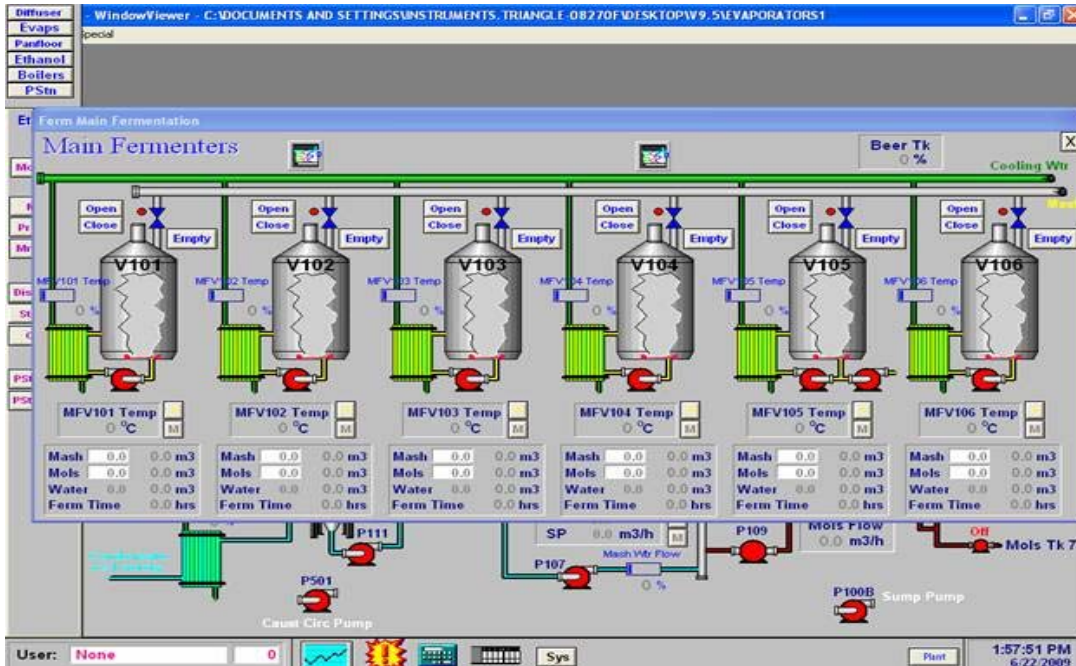


Fig. 5: The Main Fermentation Layout at the Triangle plant.

VII. THE DISTILLATION PROCESS

Distillation is a process of evaporation and re-condensation used for separating liquids of various fractions according to their boiling points. It normally concerns liquid vapour systems of various compounds.

The distillation process at the Triangle ethanol plant begins with the introduction of the fermented mixture through a pump to the bottom of the distillation column. The fermented combination is heated up to 108 °C in the heat exchanger. The various products are then tapped off the column as shown in Fig 6.

1. Fusel oils are tapped off first at about 92 °C
2. The Industrial grade rectified spirit then follows at 78 °C
3. The aldehydes are then tapped off last at between 45 °C and 55 °C.

The heat exchanger cooling is important in terms of the stillage transport to prevent the stillage from depositing calcium salts in the pipe line.

The essential property of vapour and liquid is used as a basis to identify the temperature between two pure components, based on the difference in the equilibrium of vapour and liquid at different fractions. In the case of ethanol the minimum boiling point azeotrope occurs at a mole fraction of 0.8943, which corresponds to the mass fraction of 0.9557 or the percentage volume of 96.47 percent ethanol. The distillation process therefore involves successive vaporisation and condensation as mention earlier, making the composition more and more concentrated with more volatile components as it rises through lower and lower temperatures as indicated in Fig.6 below.

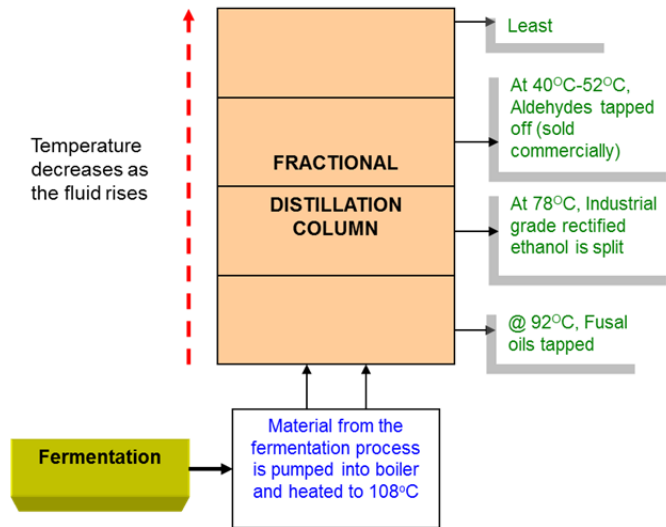


Fig. 6: A simplified observed layout of the fractional distillation column

VIII. THE DEHYDRATION PROCESS

At the time of the visit there were very limited activities involving the dehydration process, but the method used at the Triangle ethanol plant is azeotropic, where the ethanol water mixture had benzene and cyclohexane added to it to form an heterogeneous azeotropic mixture in vapour to liquid to vapour equilibrium. The polarity of benzene attracts the water molecules in the ethanol spirits there by dehydrating them. The product thus obtained after this process is pure ethanol. The diagramme in Fig. 7 shows the detail layout displayed in four different stages.

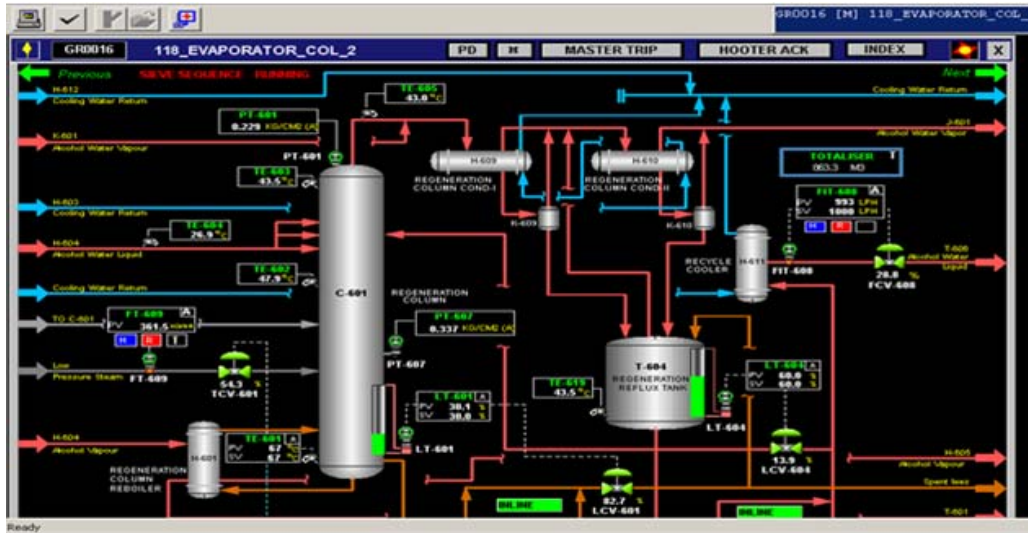


Fig. 7a: The layout of the Dehydration process at the Triangle plant first stage.

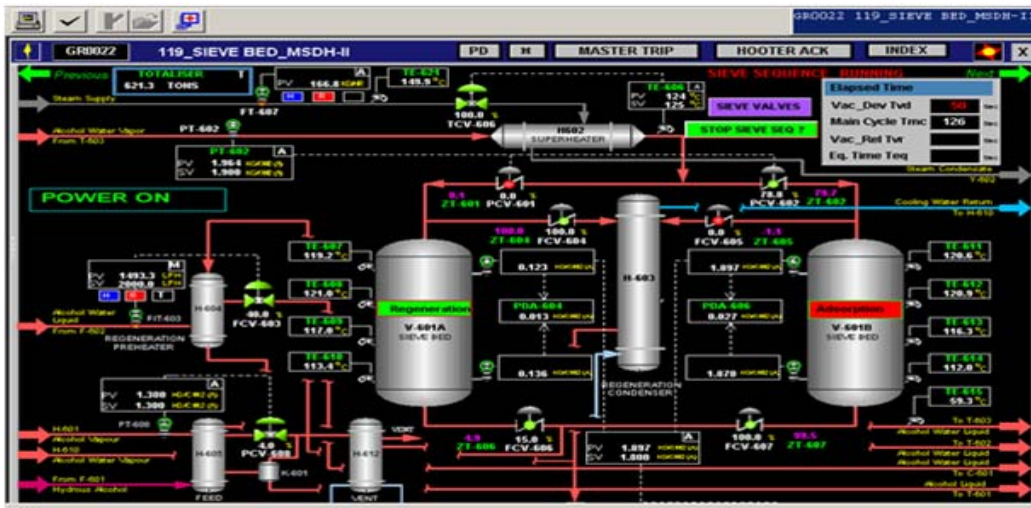


Fig. 7b: The layout of the Dehydration process at the Triangle plant second stage.

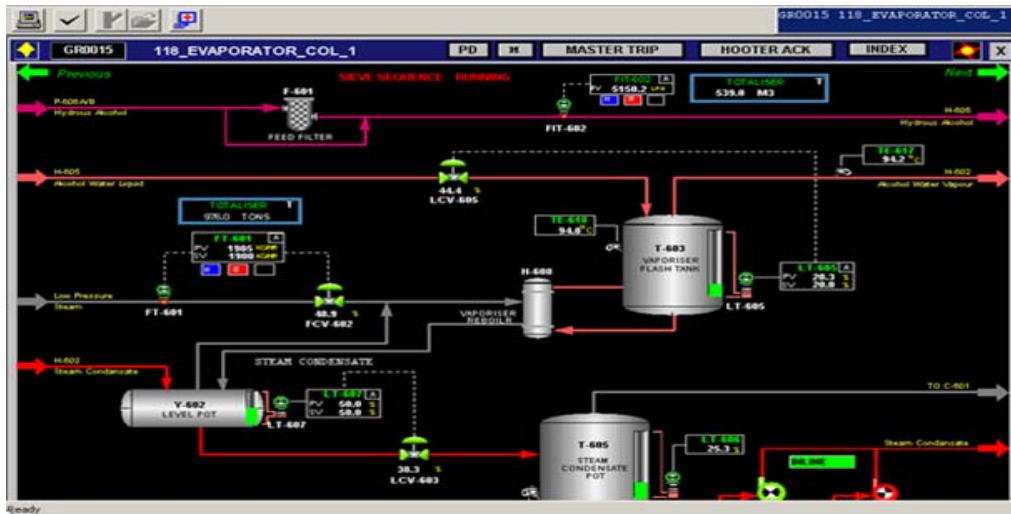


Fig. 7c: The layout of the Dehydration process at the Triangle plant third stage.

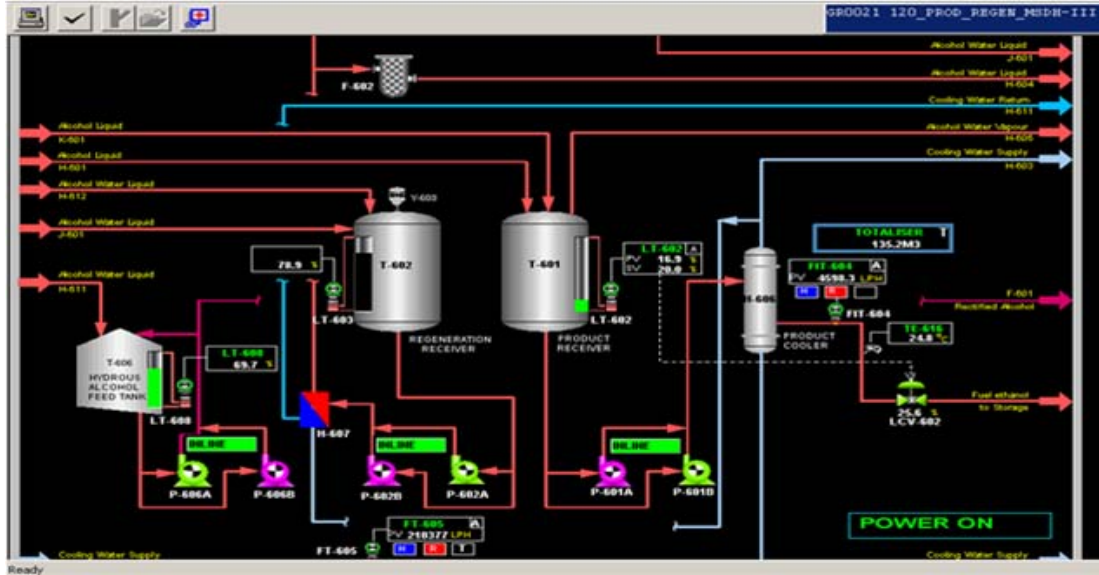


Fig. 7d: The layout of the Dehydration process at the Triangle plant fourth stage.

IX. THE STORAGE, TRANSPORTATION AND DISTRIBUTION

Ethanol is a highly flammable material, and its handling is critical. At Triangle limited, the entire ethanol plant is closely controlled, and no smoking or open flames are permitted. Besides the above, all machines and equipment in the plant are carefully grounded in-order to avoid build-up of vapour and possible sparking.

The rectified spirits are first stored in one of the three holding tanks before transferring through a flow meter using a centrifugal pump to the holding tanks in the tank farm. Each tank is crowned by a water manifold as a precaution. In the event of fire breaking out in the nearby areas, water would be sprayed down the sides of these tanks. The storage capacity of these tanks is shown in Table 2

TABLE 2: PRODUCT STORAGE CAPACITY AT TRIANGLE LIMITED ETHANOL PLANT.(SOURCE: DOMINIC DHANAH, 2001).

Tank Number	Capacity (m ³)	Product Type
1.	5000	Rectified spirits
2.	6000	Rectified spirits
3.	4500	Denatured alcohol
4.	750	Aldehydes
5.	750	Fusel oil

The products in the above tanks are monitored continually on a daily basis in-order to plan the distribution logistics. The products are normally transported by both rail and tanker to the South African port of Durban where they are exported to the Middle East and Europe as shown in Fig. 8 Shipment is usually done three times a month based on the arrival of the ships.



Fig. 8: Shows the distribution networks for Zimbabwean Ethanol (Google Map, 2014)

X. THE LESSONS LEARNT FROM THE TRIANGLE LIMITED ETHANOL PLANT FOR OTHER SOUTHERN AFRICAN COUNTRIES

The most prominent lesson learned is the harmonious co-existence between the Triangle Limited ethanol plant and its community. Most of the by-products from both the sugar and ethanol processes are used for the benefit of the community, such as local electricity supply from the combustion of bagasse. Blended fuel can be supplied very easily to the local community since they are near the source, if government support is obtained through legislated incentives so that the company produces fuel-ethanol. This also contributes to the national and regional economies through local supply of fuel and reduction of net outflows of foreign currency. The stillage is used by the community as fertiliser for their farming activities and this mainly assists contract farmers, whose livelihood is totally dependent on the sugar industry. The stock-feed is an additional by-product supplied by Triangle limited for the local and national farmers. In addition, Triangle and the Hippo valley plants have embarked on a sustainable private farmer rehabilitation programme, being driven by experts from the company who are guiding the farmers to expand their sugarcane planting base. This has resulted in an increased production and direct benefits to the local farmers. It is estimated that with the increased sugarcane price from the impacts of this operation, up to 3,300 hectares of new sugarcane land will be made available to local farmers, enabling them to employ the community surrounding the sugar estates where income is expected to exceed over US\$ 18 million.

XI. POTENTIAL CONTRIBUTION TO FUTURE APPLICATIONS

Currently the technology being used at the Triangle Limited plant for dehydration is the heterogeneous azeotropic mixture equilibrium. A potential technological method recommended for the Triangle ethanol plant to adopt for dehydration is molecular sieves. In this dehydration process water is absorbed as the ethanol vapour is forced under pressure through a bed of molecular sieves containing beads.

The beads have pores which trap only water and allow ethanol spirit to pass through. There would normally be two beds used, so that one is available while the other one is being regenerated. This technology has attracted many companies because of its energy saving capability.

Secondly the methodology used in the production of ethanol was brought to the attention of Triangle ethanol plant

Management. It was noted that if cleaner production methods could be introduced in all the production processes, a considerable amount of financial savings would be made.

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