THE SOCIO-ECONOMIC POTENTIAL OF BIOETHANOL FUEL PRODUCED FROM SUGAR PROCESSING PLANTS IN SOUTHERN AFRICA: A CASE OF MALAWI

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ABSTRACT

This paper investigates the technical advancement in the production of bio-ethanol in Malawi and examines the social and economic impacts of the bio-ethanol production in Malawi. In addition, the paper demonstrates the expansion of bio-ethanol as an alternative energy that has greatly impacted on the community resulting in increased economic development of the rural communities in Malawi.

The methodology used in this paper is a single case study conducted by the researcher who carried out a detailed extensive tour of the bio-ethanol plant accompanied by the Production Manager and several other factory officials. In addition, an extensive document review was also done to capture existing data from previous academic studies and secondary data sources such as Government and Non-Governmental Organisations.

The findings revealed that most of the bio-ethanol produced in Malawi is exported to several African countries and Europe. It was also observed that most of the by-products obtained from the ethanol production are used for the benefit of the nearby communities, such as the local electricity generated by burning the bagasse. The blended fuel is easily supplied to the community. The paper also emphasizes on the need for a speedy involvement of rural communities in the production of sugar and its by-products in order to meaningfully get community involvement in the rural economic development.

The study was based on a case study limited to only one plant that was physically toured by the researcher. The tour was scheduled and lasted for only one day. Financial analysis of the processes could not be analysed or scrutinised as the plant officials were unable to release any operational figures.

The main contribution of this paper is the expansion of the limited data and information available on bio-ethanol production in Sub-Saharan Africa. The targeted audience are the research academics, policy makers, Government officials and Environmentalists.

Keywords: Bio-ethanol, Socio-economic impacts, Bio-fuel, Malawi, Community.

INTRODUCTION

Malawi is one of the Southern African Development Corporation countries (SADAC) bordering Zambia, Tanzania and Mozambique. The interest to carry out this research in Malawi came about because of the continued trend in the expansion of ethanol production by Malawi (Nguyen et al., 2017). The ethanol production in Malawi has all been associated to the two major sugar estates located at the central as well as the Southern part of the country. The first plant in Dwangwa which was established in 1982 is located at the central part of the country about 225 km from Lilongwe, the capital city of Malawi. The second plant is situated in the southern part of the country near the shire river about 76 km north of Nchalo. The researcher visited the later which actually began its operations in 2004 at a location called Chikhwana on the west bank of river shire next to the Nchalo sugar estates. Figure 1 below shows the exact location of this plant which employs approximately 118 Malawians including Management. In addition to the above, the plant also caters for the subsistence farmers who supply the feedstock for the ethanol production.

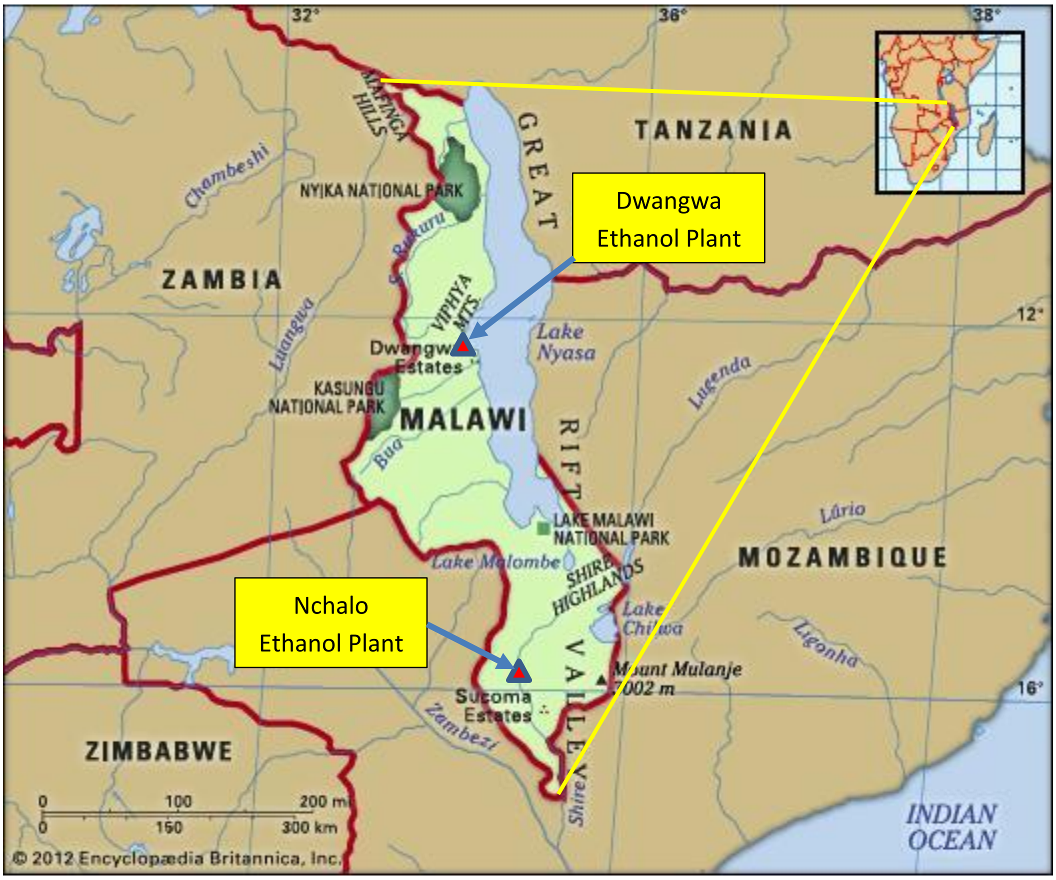

Fig. 1: The location of Ethanol production plants in Malawi. Source Google Map

Malawi began its quest to produce ethanol as mentioned above in 1982 and the major drivers which prompted this initiative were mainly the energy security; the job creation; the rural social and economic development as well the underutilised land readily available which could be used for the planting and farming of ethanol production feedstock. (Figie and Hamulczuk, 2013). Figure 2 shows how aggressive Malawi as a country, took steps to develop its ethanol fuel production from molasses. By the year 2000, the country was already utilising the highest gasoline in Sub-Saharan Africa (SSA). The figure clearly shows that only Zimbabwe, Zambia and the Democratic Republic of Congo attempted to respond in a similar manner but still followed from behind Malawi.

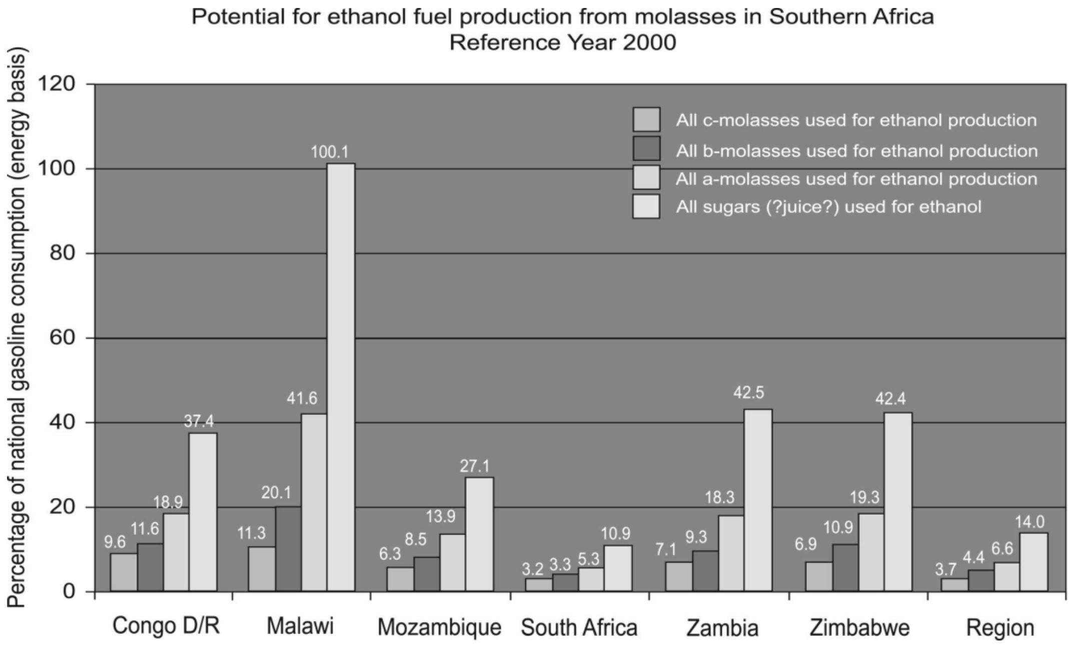

Fig. 2: The potential for bioethanol fuel production from molasses in Southern Africa.
J. Woods and g. Brown, 2001.

The energy and the economic crisis worldwide also triggered the global interest in the production of bioethanol as an alternative to fossil fuel which is speedily getting depleted. (Avinash, et al 2014). In addition to the above the volatile fossil fuel prices and the available molasses, a by-product from the production of sugar, made the production of ethanol a very beneficial venture since the production would create more employment. The global production of ethanol has since increased steadily over the years as depicted in figure 3 below. During the period from 2001 to 2011 the worldwide production of ethanol increased almost five times. (Blanco et al, 2013). It is predicted that by 2021 the global production of biofuel would reach 222 billion litres of which ethanol would account for 81%.

Although numerous studies have identified the use of bio-ethanol as an alternative energy especially in Brazil and the USA, very little data and analytical attention has been given to Southern Africa, especially Malawi. (Deenanath et al., 2012). The production of bio-ethanol in Malawi has now reached an annual production capacity of 15 to 20 million litres. As per the International Energy Statistics, the current production of bio-ethanol in Malawi is close to 32 thousand litres per day (McHenry et al., 2014). Molasses are the by-product of sugar production which is produced during refining of sugarcane into sugar. In addition to being an alternative fuel resource bio-ethanol enhances the nation's energy supply (Dunkelberg et al., 2014), the production of bio-ethanol makes an important contribution to employment and sustainable socio-economic development, particularly in rural areas and also to the national economy.

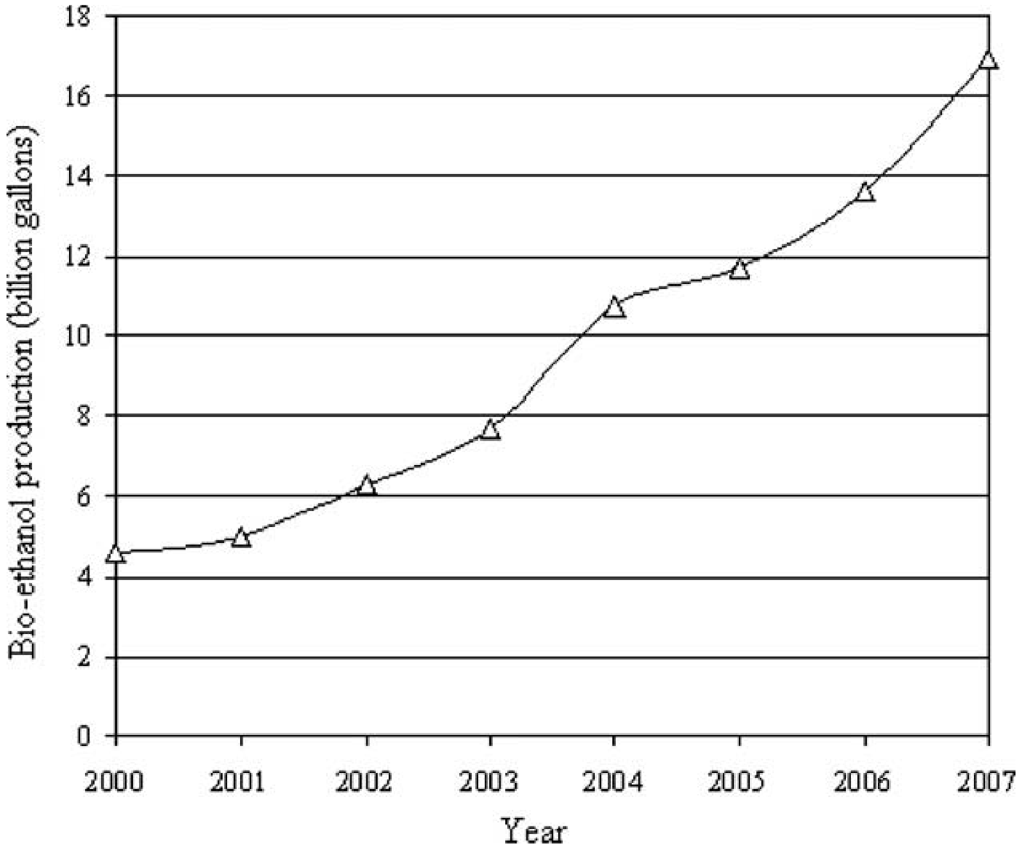

Fig. 3: The global trend in ethanol production from the year 2000 to 2007(Mustafa and Balat, 2009)

LITERATURE REVIEW

This section discusses several studies carried out on ethanol production in Africa and globally in order to present an overview of what has been achieved so far and to map the ways forward for the development of ethanol development in Malawi. The first part of this section discusses the use of bioethanol and its sustainability in Africa. This is followed by the commonly hot debate on food verses bioethanol feedstock plantation as the two usually compete for fertile land to grow sustainable products. The section is then finalised by a discussion on ethanol Biofuel Production and its implications in Malawi.

Bioethanol and Sustainability in Africa.

Bio-ethanol is currently the most widely used bio-fuel for transportation worldwide (Balat et al, 2009). In most African countries including Malawi bio-ethanol offers self-reliance in energy supplies at both National and local levels with considerable social; economic and security benefits (Amigun et al, 2010).

One of the main goals in attaining the sustainable ethanol production in Africa is to reduce the high dependency on the imported petroleum which makes these countries including Malawi vulnerable to the volatile global fuel prices and limited foreign exchange capacity. A study by Amigun et al reported over forty-two (42) African countries who are dependent on imported petroleum products.

Reconciling Food and Security and Biofuels in Sub-Sharan Africa

Bio-ethanol production generally uses elements from food crops but because there is a limited supply of these feedstocks there had developed competition between the production of ethanol and the provision of food products (Mustafa and Balat, 2009). The competition is cantered around the high quality soils which are sometimes used in the cultivation of energy crops. The same study by Mustafa and Balat also reported that most African countries including Malawi are net importers of their staple foods and therefore this is a desperate need to first increase the production of food requirements to a sustainable level before offering land for energy crops. They noted that in the year 2000 the average total imported food demand in sub-Saharan Africa rose to over 33%.

In some sub-Saharan African countries concerns over food security have resulted in Governments monitoring the developments of bio-fuels. Their major concern being some instances where the market prices of the energy crops seems to be greater than that of the food derivatives thereby inducing the diversion of resources away from the food to the energy feedstock.

Biofuel Production and its implications in Malawi

Energy sufficiency and security is a vital element in the development and prosperity of any country. It is therefore very important that Malawi considers socio-economic input into bio-ethanol in its quest to improve the standard of living of its citizens. Bio-ethanol if developed properly would play a very vital role in the provision of affordable energy, the reduction in hunger, poverty alleviation and good Educational facilities as well as good health care services.

Malawi as a country continues to depend on imported petroleum making the country vulnerable to volatility in the global fuel prices and more dependent on foreign exchange to cover their domestic energy needs. The blending of petroleum products is and attempt by the Government of Malawi to address the above challenge.

Currently Malawian ethanol has a multi-effect extractive distillation for the production of the extra neutral alcohol used to serve the beverages and pharmaceutical industries. The ethanol companies also produces the portable alcohol brand in addition to the rectified alcohol for Industrial application. The high quality ethanol produced in Malawi comes in the form of three products namely;

- Fuel ethanol
- Extra Neutral alcohol
- Rectified alcohol

These product are produced under very stringent conditions of the plant quality and safety. The fuel alcohol is usually up to a minimum of 99.5% v/v alcohol strength and is mainly used in blending the petroleum products. Normally the petrol is blended with a 2 to 8 parts ethanol/petrol ratio. This blended fuel is sold locally to petroleum companies in Malawi. The rectified industrial alcohol has a minimum of 96.0% v/v alcohol strength and is widely used as a solvent and raw material used the chemical processing industries especially in the manufacturing of paints and plastics. The potable alcohol normally has 96.0% alcohol strength and is also sold locally in bulk to the Malawi Distillers Limited for the production of various types of spirits used as beverages. In addition the pharmaceutical industry uses this product in the processing of a wide range of drugs and as a disinfectant in the form of methylated spirit.

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 of 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 Nchalo ethanol plant, as well as documents from both Government and Non- Governmental organisations were also used in this study. The resultant findings was then triangulated by observation. The study has mainly focussed on the technical feasibility due to challenges encountered by the plant officials in giving credible cost figures. The study is therefore an evaluation of the hardware and/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.

The core Processes used in the Production of the bioethanol

In this section of the paper the core processes in the production of ethanol in Nchalo plant is discussed. The emphasis being on the current methods used in the production and improvement of the ethanol yields, 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 production process, 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 Nchalo plant. Consideration has also been made of the contribution ethanol makes to the economy of Malawi as well as potential economic benefits derived from rural developments based on both the direct and in-direct support.

The introduction of Molasses from the Sugar processing plant.

In this section of the paper, the brief notes taken from the shop floor during the tour of the plant is discussed. A description of the several stages of production observed at the plant is followed logically up to the end of the process. Critical information was mainly obtained from the Plant Engineer; the Production Manager; the Chief Safety officer together with four other technicians involved in the production process. The process initially starts with the delivery of the molasses from the sugar processing plant a few kilometres away using trucks. The molasses so obtained is introduced through pipes connected to a mono positive displacement pump at a temperature of 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 pre-fermentation chamber, as it has to be diluted with water to form a mash mixture. At this stage the rate of flow in the process system is regulated by flow meters.

Pre Fermentation

The Fermentation process is achieved through two phases which allows for the sugars to produce alcohol. The first phase is pre-fermentation followed by the main fermentation. The process is biological and involves the fermenting of the sugars using yeast. The inputs and outputs derived from this process are shown in the Fig. 4. Below.

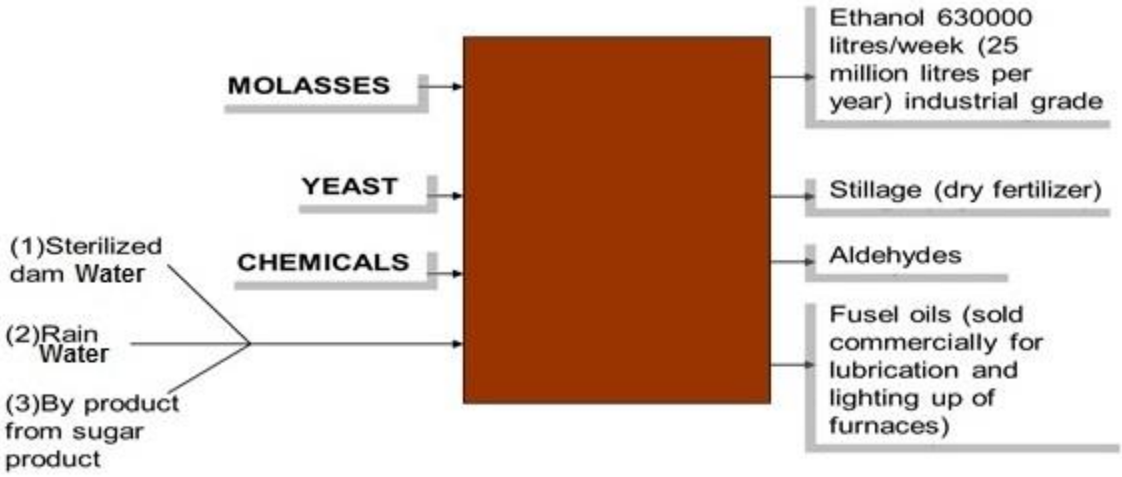

Fig. 4: The input and outputs noted during the pre-fermentation process.

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 sparred in-order to make the process 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 processing equipment is shown in Fig. 5.

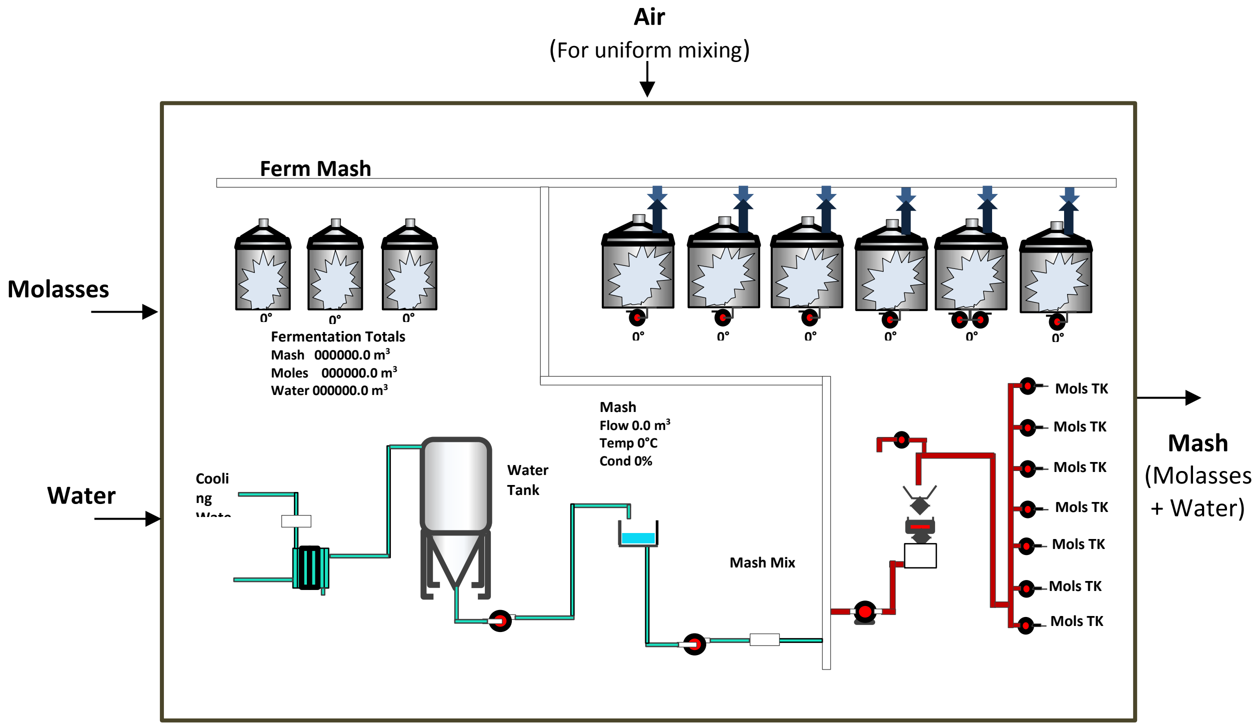

Fig. 5: The pre-fermentation process layout

The equation of the process during pre-fermentation process is given below:

$C_6H_{12}O_6 + 6O_2 \quad = \quad 6H_2O \quad + \quad 6CO_2$

When the desired yeast cell concentration is attained the mixture is emptied into the main fermenter, and the pre-fermentation tank equipment is sterilised before introducing the next batch. This is done by supplying exhaust steam at a temperature of 100^0 C for at least one hour under a constant pressure of 115 KPa

Main fermentation

The fermentation process continues in the six main fermenters shown in the layout plan below, each with a capacity of 750 m^3, constructed mainly from stainless steel. The process in the main fermentation tank involves the conversion of sugar into ethanol. Mash is pumped into the fermentation tank along with large amounts of yeast. While in the fermentation tank, yeast cells effectively converts the sugars into ethanol, CO_2 and heat are exhausted in the process. Fermentation is considered a batch process because the tanks are filled, held to allow the process to run naturally to completion, then emptied and cleaned. Filling takes between 8 and 9 hours; holding takes place for between 42 to 48 hours; and empting normally takes only about 2 hours, after which the tank is cleaned for a further 3 hours. The whole process therefore takes a cycle of 56 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 normally give a very good result. The resultant effect is that of 51% of the glucose gets converted to ethanol and the remaining 49% is converted to CO_2.

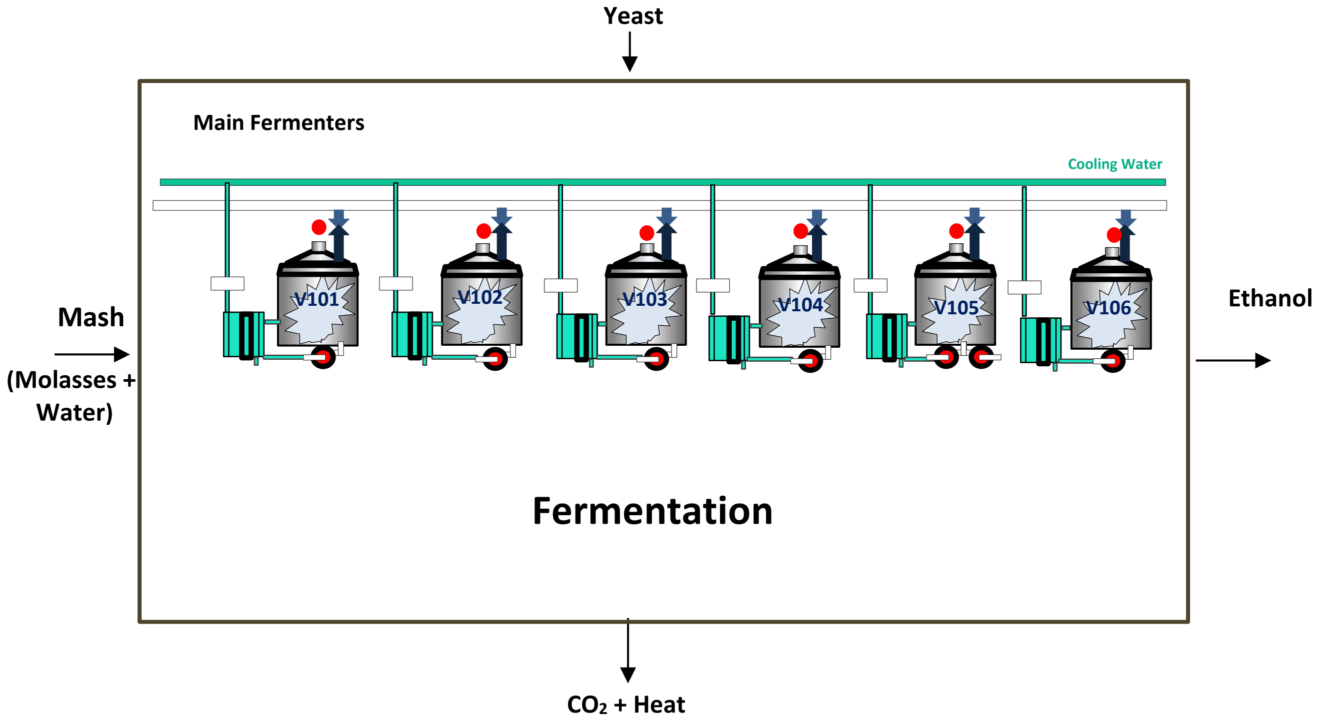

Fig. 6: The components in the Main Fermentation.

The distillation process

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

The distillation process at the Nchalo plant started with the introduction of the fermented mixture through a pump to the bottom of the distillation column. The fermented combination containing immiscible liquids is heated up to 108^{o}C. in the heat exchanger. The various products are then tapped off as they rise up the column as show on the diagram below. The temperature decreases as the vapour rises up the column enabling liquids with a very low boiling point to be tapped out last.

1. Fusel oils are tapped off first at about 92^{o}C
2. The Industrial grade rectified spirit then follows at 78^{o}C
3. The aldehydes are then tapped off last at between 45^{o}C and 55^{o}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 rose through lower and lower temperatures as indicated in Fig.7 below.

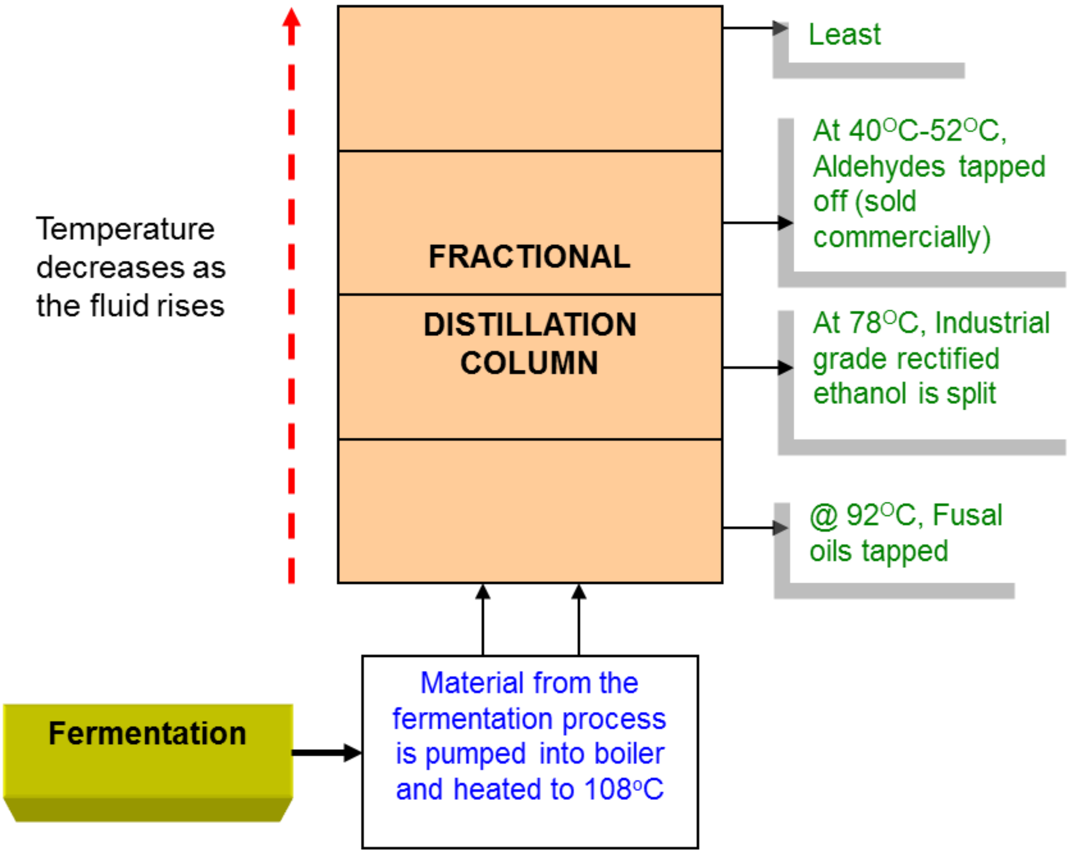

Fig. 7: The process and layout of the fractional distillation column

The dehydration process

The method used at the Nchalo plant had been revamped from the azeotropic, to the modern molecular sieve system. The azeotropic process required benzene and cyclohexane to be added to the ethanol water mixture to form a 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. In molecular sieve process water is absorbed as the ethanol vapour is forced under pressure through a bed of molecular sieves containing beads.

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

The storage, transportation and distribution

Ethanol is a highly flammable material, and its handling is critical. At Nchalo, 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 holding tanks before transferring through a flow meter using a centrifugal pump to the final safe storage area.

Malawi is a landlocked country and therefore these products are normally transported by tankers to the South African port of Durban where they are exported to Europe, Asia and the rest of Africa as shown in Fig. 8 below. The majority of the products are supplied to African countries such as Tanzania, Uganda, Kenya, the DRC, Zambia and Mozambique.

Fig. 8: Shows the distribution networks for Malawian Ethanol (Google Map, 2017)

The lessons learnt from Ethanol Plant Study

The interaction between the surrounding community and both the ethanol and sugar plants are very harmonious as the co-existence between the ethanol production companies and its community are highly treasured. Most of the by-products from both the sugar and ethanol processes are used to uplift the standard of living of the community, such as local electricity supply from the combustion of bagasse. Blended fuel introduced by the Malawian Government in 1998 are supplied very easily to the local community since they are near the source, if government support through legislated incentives has encouraged companies to expand the production of fuel-ethanol. The resultant impact to the national and regional economies has been the 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 shortage of stock-feed has created the Nkotakota farmers' project headed by ethanol producing companies in Malawi has led to an increased production of feedstock 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 the expected income could possibly exceed over US$ 18 million.

Potential contribution to future Applications

The methodology used in the production of ethanol was brought to the attention of Nchalo plant Management. It was recommended that if cleaner production methods could be introduced in all the production processes, a considerable amount of financial savings and safety practices would be made.

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