Sugarcane Molasses to Energy Conversion for Sustainable Production and Energy Transition

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ABSTRACT

Bioethanol is a potential replacement for the conventional fuels mainly gasoline because it possesses similar and few superior properties that can help reduce greenhouse emissions and fossil fuel reserves. The sugar industry is in a serious crisis in many developing countries due to cash flow challenges and inability to produce sugar cost effectively. The market is flooded with sugar from cheap producing countries. Diversification into ethanol manufacturer is one of the options to increase their competitiveness. This study examines the feasibility of establishing an ethanol plant for sugar factories. The study demonstrated the potential ethanol production a sugar factory to create an additional revenue stream and production of a potential renewable energy resource. Ethanol production process involves a series of stages starting with fermentation of the molasses. The fermentation product is distilled to separate ethanol and water through fractionation. The main parts of an ethanol plant include, the fermenter, boilers, condensers, and distillation columns, all well sized and processes. Ethanol can be blended with petrol to make a fuel blend for automotive applications besides other industrial applications. The production and use of ethanol from sugarcane molasses will improve the economic sustainability of sugar factories and farmers, improve the gross domestic product and food security due to value addition created and conserve the environment by substitute for fossil fuels if used as a fuel. The conversion of sugar cane to molasses is about 4%, about 20% of molasses is converted to ethanol by fermentation. The molasses and ethanol yield of sugar factories of varying can crushing capacity. Actual output of molasses is a function of cane milled while the actual ethanol capacity is based on the molasse produced. Milling is affected by many factors like planned and forced outage as well as availability of sugarcane for milling by factories. Ethanol as an energy resource can be used to substitute diesel and gasoline fuel in engines and other applications.

Key words

Ethanol from molasses; bioethanol from sugarcane; bioethanol; fermentation; ethanol production; ethanol plant design.

1. Introduction

Bioethanol has established itself as a feasible substitute for conventional fuels particularly gasoline and can be used directly or as a blend. These has dual benefits of reduced emissions and consumption of gasoline which is a non-renewable energy resource (Edeh, 2020). Molasses is one of the cheapest feedstock for ethanol production produced as a by-product of sugar production in sugar factories. Biogas has a wide range of industrial and domestic applications like beverage manufacture, manufacture of glycerol, acetic acid, baker's yeast, and lysine as well as animal feed and even fertilizer(Carioca & Leal, 2011; Wang et al., 2021). One of the leading goals for humanity globally is to produce renewable energy that is easily accessible, effective and safe to use (Núñez Caraballo et al., 2021). The global concern over greenhouse gas emissions and global warming have accentuated the need for sustainable and environmentally friendly energy sources to replace fossil fuels Biofuels have a potential to contribute towards the achieving environmental goals and energy demand(Huang et al., 2020; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022b; Kabeyi & Oludolapo, 2020b). Ethanol is an important biofuel, with USA and Brazil leading globally with annual production by the year 2018 of 58 billion litres from corn-starch and 28 billion litres from sugarcane(Kabeyi & Olanrewaju, 2021b; Kabeyi & Olanrewaju, 2021b; Silva Ortiz et al., 2019). For over three decades, sugarcane has been the main feedstock for largescale ethanol production in especially in Brazil(Dias et al., 2015). Ethanol is a renewable fuel that can be blended with gasoline and diesel to reduce environmental impact of fossil fuels and to increase the energy security of non-oil producing countries(Rodrigues Reis & Hu, 2017). Since ethanol has got high octane value, it is used primarily as an additive and extender for gasoline fuel. Ethanol can also be processed from carbohydrates like sugar, starch, and cellulose through fermentation using yeast or other organisms(Hamouda et al., 2015; Kabeyi & Olanrewaju, 2021c; USDA, 2006).

The world experienced a fuel crisis in the 1970s that triggered serious concerns over energy supply for many countries especially non-oil producers(Kabeyi, 2020; Kabeyi & Oludolapo, 2020c). Use of biofuels like bioethanol can limit reliance on fossil fuels as can be used in internal combustion engines. reduce reliance on fossil fuels and can reduce carbon dioxide emissions. Bioethanol is manufactured by microbial fermentation of fermentable sugars, such as glucose, to ethanol. Predominantly used feed stock for bioethanol production include first-generation feedstock like cereal grains, sugar cane, and sugar beets. Others are second generation like, lignocellulosic while third generation feedstock include algal biomass(Tse et al., 2021)

The sugar industry is currently struggling in many developing countries due to high cost of production and governance issues in countries like Kenya as a result of inefficient production leading to high uncompetitive industry that cannot survive in the liberalised market. (Kabeyi & Olanrewaju, 2021c; Kabeyi & Oludolapo, 2021; Kamate & Gangavati, 2009; Nzoia Sugar Company Ltd., 2020). The sugar industry supports thousands of sugar cane growing farmers and sugar cane factory workers. For some countries like Kenya, the domestic sugar demand is less than consumption. This deficit is met by importing sugar from the international which is much cheaper. Often importers bring in excess whenever an opportunity is granted. Cheap imports have led to closure of many local factories that cannot compete(Kabeyi, 2018a, 2018b, 2019b). Diversification into ethanol production as well as export cogeneration are diversification pathways that can increasing financial sustainability of the sugar factories besides producing green energy that society needs during the current energy transition(Kabeyi, 2020; Kabeyi & Olanrewaju, 2021a; Kabeyi & Oludolapo, 2020b). Therefore, the sugar industry through molasses can play a significant role in the energy transition by providing sustainable revenue streams, employment, environmental protection and ensure sustainable sugar cane farming in a clean environment(M. Kabeyi & O. Olanrewaju, 2022; Kabeyi & Olanrewaju, 2021a; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022a).

2. Sugar Production Process

2.1. Sugar Production

Sugar cane is the is an important crop as is grown in over 100 countries even though 10 countries alone account for over 80% of global sugar production (da Silva et al., 2017; Kabeyi, 2020). Sugar cane manufacture involves two main energy intensive operations. These operations are processing of beets or sugar cane to raw sugar and refining of raw sugar. Cane and beet sugar extracts consists of mainly sucrose, polysaccharides, proteins lignin, gums, starches, waxes, and other colloidal impurities. The removal of the proteins and colloidal matter requires addition lime, heating, and clarification processes (Singh, 2015). In cane sugar production, bagasse which is the important cogeneration fuel is produced after milling cane to remove the sucrose rich juice. Sugarcane crop is used as a feedstock for efficient biofuel production and energy generation. Sugar cane and sugar and byproducts of sugar production have many industrial applications as raw materials including steam and power generation from bagasse combustion in boilers(Kabeyi & Olanrewaju, 2021c; Rabelo et al., 2020).

2.2. Molasses production and Uses

Molasses is a syrup residue with sugars that do not crystalise with sucrose as well as other impurities. The composition of molasses is influenced by the sugar cane characteristics and the state of the manufacturing process(Kabeyi, 2020; Kabeyi & Olanrewaju, 2020). Molasses yield varies from 2.5% to 3% of the weight of cane milled while its composition normally varies depending on the cane variety and the production process applied(Tao & Aden, 2009). The thick black or brown sugary syrup left behind after crystallization process in the sugar production process(Tao & Aden, 2009).

2.3. Properties and Characteristics of Molasses

Molasses is a thick black or brown sugary syrup created during juice crystallization process in the sugar production process and separated during centrifuging (Tao & Aden, 2009). Molasses is rich in simple sugars and being a by-product makes it one of the cheapest feedstock for bioethanol for bioethanol manufacture. And is also a commodity for international trade of sugar producing countries(Kabeyi, 2019a; Kabeyi & Olanrewaju, 2020). Molasses has got many applications which include production of beverages, glycerol, baker's yeast, acetic acid, lysine through fermentations, animal feed and fertilizer(Kabeyi, 2020; Kabeyi & Oludolapo, 2021).

The composition and hence physical properties of molasses may vary based on the production technology used and non-sucrose soluble components of juice used in crystallization. Generally, molasses consists of 75–85% of total solids, sucrose varies between 30–36%, 10–17% is fructose + glucose, 10–16% ash. Smaller constituents smaller constituents include polysaccharides, organic acids, oligosaccharides, nitrogen compounds and , proteins.. Since molasses has more than 50% fermentable sugars, it is a good feedstock for fermentation. The difference between beet and sugarcane molasses is that although they are similar in composition, beet sugar molasses has a lower concentration of reducing sugars and higher in sucrose content (Carioca & Leal, 2011).

3. Ethanol Production from Sugarcane Molasses

Ethanol is mainly produced by fermentation of sugary feedstock that are rich in fermentable sugars. Micro-organisms, better known as yeast culture, use this feedstock as substrates to produce energy, water, ethanol, and carbon di oxide gas as waste products in a process called fermentation. The products of fermentation mentioned (ethanol, water, and CO_2) undergo fractional distillation, gas scrubbing and additional purification and finalization processes to yield high quality ethanol(Kabeyi, 2020; Kabeyi & Olanrewaju, 2021c; Kabeyi & Oludolapo, 2020b).
The fermentation process requires handling facilities and yeast propagation, pre-fermentation, and fermentation before distillation of the mixture.The process of ethanol production can be summarised as pre-treatment to remove lignin or hemicellulose and liberate cellulose; depolymerization of carbohydrate polymers to produce free sugars by the action of cellulase mediated process; fermentation of hexose and/or pentose sugars to which produces ethanol; followed by distillation to produce alcohol. Ethanol from sugarcane molasses is a feasible alternative for partial replacements of fossil fuels. The use of bioethanol contributes to the climate change mitigation by reducing greenhouse gas emissions by blending with fossil fuels(Canilha et al., 2012; Raharja et al., 2019).

3.1. Molasses Handling and Distribution

In the molasses ethanol plant, molasses is screened and stored in the day tank from which it is fed to a receiving tank where it is weight and transferred to the cell mass propagation, fermentation, and yeast activation sections(Edeh, 2020; Sheth & Borse, 2018).

3.2. Yeast Propagation

The yeast propagation section consists of molasses diluter and hygienically engineered yeast vessels which has embedded heating, cooling, and air sparging facilities (Sheth & Borse, 2018). The process involves preparation of dilute molasses media in a yeast vessel by recirculating media through a molasses diluter. A series of yeast vessels are used to scale up the laboratory propagated cell mass is scaled-up in a series of yeast. To ensure optimum growth of yeast, sterile air is sparged in the dilute molasses medium that is pasteurized and cooled. Cooling water is recirculated through a jacket to maintain the temperature is maintained by recirculation of cooling water through a jacket of the yeast vessels. A cell transfer pump is used to transfer cell mass from the yeast vessel to yeast activation vessel to build up the cell mass needed for fermentation. There are various types of yeast available globally.(Edeh, 2020; Sheth & Borse, 2018)

3.3. Pre-fermentation

Pre-fermentation in vessel where process water, nutrients, molasses, and additives are added for to facilitate activation/growth of the cell mass. Clean air which is filtered is sparged as a requirement to repair cell membranes and other cell components. The activated cell mass is then moved to fermenter in a way to maintain the desired cell mass concentration during fermentation (Sheth & Borse, 2018). Pre-treatment is necessary to disrupt the recalcitrant lignocellulosic structure and algal cell wall, to make the fermentable sugars accessible especially for second and third generation feedstock(Tse et al., 2021).

3.4. Fermentation

The purpose of fermentation is to convert sugars that are fermentable to ethanol. Based on the quality of molasses, fermentation is designed to operate in batch mode. In the process of fermentation, the sugars are broken down into to ethanol and carbon dioxide, while heat is released. The temperature of the fermenter is maintained between 30–32°C by forced recirculation flow via a plate heat exchangers(Edeh, 2020; Sheth & Borse, 2018). Molasses has got about 62% of fermentable sugars hence a good very good substrate in the fermentation process in which micro-organisms feed on this substrate to yield ethanol as a by-product. However, molasses as is has a high concentration of sugars and a very high pH unsuitable for microbial activity making pre-treatment or preparation before injection into the pre-fermentation and fermentation chamber critical measure(Kabeyi, 2020). The most common preparation methods include acid dosing to lower pH to a recommended value of 4-5 and dilution to lower concentration of sugars to 10-15%. These are the optimal conditions desired for microbial activity. After fermentation, ethanol produced is mixed with water and carbon IV oxide gas which must be removed by fractional distillation and gas scrubbing respectively to yield higher quality ethanol(Raharja et al., 2019).

The feedstocks selected vary depending on availability, alternative/competing uses, percentage of fermentable sugars present and the cost of the feedstock. There are four major categories of feedstock for ethanol production namely, first generation-use of food crops as feedstock e.g., corn, fruits, wheat, sorghum, sugarcane etc. second generation which use lignocellulosic biomass as feedstock e.g., bagasse, wood shavings, straw, molasses, maize stalks, and grass; third generation which use high yield Genetically Modified feedstocks and fourth generation feedstocks which use a combination of genetically optimized feedstock alongside gnomically synthesized microbes in ethanol production(Núñez Caraballo et al., 2021; Tse et al., 2021). Fermentation can be controlled by applying different types of fermentation based on prevailing challenges and process requirements while addition of supplementary materials like Mg^{2+} and other micronutrients and adaptive responses enhance stress tolerance e.g. , heat shock and ethanol shock) on yeast organisms and as a result help improve process performance(Tse et al., 2021).

3.5. Types of Fermentation.

There are three major types of fermentation used widely in ethanol production:

i.) Batch Fermentation: fermentation media is filled up to 80% of fermenter space leaving 20% head space. This head space allows room for accumulation of air, gasses, and foam. The fermentation process is stopped periodically, and contents emptied. A steam sterilisation is done to the chamber before admission of fermentation media for the next cycle. This method is however not widely used despite requiring less space because of high costs incurred in periodic sterilization. Furthermore, it is labour intensive and time consuming(Raharja et al., 2019).

ii.) Continuous Fermentation: the process is continuous and requires no periodic emptying of the fermentation tank. Addition of fermentation media and withdrawal of fermentation products is continuous. It is further subdivided into 3 other classifications depending on modes of operation namely. Single stage continuous, single stage recycle fermentation and multistage fermentation. In single-stage continuous fermentation in which the fermenter is used continuously, and fermentation media is added at specific rates and fermentation products removed are removed continuously. For single stage Recycle Fermentation, a single fermenter is used continuously while rate of inoculation of fermentation media is equal to rate of withdrawal of fermentation broth with a portion of this broth being recycled to fermenter. In multi-stage Continuous Fermentation there are two or more fermenters are operated at continuously in sequence. And the effluent of the first fermenter is used as influent of the next fermenter(Raharja et al., 2019).

iii.) Dual or Multiple Fermentation: this employs a combination of both batch and continuous fermentation in a better hybrid design or a combination of continuous fermentation designs. This type of fermentation is new but seems promising due to high efficiency(Raharja et al., 2019).

3.6. Aldehyde Separation.

Removal of aldehydes from ethanol is necessary because reduced concentration of aldehyde reduces the formation of acetals in the process. Ethanol produced immediately after fermentation usually contains aldehyde, carbon IV oxide gas and water as impurities. The aldehyde separation column filters out aldehyde impurities by reactive absorption from the stream(Uebelacker & Lachenmeier, 2011).

3.7. Distillation/Rectification.

Distillation or separation is an important process in ethanol production because it is the stage where the main product in finally extracted and it is a process with highest energy consumption, hence an important cost centre.(Amornraksa et al., 2020). Distillation is the process by which a liquid mixture is separated into fractions with higher concentration of certain components by exploiting differences in relative volatilities (boiling points). The feed stream enters at the middle of the column then two streams leave the column, one at the bottom and another at the top of the column above the intake stream. The stream at lower boing temperature is concentrated at the lower portion while the stream with higher boiling point is concentrated in stream leaving the bottom of column. This separation is achieved by controlling column temperature and pressure to take advantage of differences in relative volatilities of mixture components and their ability to change phase at different temperatures. Lighter lower boiling point component evaporates and travels up the column to form top product while heavier higher boiling point component condenses and travels down the column to form bottom product. Ethanol and water have different physical and thermal properties making fractional distillation possible(Amornraksa et al., 2020; Edeh, 2020).

Ethanol is the lighter(789.3kg/m^3) and inn additionally has low boiling point of 780C point making it the lighter component while water is the heavier density of 1000kg/m^3 with higher boiling point of 100^{0}C(Edeh, 2020).

3.7.1. Column Distillation Stages.

There are two types of distillation, namely batch and continuous distillation. In batch distillation, a batch is fully distilled before another one is introduced while in continuous distillation, the process occurs uninterrupted(Amornraksa et al., 2020; Edeh, 2020). The distillation takes place in two distinct stages, namely rectifying stage, and the striping stage

i.) Rectifying Stage: takes place above the feed Trevor phase is continuously enriched in light components which finally make up overhead product. A liquid recycle condenses fewer volatile components from rising overcooling is applied to condense a portion of vapor to be re-introduced into the column called the reflux(Amornraksa et al., 2020).

ii.) Stripping Stages: occurs below feed tray. Heavy contents are stripped off and concentrated in liquid phase to form bottom product(Amornraksa et al., 2020; Edeh, 2020).

3.7.2. Components/parts of a Distillation Column and Their Functions.

Distillation is a common industrial purification technique of ethanol that exploits the differences in volatilities of constituents to separate them. The basic principle of distillation is that upon heating the mixture, the low boiling point components accumulate at the vapor phase and by condensing them, fewer volatile elements are obtained in the liquid phase(Amornraksa et al., 2020; Edeh, 2020; Oropeza-De la Rosa et al., 2017). This is done in the distillation column which has got many functional parts. The main components or parts of the distillation column are as follows.

(a) Stripping Section: this refers to trays between the bottom of column and the feed tray. Its work is to concentrate heavier content in liquid phase.

(b) Rectifying section: trays between the feed tray and the top of the column. The main aim of this arrangement is to concentrate the lighter component in vapour phase.

(c) Reboiler: a heat exchanger at the bottom of the column which boils some of the liquid leaving the column. The vapor generated returns to the column at the bottom of stripping section.

(d) Reflux: a portion of the vapour from the top of the column which has been condensed to a liquid and returned to the column as the liquid above the top tray.

(e) Condenser: a heat exchanger at the top of the column which condenses some of the vapour leaving the column. The liquid generated(reflux) returns to the column at the top of rectifying section. The condenser can be total or partial condenser.

 i.) Total condenser: all vapour leaving the top of the column is condensed and re-introduced into the column.

 ii.) Partial condenser: only a portion of vapour entering condenser is condensed and re-introduced into the column.

(f) Column Internals: These form surfaces over which heat, and mass transfer takes place between liquid and vapor phases. They are of many types as highlighted, but the most preferred type is the tray type.

 i.) Trays or plates: they are in the form of trays and plates aligned inside the column horizontally. They are also of many types e.g., sieve, bubble-cap, valve trays etc.

ii.) Packings: these are rings and saddles packed inside the column. The packings can be classified into random and structured packings.

a.) Random packing: rings and saddles packed into the column without any specific order.

b.) Structured packing: rings and saddles stacked in a regular pattern in the column.

3.7.3. Factors affecting distillation

The operation of the ethanol distillation column is affected by feed conditions, internal fluid flow conditions, state of trays or packing and environmental conditions(Amornraksa et al., 2020; Edeh, 2020).

i.) Molecular Sieve Dehydration.

Rectified alcohol is an azeotropic mixture. An azeotropic mixture is one of 2 liquids which has a constant boiling point and composition throughout distillation process. Separation by fractional distillation thus becomes very hard. There is need to employ a technique called molecular sieve dehydration to separate the 5% water in this alcohol to attain a higher ethanol concentration of even 99.89% (absolute alcohol). This sieve contains very tiny pores of uniform size of 3 Angstroms. These pores cannot absorb molecules of larger sizes. As ethanol-water mixture passes the sieve, components of highest molecular weight (water) are obstructed thus leave the bed first. This way, water is separated from rectified alcohol to form a higher concentration ethanol of 99.89% called absolute alcohol(Amornraksa et al., 2020; Edeh, 2020).

ii.) Finalization and Storage.

After all these processes, ethanol is ready for use. All that remains are customization to suit respective uses. Ethanol for use as biofuel is made unsuitable for human consumption by denaturation i.e., addition of denaturing components. The final ethanol desired is then stored in large stainless-steel tanks awaiting sale or use. It can also be filled in drums and stored awaiting further use, exportation, or sale(Amornraksa et al., 2020; Edeh, 2020).

3.8. Ethanol Production from Molasses.

The fermentable sugars in molasses sucrose, fructose, and glucose through fermentation by means of micro-organisms, commonly Saccharomyces cerevisiae or any other yeast culture. The guiding fermentation are.

Main reaction:

$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

Side reaction:

$2C_6H_{12}O_6 + H_2O \rightarrow ROH + RCHO$ (high molecular weight alcohols C_2H_5OH).

The process of ethanol production from molasses is summarised in figure 1 below

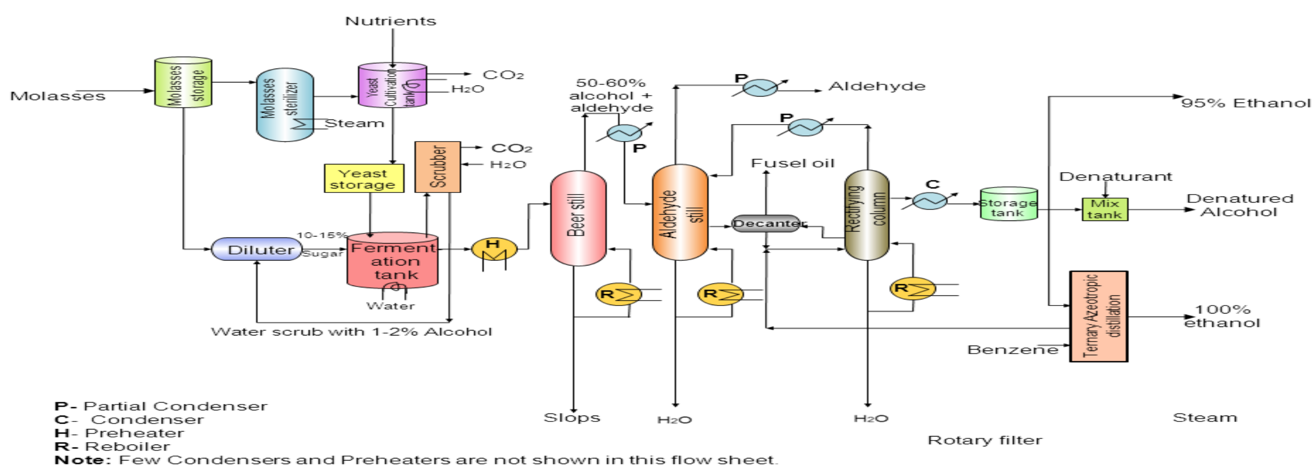

Figure 1: Process summary in an ethanol Plant

From figure 1, it is noted that molasses produced after crystallization of sugar is stored in molasses tanks awaiting introduction into the ethanol plant. Water is used to dilute the molasses to a desired concentration of 10-15% and later fed into the fermentation tank where yeast culture is added. The yeast feed on this molasses substrate and produce alcohol(ethanol) and carbon IV oxide gas as a by-product. This gas is detrimental to downstream operations and must thus be eliminated from produced ethanol by use of CO_2 scrubbers. The composition of the stream now contains ethanol mixed with aldehydes stored in the beer still which must be removed by aldehyde separation column/aldehyde still. The aldehyde-less stream is then fed into rectifying column which enhances concentration of ethanol to 95% v/v. This ethanol is then stored in ethanol tanks awaiting respective finalizing operations into desired forms of ethanol. To produce 100% ethanol, benzene is added in Ternary Azeotropic Distillation chamber. To produce denatured alcohol, a denaturant is added to the stream.

4. Ethanol Potential of Molasses

Molasses produced in cane milling is about 4% of cane milled by a sugar milling factory. Molasses contains a high percentage of nutrients and hence an ideal raw material for ethanol production. organic acids especially ethanol (Teclu et al., 2009). Ethanol is produced by anaerobic fermentation using specific microorganisms. The process releases heat and carbon dioxide that will be utilized largely in food preservation industries. Ethanol can be used as a fuel either alone or can be blended with gasoline to minimise pollution from conventional fuels especially fossil fuels. Competing applications of molasses are production of industrial chemicals, coatings, cosmetics, varnishes, and pharma industries. The conversion from molasses to ethanol is such that one tone of molasses produces about 200 L of ethanol by means of fermentation process (Karthiga Devi et al., 2020). Therefore, molasses fermentation generates 20% ethanol.

The fermentation efficiency is the ratio of actual ethanol yield to theoretical ethanol yield multiplied by 100%. The theoretical ethanol concentration is a function of the alcohol fermentation stoichiometric reactions, in which 1 mole of glucose will produces 2 moles of ethanol. Generally 100 g of glucose generates 45-49 g of ethanol with a but the theoretical ethanol limit of 51.1 g .(Raharja et al., 2019). The composition of ethanol can be analysed at the end of the process of fermentation by means of a density meter(Raharja et al., 2019). The ethanol content of fermentation was calculated using the equation; V1 x M1= V2x M2
Where: V1 represents the volume of fermentation, M1 is fermentation ethanol content, V2 is distillate volume and M2 is the content of ethanol in f the distillation(Raharja et al., 2019).

4.1. Molasses and Ethanol Potential of Sugarcane

Since the conversion sugar cane to molasses is about 4% while conversion of molasses to ethanol is about 20%, the molasses and ethanol yield of sugar factories of varying cane crushing capacity is summarised in table 1 below

Table 1: The molasses and ethanol potential of sugar factories

	FACTORY CAPACITY	Molasses (4% weight of cane crushed	Ethanol (20% weight of molasses
1	(Tons of cane crashed)	(Tons)	(Tons)
2	1	0.04	0.008
3	100	4	0.8
4	500	20	4
5	1000	40	8
6	2000	80	16
7	3000	120	24
8	4000	160	32
9	5000	200	40
10	6000	240	48
11	7000	280	56
12	8000	320	64
13	9000	360	72
14	10000	4000	800

Table 1 above shows the various factory's molasses and ethanol capacity based on their design capacity per day. Actual output of molasses is a function of cane milled while the actual ethanol capacity is based on the molasses produced. Milling is affected by many factors like planned and forced outage as well as availability of sugarcane for milling by factories.

4.2. Ethanol and Fermentation Yield and Fermentation Efficiency

The ethanol yield is proportional to fermentation efficiency, and greater fermentation efficiency is achieved when ethanol; yield is higher. Ethanol has a maximum theoretical yield of 0.51 g ethanol/ g glucose i.e. 51% for stoichiometric reactions (Raharja et al., 2019). The quantity and properties of ethanol is significantly affected by concentration of sugar, process parameters control, use of yeast and nutrients. If the substrate conditions of the substrate are suitable for the performance of yeast, then the fermentation efficiency is increased leading to more output(Arshad et al., 2017; Raharja et al., 2019).

4.3. Energy Value

The biofuel is liquid oxygenated fuel having 35% oxygen. The global production of bioethanol in 2018 was 110 billion litres is expected to increase to 140 billion litres in 2022 based on compound annual growth rate (CAGR) of 7.6%.(Edeh, 2020). Fermentation efficiency and bioethanol yields are influenced by type of feedstock, cultivar, and organism used in the process. It is necessary to address biotic conditions like microbial contamination as well as and abiotic factors like nutrient, presence of trace metal, and deficiencies to ensure optimum fermentation rate in ethanol production (M. Kabeyi & O. Olanrewaju, 2022; M. J. B. Kabeyi & A. O. Olanrewaju, 2022; Kabeyi & Oludolapo, 2020a; Tse et al., 2021).

5. Overview of an Ethanol Plant Design

A basic ethanol plant contains molasses storage tanks, fermentation tanks, yeast culture tanks, distillation columns, aldehyde separation columns, molecular sieve dehydration chambers and ethanol storage tanks all performing roles explained and discussed in detail in chapter 2 before. Other support parts and equipment like sterilizers, diluter, decanter, denaturant tanks, and CO_2 scrubbers also exist on this layout. However, emphasis will be on major components of the plant namely molasses storage tanks, fermentation tanks, aldehyde separation columns, rectification/distillation columns, molecular sieve dehydration chambers and ethanol storage tanks.

5.1. Fermentation Tank

The recommended material and operational conditions for the fermentation tank are summarized in table 2

Table 2: Materials and Equipment in Fermentation Tank

Part	Material/description	Reason for Choice
Fermentation vessel	Stainless steel	To minimize contamination/corrosion
pH controller		To maintain optimum pH (4-5)
Baffles		To allow maximum aeration
Sparges		To remove contaminants from liquid phase
Agitators		To whirl and mix fermentation media
Temperature controllers		To maintain optimal temperatures (28-32^{0}C)
Feed ports		To introduce inoculant into fermentation tank
Thermal jacket	Aluminum foil	To insulate tank from thermal losses

Tale 2 above shows the major elements of an ethanol plant which include fermentation vessel, PH controller, agitators, feed ports, temperature controllers among others.

5.2. Distillation Column Materials

The recommended material and description of the distillation column is shown in table 3 below.

Table 3: Table of Materials and Equipment in Distillation Column

Part	Material/description	Reason for Choice
Vertical shell	Aluminum.	Where the separation of liquid components is carried out.
Re-boiler		Used to provide heat to the bottom of industrial distillation columns.
Condenser	Stainless steel	To condense the vapor leaving the top tray of the column.
Reflux Drum		To achieve a more complete product separation.
Trays/plates	Perforated metal.	To transfer mass between a liquid phase and a gas phase.
Packings	Perforated metal.	To transfer mass between a liquid phase and a gas phase.

From table 3, it is noted that aluminium is the recommended material for manufacture of the distillation column. They include aluminium for vertical shell, stainless steel for vessel and perforated metal for packings. The designers can also select any other appropriate material in line with food grade materials selection guidelines.

5.3. Molecular Sieve Dehydration Chamber

The recommended materials for the molecular sieve dehydration chamber are summarized in table 4 below.

Table 4: Table of Materials and Equipment in Molecular Sieve Dehydration Chamber

Part	Material/description	Reason for Choice
Recycle column	Stainless steel	Reuses purge to produce anhydrous ethanol.
Product super heater		Convert saturated product steam or wet steam into superheated steam or dry steam.
Product condenser		Condense draw or product.
Feed super heater		Convert saturated feed steam or wet steam into superheated steam or dry steam.
Purge pump		Pumps purge back into recycle column.
Purge condenser		Condenses purge.
Beds A and B	Stainless steel	Contain zeolite which separates water molecules from ethanol.

From table 4, it is noted that stainless steel is the recommended material for the construction of the molecular sieve dehydration chamber. Other materials can as well be selected in line with acceptable and applicable standards for food handling materials.

6. Ethanol as A Fuel

Ethanol is a renewable bio-based oxygenated energy resource, with significant potential to reduce particulate emissions in compression–ignition engines. In addition to well established use in petrol engines as blend with gasoline or 100% a power ethanol. To maintain blend stability, appropriate additives have to be formulated. While modifications have to be done on the engine with respect to parameters like injection and ignition timing (Hansen et al., 2005; Kabeyi & Olanrewaju, 2021b, 2021c; Kabeyi & Oludolapo, 2020c). When ethanol is used to blend diesel, fuel is often, it is referred to as "E-Diesel", "eDiesel" or ethanol-diesel blends. The ethanol-diesel blend is also called "oxygenated diesel", which is a term that is not particularly precise, because diesel blends with methyl ester biodiesel or any other additive that include oxygen are referred to as oxygenated diesel(Hansen et al., 2005; Moses Jeremiah Barasa Kabeyi & Oludolapo Akanni Olanrewaju, 2022; M. J. B. K. Kabeyi & O. A. Olanrewaju, 2022).

There are various techniques used to run diesel engines on ethanol e.g. alcohol fumigation, alcohol-diesel fuel emulsions, dual injection, and alcohol-diesel fuel blends. For most commercial diesel engines only alcohol-diesel emulsions and blends are compatible. Emulsions are difficult realise and tend to be unstable. The common approach is to use blends as micro-emulsions or using co-solvents for engines with little or no relatively no modifications(Hansen et al., 2005). In e-diesel blends, standard diesel fuel is blended with up to 15% by volume of ethanol using while additives are added to maintain blend stability and other properties particularly the cetane number and lubricity of the diesel-ethanol blend. Additives used may account for 0.2% to 5.0% of the total blend. The specification for e-diesel are still under development (Hansen et al., 2005). The use of e-diesel can bring some reductions in diesel PM emissions, while contradictory reports exist on its effect on NOx, CO, and HC emissions. Perhaps the biggest advantage of e-diesel is its partially renewable character, if renewable ethanol is used as the blending stock. Considering its potentially significant operational and safety issues—the latter including very low flash point—e-diesel will likely remain a niche market fuel of limited applicability(Hansen et al., 2005). An alternative way to use ethanol in diesel engines is ethanol fumigation into the engine intake port. This requires engine modifications and hence limited application (Hansen et al., 2005).

Therefore, ethanol from molasses and other bio-resources can be used as a fossil fuel substitute as a combustion fuel either as a blend or pure ethanol. Other than blending, addition of additives and engine as well as combustion and fuel system modifications may be necessary for specific applications.

7. Conclusion

Bioethanol manufactured from renewable feedstock is a valuable product and environmentally friendly fuel as the global energy demand grows and concerns of emissions and global warming intensify. The main challenge with bioethanol is the competition it causes to global food supply and other domestic and industrial applications. There are several factors that influence bio-ethanol yield of sugarcane molasses. This includes the percentage brix, pre-treatment done and process parameters control. This study demonstrates that ethanol obtained by biotechnological methods is a feasible alternative to fossil fuel. With the high cost of sugar production in many countries, diversification into ethanol production from molasses which is a by-product of sugar production will create an additional revenue stream hence improve the financial sustainability. Ethanol has wide range of applications in industry and domestic or household applications e.g., manufacture of beverages, wines and spirits thus boosting the gross domestic product of sugar producing countries. Additional ethanol has significant energy potential and can be used as substitute for fossil fuels particularly petrol. This implies that sugarcane molasses has an important role to play in the energy transition.

The conversion sugar cane to molasses is about 4%, while conversion of molasses to ethanol is about 20%, the molasses fermented. The ethanol capacity of sugar factories varies with the crushing capacity. However, actual output of molasses is a function of cane milled while the actual ethanol capacity is based on the molasse produced. Milling is affected by many factors like planned and forced outage as well as availability of sugarcane for milling by factories.

This study demonstrates the significant potential of ethanol from molasses as a sustainable energy resource and therefore the sugar industry can play a leading role in the sustainable energy transition. The only challenge is the need for technological advancements, modification of engines and development of additives that enhance combustion of ethanol in its pure form or as an additive.

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