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Research Article

Modification of the Cooling and Control System of BAERC Bio Ethanol Micro Distillery

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Abstract

Modifying the cooling and control system for a BAERC Bio Ethanol Micro Distillery can significantly improve efficiency, reduce energy consumption, and enhance overall system reliability. The cooling and control systems are crucial in optimizing the distillation process, which involves controlling temperature and heat exchange during fermentation and distillation. The improved and tested batch system micro distillery-based ethanol production from molasses was successfully operated by firewood and produced ethanol at the alcoholic levels of 60-93%. Though the system was not operated at its full capacity, it made 10 to 12 liters from 80 to 100 liters of the substrate with various sources and brix. The average boiling point of the substrate takes about 1 hour and 30 minutes, on average, to reach the boiling point of ethanol when a wood fuel gasifier stove is used as a heat source. The micro-distillery paved the way for small-scale ethanol production from molasses and to produce clean-burning ethanol, mainly for household cook stoves. So that individual Farmers' Youth and Women micro-enterprises can use it and make income from the technology. Additionally, if a scaled-up micro-distillery is established in a village, individual farmers can be the supply of input and make additional income out of it.

Keywords

Condenser, Ethanol, Formation, Heat Exchanger, Micro Distillery, Substrate

1. Introduction

There is a need for biofuel production to augment the use of fossil fuels and to establish a strong link between the downstream petroleum industry and agricultural activities [1], especially in developing countries. Consequently, countries are steered towards establishing a commercially viable biofuel industry for both investors and consumers and providing sustainable job opportunities that could reach the common man. Biomass wastes are among the feedstock for renewable energy to achieve the requirement of Carbon Emission Reduction (CERs) credits. Owing to its widespread availability, renewable fuel technology will potentially result in the employment of more people than fossil-fuel-based technology [2, 3]. Palm oil industries that are striving towards quality and environmental conservation through a 'sustainable development and cleaner technology' based on the requirements of the Environmental Quality Act (EQA) and the specific regulations governing the management of Palm Oil mills; can then fully comply with regulatory requirements in terms of combustion, fly ash and energy conservation [4] by transforming the residue into biofuel 'a more-valuable end product' [5] such as waste palm bunch to bioethanol. Efficient implementation of bioethanol production from these wastes can be a break-

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through in the fuel market or the world's energy portfolio [6].

This feedstock when properly treated can be reduced to biofuel. There is a need to separate the pure biofuel from the obtained mixture and this is mostly achieved by distillation for bioethanol. Distillation is a thermal separation technique relying on differences in the boiling points of the component liquids to be separated [7]. The motive force in all thermal separation is the drive towards thermodynamic equilibrium between the different phases (vapor-liquid equilibrium, VLE) (Tongfan et al., 2004). The concentration of the lighter components will be greater in the vapor phase. Conversely, the concentration of the heavier components will be greater in the liquid phase, and only in the case of pure components or azeotropic mixtures will the equilibrium composition be the same in both phases [8].

Boiling point and vapor pressure are the key parameters and higher vapor pressure creates a lower boiling point. Note that when the alcohol/water mixture is boiled, vapors with a greater concentration of alcohol form while liquid with a lesser concentration of alcohol remains behind. Separation of the bioethanol from water is initiated at this stage taking advantage of the low boiling point of bioethanol (78 ℃) and the positive azeotrope it forms with water [8]. Depending on availability and cost, various fuels can be used for heating, including fossil fuels such as kerosene, diesel, and LPG; electricity; or biomass, such as firewood, charcoal, and pellets.

Biomass or electricity is often used because of its availability, ease of handling, and simplicity of design. Biomass combustion equipment is often simpler and cheaper than equipment for other technologies [7]. The potential of biomass as an alternative fuel source to replace LPG is a promising option [9]. Traditionally, energy in the form of firewood, pellets, twigs, and charcoal has been the major source of renewable energy for many developing countries [10]. Charcoal could be used as a heat source for bioethanol distillation because of its low price and ease of procurement in agricultural countries like Nigeria. A fuel's energy density can depend on its concentration, which is the purity, and yield as a basis of economic measure of its viability as related to the process technology adopted [11]. Presently, only a few industries produce bioethanol fuel partly because of the cost of importing a sophisticated distiller. Also, irrespective of the negative health effects, people have taken to local production of bioethanol for consumption due to the ease of doing this with ordinary pots but in hideouts as it is banned by the government.

In the past, Bako Agricultural Engineering Research Center had developed micro distillery technology for ethanol production using agricultural by-products. Raw fermented feed could be converted to ethanol by employing a simple distillation technology to change it to ethanol. Since excessive pressure was seen as popping the valves and feared accidents, in addition to using other components, some other arrangement needs to be used to hold temperature sensors, and a pressure relief valve. Therefore, it was initiated to solve all these problems with appropriate control materials. The distiller will engage more industries in biofuel production as well as encourage local producers to produce bioethanol for fuel rather than consumption which has a negative health effect and low efficiency due to the problem of incorrect condenser and cooling storage tank. Therefore, the general objective of the activity was to modify the overall size of the control and cooling system of technology and evaluate the technology that plays a great role in a green environment.

2. Methodology

Under this part, three activities were accomplished according to their continual implementation order.

1) Overall construction and ethanol production performance evaluation of the micro-distillery
2) Evaluation of molasses fermentation
3) Distillation and measuring of the produced ethanol alcohol level by using a simple instrument in the center

2.1. Construction Assumptions of the System

a) *Construction criteria*

Main considerations for the design of the parts and distillery

1) Feed 300-500 liters in every batch
2) Ethanol concentration of 4-6 volume% in fermented substrates for distillation
3) Expected distillation production is 60-90% ethanol at 15-20 liters per hour
4) A basic reflux rectifying column that was connected to an appropriate boiler was utilized
5) The process was designed to operate by using both firewood as a fuel and electricity
6) Process as extensive data collection, controlling, and monitoring capability
7) It would be capable of producing about 15-20 liters per hour, based concentration of the substrates

b) *Boiler description*

The fermented substrate was poured into a boiler tank to begin the distillation process. In field distillation units, the stills are employed to achieve higher temperatures instead of just forcing steam through the substrate enclosed in the distillation unit. Boilers in these units operate at around 7 bars of pressure [12]. Following this, 500 litter boilers were developed and built using a 3 mm steel sheet. In addition, certain factors that were taken into account in sizing the boiler were required column units, time to operate, dimension of the stove, the mass of fuel, and personal preference of the system for easy process management. Thus 1m long and 97.5cm diameter cylindrical boiler was constructed in such a way that it was easy to discharge and charge, fitted with inlet and outlet valves. The inlet opening through which the substrate is getting in was 4 inch in diameter and fitted with equivalent diameter water pipes end plug and similar without let with ball valves.

Figure 1. *The old and new constructed boilers.*

c) *Reflux column*

The overall size of the column depends on the plate sizing, and the Plate spacing depends on the column diameter and operating conditions.

The principal factor that determines the column diameter is the vapor flow rate. The vapor must be below that which would cause excessive liquid entrainment or high-pressure drop, so the column diameter was designed based on the diameter and required number for making the packing plate and heat exchanger inside it. Thus, the column is 16cm in diameter and a 220cm long column design. The column pipe was fitted with a packing material to provide a large internal surface area. 12 copper pipes, 1/8 inch, were fitted on two plates and used as the packing material in the column. The packing materials were placed at two points, just next to the boiler and above the two heat exchangers. The column consists of two heat exchangers at 50cm above the boiler and on the top of its length by leaving 80cm between its parts and the end of the column.

To check the temperature of the vapors going to the condenser was being held in place by a tube which 1/3 of its parts made to be submerged into the column.

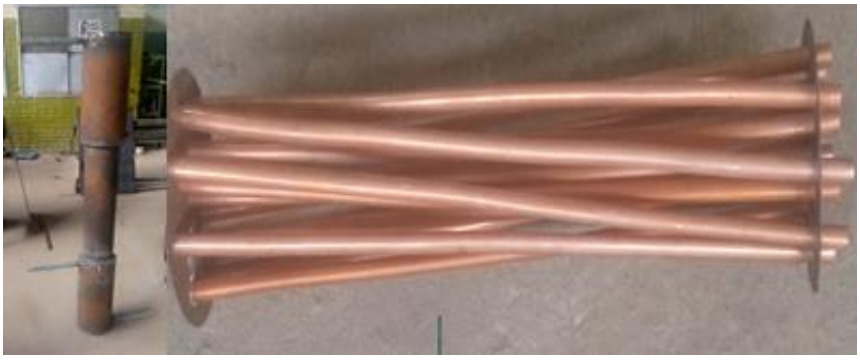

Figure 2. *The reflux and packing materials.*

d) *Heat exchanger*

Two heat exchanges were made from 6 water pipes of ¾ inch diameter into a unit for transporting the vapor and while their outer are flooded by cold water, pumped through the outer shell parts. The diameter of the heat exchanger is the same and made of 25cm and 35cm outer shell dia. Both heat exchangers are made up at 50cm above the boiler and below the top end of the column. Water is used as heat exchanger medium.

Figure 3. The shell and tube heat exchanger.

e) *Condenser*

Top of the column connected to a condenser to cool the vapors back into liquid form. The condenser was made from 2 water pipe ½ inch diameter into a unit for holding the vapor while its outer part is flooded by cold water, pumped through the outer shell part to circulate. The condenser diameter is made up of 2m and 30cm outer shell diameter. The main reason for enlarging the outer body of the condenser was that the condenser be large enough to cool all of the vapors from the column at about 78 ℃ and preferable to about 30 ℃.

Figure 4. The old and modified condenser types.

2.2. Process Description

Production of ethanol involves three major stages

1) Fermentation
2) Distillation
3) Alcohols level measuring

2.3. Substrate Preparation

a) Bric checking b) Acid dilution c) Mixing

d) pH value test e) Penicillin added f) Packaging

Figure 5. *The Procedures of substrate preparation.*

After the distillery was built and ready for experimentation, the mash was prepared for fermentation. In the preparation of mash for formation additives for pH level adjustment, penicillin, procaine, yeast, and Vb were used in some batches of experiments. Sulphuric acid is used to adjust the pH value of the substrate from neutral to an acidic level (4.5-5.5), which is recommended for yeast growth. Penicillin procaine was added to protect the yeast from bacteria, and the Vb complex was used as an additional source of nutrition for yeast growth.

2.4. Fermentation

Anaerobic fermentation of the substrate was carried out at BEARC, where the fermentation and distillation conditions were monitored in the room. It was loaded into the fermenting buckets, it was allowed to ferment for 48 hours and 72 hours to evaluate the effect of time on yield. The procedure was repeated.

2.5. Distillation Process

The prepared substrate in the bucket was poured into the distillation tank. The distillation process was monitored carefully by using the thermometers on the column, cold water pumping, and valve controls for the heat exchanger, condenser, refluxing, and corresponding safety. The temperature increments of the system were measured and made to be adjusted below 78 ℃. When the temperature of the distillery attains the maximum level and pressure in the boiler tank is increased the control valves of the reflux pipe to the boiler are closed and that of the ethanol outlet to the collector is opened. Know the volume of used plastic bottles to collect and store the produced ethanol. After collecting and its temperature gets down to room temperature, the% of alcohol in ethanol was measured by an alcohol hydrometer and labeled on bottles for further analysis.

3. Results and Discussion

3.1. Substrate Preparation and Fermentation Process

The molasses contained 83 °brix, 17% reducing sugars, 32% sucrose, and 49% on a wet weight basis. The, pH value of the obtained molasses was 5.8. The brix value determined in this study was lower than the value (85.4 °) reported by (Paturau, 2012). Results indicated that the chemical composition of sugar cane molasses was in close agreement. The substrate measured pH value was between 5.8-8 which was almost nearest to neutral 7 since the adjustment of pH of the substrate into acidic media for the yeast is one factor for effective growth of the yeast and reaction to produce ethanol. So, the substrate pH was changed to 4-5 levels by adding 30 drops of sulphuric acid to 80 liters of prepared substrates. The levels of pH were selected based on experiment results kinds of literature [13]. After the addition of all ingredients to form a substrate, the most important was yeast. It was added in all of them at a rate of 6.25g/l. Accordingly, 3 barrels of 80 liters were stored for 72 hours and tested for fermentation. As the formation was a heat-releasing reaction, temperature levels of the storage room and external buckets showed little difference of 5-8 ℃ after 24 hours. After 48 hours of storage, the temperature of the fermentation tank attained a steady average of 30 ℃ indicating that the product was ready for distillation. As shown in Table 1, the lowest room temp recorded was 23 ℃ and the highest 27 ℃ while that of fermentation was in the range of 29-35 ℃ respectively.

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Table 1. *Results of the substrate preparation and fermentation.*

Usedkg of molasses	Liters of solution	Adjusted sugar brix	Measured and adjusted the pH of solution	Ferment, room & buckets body temperature
10	100	18	7.1, 4.5	25 ℃, 35 ℃
8	80	22	7.8, 5.5	26 ℃, 33 ℃
8	80	20	7.2, 4.5	25 ℃, 32 ℃
8	80	19	6.8, 5.2	25 ℃, 32 ℃

3.2. Distillation and Ethanol Production Processes

During the distillation of the substrate, the column bottom and top temperature measuring thermometers were continuously observed and recorded. The temperature was measured indirectly via the oils inserted tubes, but the difference between the bottom and top showed the effects of the two heat exchangers in controlling the rising of the temperature below 80℃ to separate ethanol from water. The observed average temperature of the bottom and top were range of 65 ℃ and 77 ℃ respectively. The distillery consumption of wood fuel used was about 18-25kg per batch of distillation which takes about 1: 30 hours. The output of the distillation ethanol was obtained in the range of 10-12 liters per batch of 80- 100 liters of input substrates. The alcohol contents of the out ethanol were measured at 60-93% range from inputs of substrates of 18-22 brix. The amount of output of the ethanol depends on amounts of input, brix, and duration of distillation, which also increased with the increase of time. The minimum alcohol content of the output (60%) was a suitable requirement for an ethanol stove, whereas the max. ethanol separation capability of the distillery 93% was beyond the minimum requirement of 80% ethanol content for a standard stove [14]. Alcohol at 85% was generally the minimum required to run a generator or an internal combustion engine. But according to Brady luceno, 2012 ethanol at 50% was igniting, and ethanol at 60% to 65% was the minimum necessary to support a stable flame.

Table 2. *The average result of distillation.*

Fuel wood/distillation per batch (kg)	Distillation temp at bottom and top (℃)	Distillation time (hrs)	Alcohol /100 liters	Alcohol level (%)
18	62	1: 32	12	72-90
19	67	1: 43	9	60-91
22	65	1: 15	11	75-90

Regarding fuelling of the system by wood fuel the observations of the process showed clearly that constant and sufficient heat was used for the distillation process. Thus the concentrated gasifies stove proved that it can burn the wood fuel efficiently without constant fellow up and additional supply of natural gasification.

4. Conclusions and Recommendations

The modified and tested batch system micro distillery-based ethanol production from molasses was successfully operated by firewood and produced ethanol at the alcoholic levels of 60-93%. Though the system was not operated at its full capacity, it produced 10 to 12 liters from 80 to 100 liters of the substrate with various sources and brix. The average boiling time of the substrate takes about 1:30 hours on average to boil the boiling point of ethanol when a wood fuel gasifier stove was used as the heat source. The micro-distillery paved the way for small-scale ethanol production from molasses and to produce clean-burning ethanol, mainly for household cook stoves. So that individual farmers' youth and women micro-enterprises can use it and make an income out of the technology. Additionally, if a scaled-up micro-distillery is established in the village, individual farmers can be the suppliers of input and make additional income out of it.

Researchers and students can be beneficiaries concerning making the technology a baseline for future similar technology improvements and developments. The modified and tested distillery was made of milled steel and water pipes; however, ordinary steel does not work because it will quickly rust. Due to the properties of construction materials, the distillery components show visible leakages of some steam with ethanol. Therefore, the distillery needs to be constructed from copper or stainless steel and be checked in future work.

Abbreviations

BAERC	Bako Agricultural Engineering Research Center
CER	Carbon Emission Reduction
EQA	Environmental Quality Act
LPG	Liquid Petroleum Gas
Vb	Vitamin B Complex
VLE	Vapor-liquid Equilibrium

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Conflicts of Interest

The authors declare no conflicts of interest.

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