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Design, Fabrication and Performance Test of a Pilot Scale Bioethanol Plant with Fractional Distillation Unit

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Abstract: This study presents the design and development of a pilot scale bioethanol plant. The pilot plant was designed to produce an average of 20 liters/day of ethanol from a 60 litre volume of brut/beer from agricultural waste materials. The design of the bioethanol plant covers the stages of concept formation to the production of specification sheets for components parts and equipment, the design consideration for the plant was also included. The pilot plant consists of the fermentation pot, radiator, water pot, ethanol collection pot, fractional distillation unit, boiler, reboiler, condenser, pumps, electrical components, frame and base of the plant and tyres for mobility. The materials used for the development of the plant are mainly stainless steel, mild steel and copper. A performance test was carried out on the bioethanol plant with fractional distillation unit. Agricultural waste material was used for the testing of the plant. The feedstock was processed and allowed to undergo fermentation during which physicochemical parameters like pH, sugar content, alcoholic content, conductivity and specific gravity was carried out for a period of four days. The fermented beer/brut was then distilled to produce an average of 79% alcohol. The equipment was locally fabricated in the National Centre for Energy and Environment, University of Benin, Benin City, Edo State Nigeria using about 85% local content. The pilot plant has proven the availability of local technology for bioethanol production in Nigeria.

Keywords: Bioethanol Plant, Raw Material, Distillation Unit, Feedstock, Agricultural Waste

1. Introduction

The need for energy to carry out our day to day activities both at our homes and in the industries cannot be over emphasized [1] Energy demand is increasing with growth in technology and urbanization. The fossil fuels (i.e, oil, natural gas and coal) which is our main source of Energy are depleting on a daily basis [2]. The effects from the exploration of fossil fuels create environmental and sustainability concern. Energy is very significant in any economic development of any developing nation. Due to the declining oil reserves and rising cost of petroleum products and the environmental and sustainability concerns, this has led to the bedrock of the advocacy for Bio-fuels globally, especially Ethanol. Ethanol has been produced from different sources in the past. The generally accepted sources of raw material for ethanol production from starch are cereals such as corn, wheat, barley, millo (sorghum grains) rice, potatoes etc [3]. Cassava root was transformed into ethanol in a one-step process of fermentation in which are combined the conventional process of liquefaction, saccharification, and fermentation to alcohol [4]. More of the 95% of ethanol produced today is from simple biomass. The use of this type of Biomass has been increasingly debated due to its impact on food and feed prices as well as for environmental reasons [5].

Ethanol has been produced since ancient times by fermentation of sugars (i.e. conversion of simple sugars in the form of yeast (zymase) into ethanol and carbon dioxide)

[6]. Bioethanol can be used as fuel for automobiles alone (E100) in a specific engine or as an additive to gasoline (such as E10) for petrol engines. Ethanol has a flash point of 12.8°C, ignition temperature of 360°C, vapors density of 1.6 and boiling point of 77.8°C [7]. Ethanol can be blended with gasoline to reduce toxic gas emissions. Ethanol can be used in transport and electricity generation sectors in Nigeria. The conventional petrol engines of the vehicles we have today would not require major modification to use these alternative bio-fuels. Agricultural wastes such as sugarcane, corn stalk and comb, rice straw, millet, neem seeds, jatropha seeds etc. can be used for bioethanol production [8; 9]. The use of these agricultural wastes as Bioethanol production will reduce over dependences on fossil fuels as energy and will meet up Energy availability and sustainability for both our homes and industries.

The aim of this paper is to develop a functional Bioethanol production pilot scale plant with fractional distillation unit in order to utilize the plant for the production of ethanol from the abundance raw materials from agricultural waste and also recommend this technology to stakeholders and investors in the Energy and Environmental sector of the Country.

2. Materials and Methodology

The materials used for the fabrication of the plant are mild steel, copper and stainless steel. The design of the bioethanol plant covers the stages of concept formation to the production of specification sheets for component parts and equipment. Also included in the design consideration for the plant are the System international units (SI) which were considered throughout the design and the fabrication.

Table 1. *codes and design of pilot scale bioethanol plant.*

ASME Division 1 Section VIII	Boiler and Pressure Vessel Code
ASME B31.9	Working pressure and Temperature Limits
ANSI B16	Standards for pipes and fittings
ASTMF1267-18	Standards specification for metals, Expanded, Steel

2.1. Design Consideration

The considerations for each concept were primarily driven by the need for flexibility and ease of operation. This would allow the order of unit operations to be reconfigured, new unit operations to be added and a host of operating conditions to be tested without a need for a total overhaul in the future. Other criteria that helped to define the design specifications for the bioethanol plant include:

1. Facilitating ease of fabrication.
2. Minimizing the layout space of the plant.
3. Represent process conditions accurately.
4. Ensuring the system is safe.
5. Minimizing the cost of the system.

Design of the Fermentation System

The main objective of a fermentation tank is to maintain a controlled environment that supports the growth of the bacteria or any other organism.

2.2. Sizing

Diameter and Height

From standard Practice, the tank Diameter (T) to Height (H) ratio is normally selected in the range 3 - 5. Exceptions only apply for animal culture where a ratio of 2 is advised. 1/3 of the volume at the top of the vessel is left free to allow for the accumulation of beer, foam and gas. This is because the expansion of liquid due to gas hold up is usually 10% to 20%.

From several literature and text, the optimum Impeller Diameter (D) to tank diameter (T) ratio ranges from 0.3 - 0.4. Distance between two impellers is between (1/2D) to (4/3D) Standard. The maximum is given as 0.51T. Impeller type and dimensions were selected in accordance with A315U. Bottom Impeller Clearance is between 0.33T to 0.5T. This is common for solid suspension. The baffle Width are always set at (1/12T) with the standard Baffle Wall Clearance at (1/60T).

2.3. Design of the Bioler and Reboiler

The dimension for the height, h and diameter, D of the boiler can be calculated by knowing the volume, V of beer/feedstock expected to be in the vessel at some time t using the formula;

$$V=\pi \cdot r2h$$

Where;

r=Internal radius of boiler h=Boiler height

Suitable h/D ratios of 1, 1.5, 2, 2.5, etc. adequately size the boiler.

2.4. Frame Design

The Frame was designed using Standard Structural Steel 2.0 in x 2.0 in square tubes for rigidity and support. The structural members are to be welded with arc welding using appropriate class of electrodes. The frame is to be made with mild steel or material of equivalent strength. To prevent corrosion, suitable anti-corrosion coating was applied.

All lengths and cut angles in the cut list were strictly followed. Extra members may be added for extra support. The Sheet Metals used as base plates on the frame are the AISI 304 standard 3mm thick sheet.

2.5. Design of the Distillation System

The two types of column are plate columns and packed columns. With a careful consideration of several factors, the plate type column was selected for the following reasons;

1. Plate columns can be designed for a broader range.
2. Maintenance of columns is easier with plate columns.
3. Low liquid rates are better done on plate columns.
4. The addition of side streams is more easily done with plate columns.

Below are the various components that make up the bioethanol plant

a. Fermentation pot
b. Boiler
c. Re-boiler
d. Distillation Unit
e. Condenser
f. Ethanol Collection Pot
g. Radiator
h. Cooling drum
i. Water pumps
j. Electrical Components
k. Frame and Base of the bioethanol plant
l. Tyres

Figure 1. *The orthographic design of the bioethanol plant.*

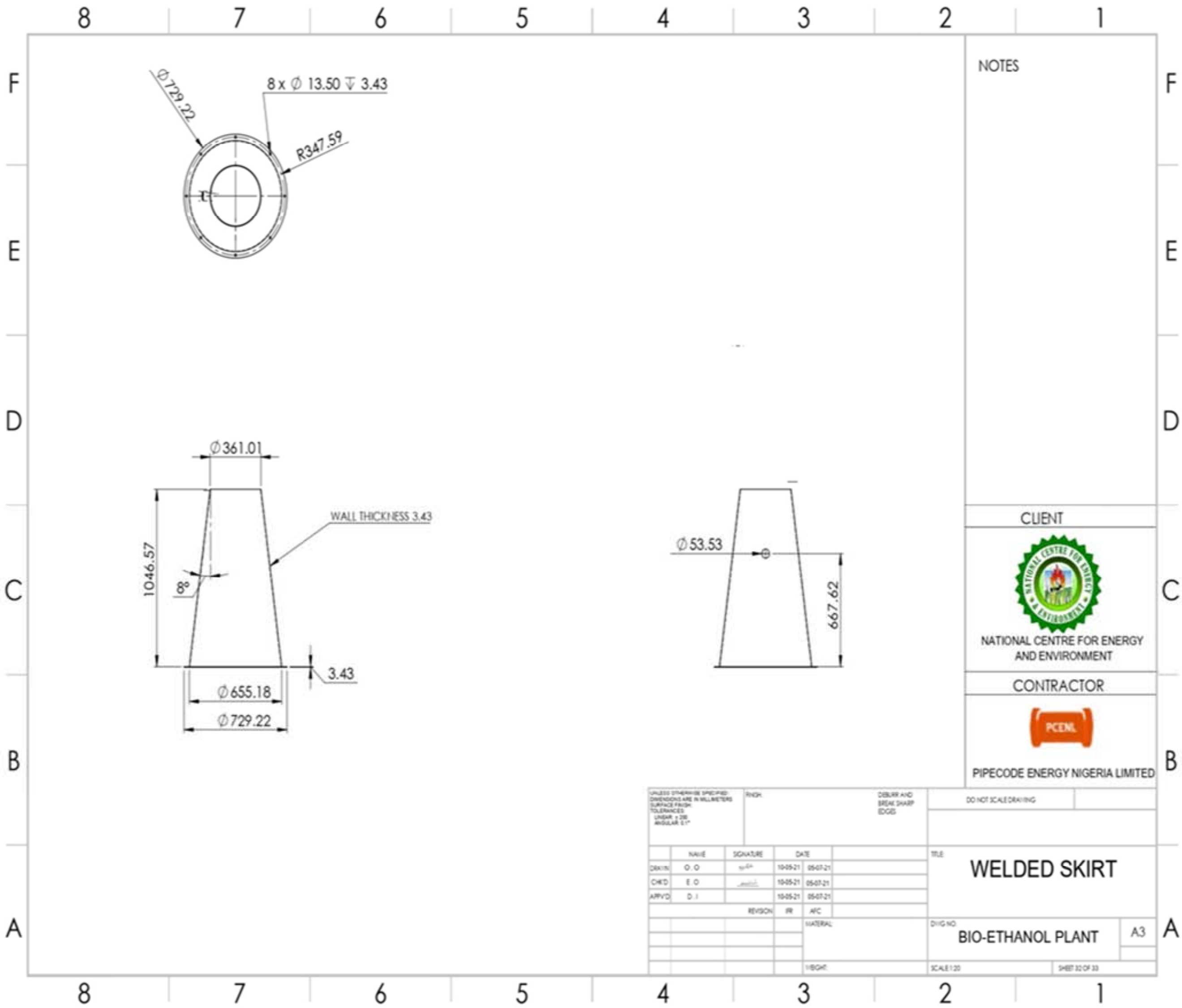

Figure 2. *Welded Skirt of the bioethanol plant.*

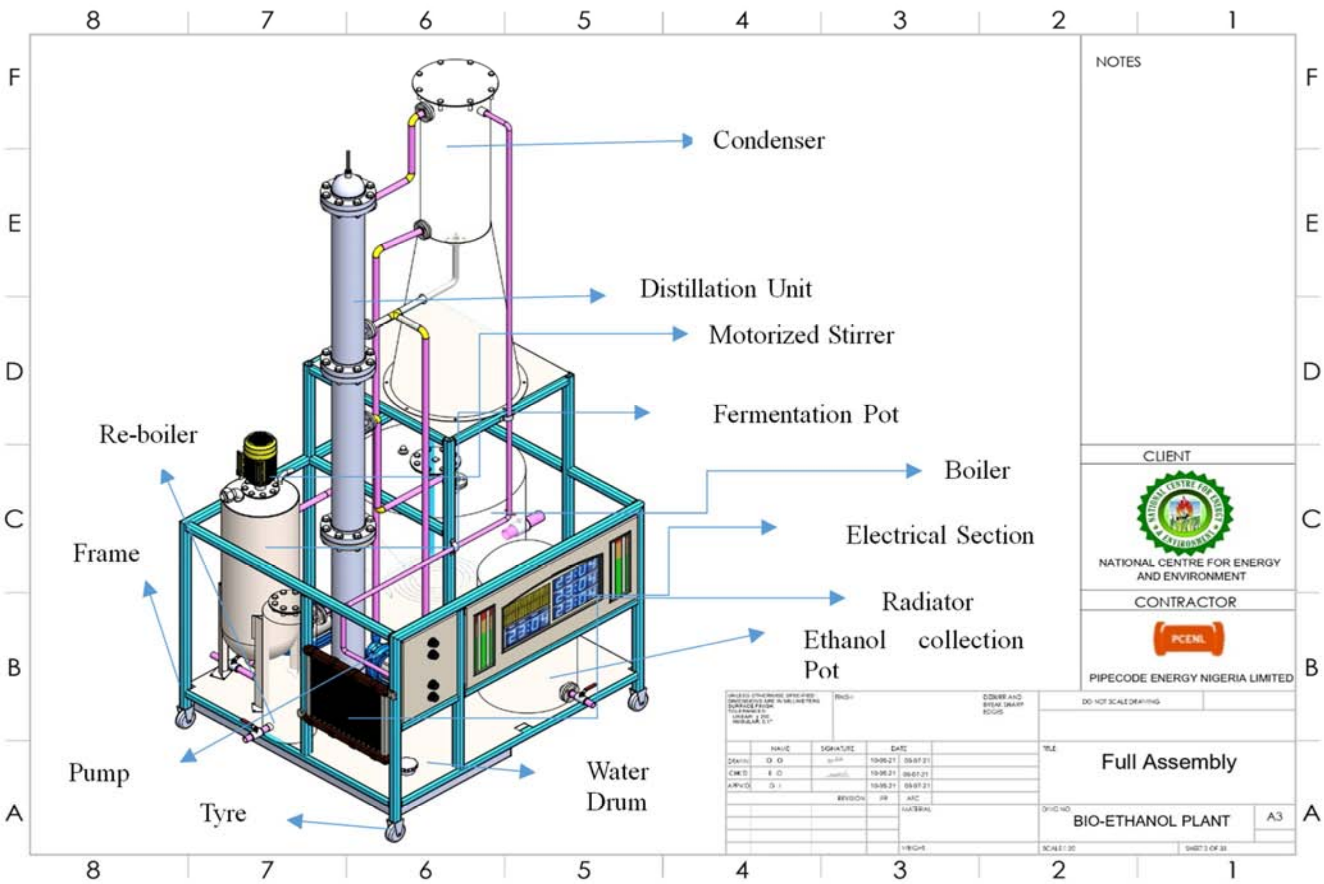

Figure 3. *Full Assembly of the bioethanol plant.*

Figure 4. *Complete Bioethanol Plant with Fractional Distillation unit.*

3. Results and Discussion

3.1. Description of the Bioethanol Plant

The plant is built to be compact, covering an area not exceeding $2m^2$ while ensuring that the process efficiency is maintained. All vessels are fitted with necessary monitoring gauges and sensors. The entire system is connected to an electronic control panel to facilitate easy control and monitoring. The fermentation tank is the first stage in the process designed to ferment 100 litres of fruit juice in about 3-4days and it is fitted with a stirrer which is powered by a low-speed motor to stir the juice and enhance the process. The fermentation vessel contains openings for inserting pressure, temperature and pH probes to monitor the process. The Distillation process involves the stages of heating the fermented beer in a well-insulated heating vessel with the heating requirement supplied by heating filaments. The next stage is a process where the heated gas flows to the distillation column with evenly spaced trays where the separation of ethanol from water molecules takes place. The distillate then flows into coiled tube condenser equipment from where the ethanol vapor is water cooled to the liquid condensate. The output from this equipment is routed with piping to a point of reflux on the distillation column to increase the quality of the distillate while another line is routed to a storage tank where ethanol is collected.

3.2. Testing of the Bioethanol Plant

The pilot scale bioethanol plant with fractional distillation unit was tested to ascertain its functionality. Raw materials from agricultural waste which is a potential energy resource were gotten from the market. The raw materials used to test the plant were pineapple, water melon wastes respectively gotten from the market and fermented palm wine which was gotten from the Nigerian Institute for Oil Palm Research (NIFOR).

The various feedstocks were prepared by extracting the juice and allowed to ferment in an anaerobic condition at room temperature after pretreatment. Physicochemical parameters (pH, Conductivity, Specific gravity, Sugar content and alcoholic content) were taken for analysis during the fermentation process. This is important because it helps us to know when the beer/content can be distilled. The fermentation process takes about 3-4 days. The bioethanol plant with fractional distillation unit produced ethanol from all the feedstock.

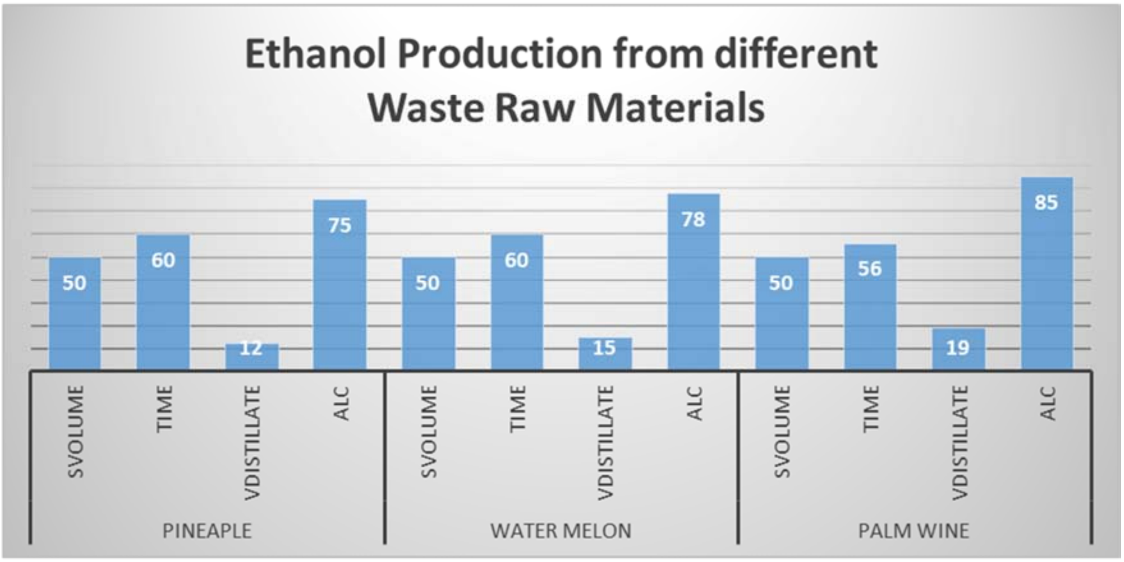

Figure 5. *Production of Ethanol from different Waste Raw Materials.*

4. Discussion

The chart above displays the results of the production of ethanol from pineapple, water melon and palm wine which shows that 50 litres of juice from the various feedstcok was used as a baseline. From the chart 50 litres of pineapple juice produced 12 litres of ethanol/alcohol in 1 hour with 75% alcohol, while 50 litres of watermelon juice produced 15 litres of ethanol/alcohol in 1 hour with 78% alcohol and 50 litres of palm wine produced 19 litres of ethanol/alcohol in 56 minutes with 85% alcohol. It therefore shows that the bioethanol plant with fractional distillation unit produced an average of 15 litres with 79% alcoholic content from a 50 litres volume of beer in 1 hour.

5. Conclusion

The National Centre for Energy and Environment an agency of the Energy Commission of Nigeria as part of its mandate to carry out research and development on renewable energy technology and environment and the Centre's advocacy of waste to energy and also waste to wealth designed and developed an operational friendly mobile and indigenous pilot scale bioethanol plant with fractional distillation unit which was used to produce ethanol from agricultural waste materials. The bioethanol plant which was fabricated with 85% local content produced a distillate of an average of 79% alcohol from water melon waste, pineapple waste and fermented palm wine. The feedstock process and physicochemical analysis in this paper agrees with [10-19]. The results and aim of this study corroborates with the findings by [20] saying that agricultural waste materials are good substrates for ethanol production. It further suggests that ethanol can be produced from agricultural waste rather than allowing it constitute a nuisance to the environment. The bioethanol produced is currently been utilized in the laboratory of the National Centre for Energy and Environment, apart from that it can be used for a host of things like in pharmaceuticals, for making cosmetics as fuel for cooking and driving our automobile engines when modified to run on only ethanol or properly blended with gasoline.

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