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Some Parametric Factors Influencing Cottage Ethanol Plant

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Abstract: A cottage ethanol plant was designed, constructed and tested in major effect to make reasonable contribution in the current drive for renewable energy. The plant consists of a stoker chamber, fermentation vessel, two-stage distillation column, a condenser and the ethanol receptacle. The conditioned feedstock, freshly harvested cassava, was feed into the fermentation vessel, allowed 48 h fermentation with enzymes and yeast added. The ethanol was distilled and allowed to pass through a condenser and finally the ethanol was collected. The ethanol unit prototype was evaluated using tests on three varieties of cassava. The degree of recovery of the distilled sample ranged from 18.28 % ethanol for 3-5 mm Cassava chips to 62.03% ethanol by volume for sieved cassava liquor on one hand, and ranged from 49.37% of ethanol for a packing size of 3-6 mm to 62.81% of ethanol for a packing size of 8-10 mm. Mean values of some tests parameters were also determined. These parameters as quantitatively analysed using ANOVA, showed high significant difference ($p<0.01$) for the conditioned samples effect on volume of sample, percentage ethanol, density and refractive index, but was just significant ($p<0.05$) for the effect of variety of feedstock on density and percentage ethanol while having no significant effect on the volume of sample and refractive index. With the change in the design figuration of the condenser, the ANOVA result showed high significant ($p<0.01$) effect on volume of sample, significant ($p<0.05$) effect on percentage ethanol, density and refractive index. The varieties however, showed no significant effect on density.

Key words: Cassava, cottage ethanol plant, distillation, fermentation, ingress stoker

INTRODUCTION

Ethanol is the most important member of the alcohol group. It is a two carbon with hydroxyl group. It is a clear colourless, volatile flammable oxygenated hydrocarbon that is the intoxicating agent in liquors. Aside from its major use in alcoholic beverages, ethanol is also used (although highly controlled) as an industrial solvent/raw material and recently as liquid fuel by the fermentation of sugars, as a mixture of 95% from total distillation (Adikwu, 2005).

The transport and electricity generating sectors in Nigeria are heavily dependent on petroleum fuels. Today, Nigeria consumes on average 30 million litres of petrol daily such that finding sustainable alternatives for these sectors is necessary for the economic development of the country. The transportation sector, consumes fuels in two major ways, as petrol (or gasoline) for most small capacity vehicle and as diesel for most of the heavy-duty vehicles and plants. Petrol can be substituted with bio-ethanol partly or wholly and ethanol has an energy content which is one third less than petrol which means that one litre of ethanol replaces about 0.66 L of petrol (Mohammed, 2008). With the gradual introduction of fuel ethanol in the fuel mix, the amount of petrol consumed would reduce significantly, making it available for future use (Bugaje and Mohammed, 2007).

The conventional petrol engines of the vehicles we have today would not require major modification to use these alternative bio-fuels (Misau, 2007). Our various agricultural waste products, such as corn stalk and comb, millet stalk, rice straw, bye products of sugar industries such as bagasse and molasses can all be processed to produce bio-ethanol. This would not create unfavourable competition with the production of food cereals so that the cost does not go beyond the reach of the common man.

Ethanol is a clear, odourless, colourless, flammable oxygenated hydrocarbon which consists of hydrogen, carbon and oxygen with the properties shown in Table 1. It is an automotive fuel as well as a gasoline blend that offers excellent performance plus low hydrocarbon emission. Ethanol or ethyl alcohol has the chemical formula C_2H_5OH and can be produced from any biological feed stocks (e.g., cereal grain) that contains sugar or materials that can be converted into sugar such as cassava, sugarcane as well as from cellulosic materials such as wood or paper wastes, potentially minimizing the accumulation of green house gas and subsequent

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Table 1: Properties of Ethanol

Property	Ethanol
Chemical formula	C_2H_5OH
Density 20°C	0.791 g/cc or 0.78 g/mL
Boiling point (a)	78.5°C
Melting point	-117°C
Heat of Combustion (b)	56.25 kcal/1
Heat of vapourization (c)	9.225 kcal/mole
Stoichiometric Air/Fuel Ratio(d)	9/1
Solubility in water	Completely soluble in all proportion
Action on metal sodium	Vigorous reaction, hydrogen evolved
Condensed Structural formula	CH_3CH_2OH
Molecular weight	46.07
Octane Rating	106-108

Source: (Bradley and Runnion, 1984)

depletion of ozone layer. Because ethanol can be produced from crops, it is classified as a renewable fuel source (Wright, 2001).

The very little work done on development of bio-ethanol production technology in Nigeria and the rising and fluctuating petroleum prices, increasing threat to the environment from exhaust emissions and global warming have generated an intense interest in developing alternative non-petroleum fuels. Surprisingly, the country now imports petroleum with her four refineries which have the capacity to process 445,000 barrels of crude oil per day (Malgwi *et al*., 2002). There is therefore the urgent need for capacity building through the establishment of pilot plants for the adoption and local development of the biofuels process technology and optimization of process design parameters for specific Nigerian biofuels raw materials. It is in this framework that this project work is limited to the design and construction of a cottage fermenter-still combination unit for cottage production of ethanol from agricultural material like cassava that can be sourced within farmsteads or localities

Today, over 12 countries produce and use significant amount of ethanol. Brazil for example first used ethanol as a transport fuel in 1903, and now has the world largest bio-ethanol programme. Other countries with government or private ethanol fuel programme have been involved principally to reduce dependence on costly imported fuel and to assist in creating a new domestic fuel industry (Bradley and Runnion, 1984).

The Nigerian National Petroleum Corporation (NNPC) has now joined the developed countries by establishing a Renewable Energy Division to grow the biofuel industry in Nigeria and some preliminary studies have already started. The plan of the NNPC is to develop a fuel grade ethanol from its immense biofuel potentials, such as sugarcane, cassava, other starch and cellulose based materials, agricultural wastes, etc., which can be appropriately and systematically harnessed (Bugaje and Mohammed, 2007) that will be blended with petrol in proportions not exceeding 10% ethanol by volume. The resulting blended fuel will be called 'Green fuel'. Nigeria has the capacity to locally develop its bio-fuels industry using our vast agricultural resources.

There are many widely available raw materials for ethanol production which can be conveniently classified into three types: (a) sugar from sugarcane, sugar beet and fruit, which may be converted to ethanol directly; (b) starches from grain and root crops, which must first be hydrolysed to fermentable sugars by the action of enzymes; and (c) cellulose from wood, agricultural wastes which must be converted to sugars using acid or enzymatic hydrolysis. These new systems are, however, at the demonstration stage and are still considered uneconomic. Of major interest are sugarcane, maize, wood, cassava and sorghum and to a lesser extent grains and Jerusalem artichoke. This shows that plants are the most common source of biomass raw materials as shown in Fig. 1.

Cassava (*Manihot Esculenta*) which is being considered in this work is a staple food for hundreds of millions of people within the tropical regions. More than two-thirds of the total production of cassava is used as food for humans, with lesser amounts being used for animal feed (Nwokoro *et al*., 2002) and industrial purposes. Its roots contain a high proportion of starch and it is possible to obtain relatively high yields of 40-50 tonnes per ha without expensive fertilizer. It can also be grown on soils not suitable for more demanding crops, such as maize without additional nutrients (Burrell, 2003). A major limitation of cassava production is the rapid post harvest deterioration of its roots which usually prevents their storage in the fresh state for more than a few days (Okezie and Kosikowki, 1982).

There are two main types of cellulose materials, which are potentially available for ethanol production in large quantities. They are cellulose containing agricultural wastes (straws, cotton stalks, rice and wheat straws, rice hulls and other crop wastes) saw mill wastes and wood. Cellulose containing raw materials should contain 50-60% hydrolysable poly saccharides, preferably high in hexoses so that a 40-50% yield of fermentable sugars can be attained (NRC, 1981). In the conversion of cellulose to ethanol, the cellulose must first be hydrolyzed to glucose by either enzymatic hydrolysis or acid hydrolysis.

These "Biomass Fuel Crops" (tubers and grains) commonly include sugar beets, potatoes, corn, wheat, barley and sweet sorghum. Sugar crops such as sugar cane, sugar beets, or sweet sorghum are extracted to produce a sugar-containing solution that can be directly fermented by yeast. Starch feed stocks, however, must be carried through an additional step. Starch is a long "chain" polymer of glucose (i.e., many glucose polymer units bonded in a chain). Starches cannot be directly fermented to ethanol. They must first be broken down into simpler glucose units through a process of hydrolysis. In the hydrolysis step, starch feed stocks are

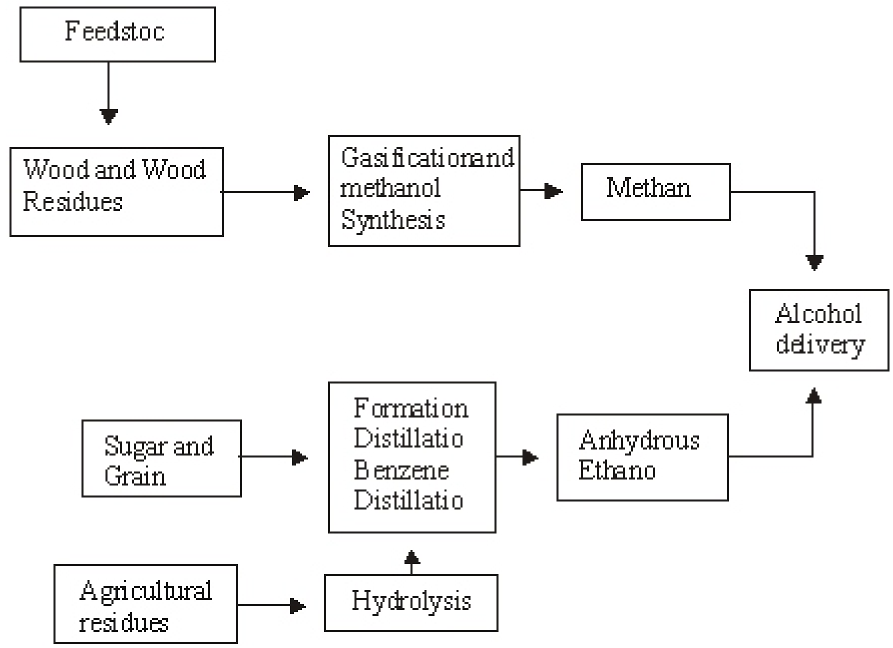

Fig. 1: Biomass to alcohol (Source: Malgwi *et al*., 2002)

chopped/ground and mixed with water to produce a mash typically containing 15 to 20% starch. The mash is then cooked at boiling point or above and treated in sequence with two enzymes preparations. The first enzyme hydrolyzes starch molecules to short chains; the second enzyme hydrolyzes the short chains to glucose. The mash is then cooled to 30ºC, and yeast is added followed by Fermentation and distillation processes (Bradley and Runnion, 1984). It is the objective of this work to study these parameters that influence the production of ethanol in a cottage plant.

MATERIALS AND METHODS

Equipment design and description: The equipment was designed with certain criteria considered appropriate which include:

- The process require no electricity- this feature makes it adaptable to any location in a rural environment
- The cottage plant should run on locally available biomass energy sources such as charcoal, wood, rice husks and other agricultural by-products.
- The building technique must be known to local craftsman and/or farmers.
- The basic extracting units (feedstocks, fermenter or boiler and distillation) should be a batch system that should be operated and maintained by the farm family. The batch size should be such that it will encourage faster operation.
- Cost of the cottage plant should be affordable to the intended users either as co-operatives or as individuals.

The plant is basically made up of four sections, the combustion chamber (F), the boiler (A), distillation column (C), and condenser (D) (Fig. 2). The combustion chamber is made up of ingress stoker, ash pit, grate bars and a chimney pipe (G) that projects out of it. The combustion chamber is built with the following materials.

- Burnt bricks of 24 cm x 10 cm
- Door of cast metal sheet of 20 cm x 15 cm
- Grates made up of iron rods held together by a perforated metal piece
- An ash pit which has opening measuring 30 cm x 20 cm from base of chamber

The stoker is built in such a way that it has enough room above grate bars separating the ashpit for sufficient combustion to take place, allow easy access for raking, openings leading to the chamber.

Other guidelines include:

- Placing the grate bars at appropriate point above the ash pit floor at least ⅓ of the chamber height
- Spacing of the grate bars is extremely important for fuel and firing control to ensure improved air draft
- No rule can be stated for determining the height of the stoker but one half of the height should be allotted to the combustion chamber while the remaining can be taken up by the ash pit (Olsen, 1983). If the grate is too low, the fuel (wood, coal, sawdust etc.) tend to build up and cause choking
- The ash pit must be easily accessible for raking out charcoal. The grate bars must also be accessible in

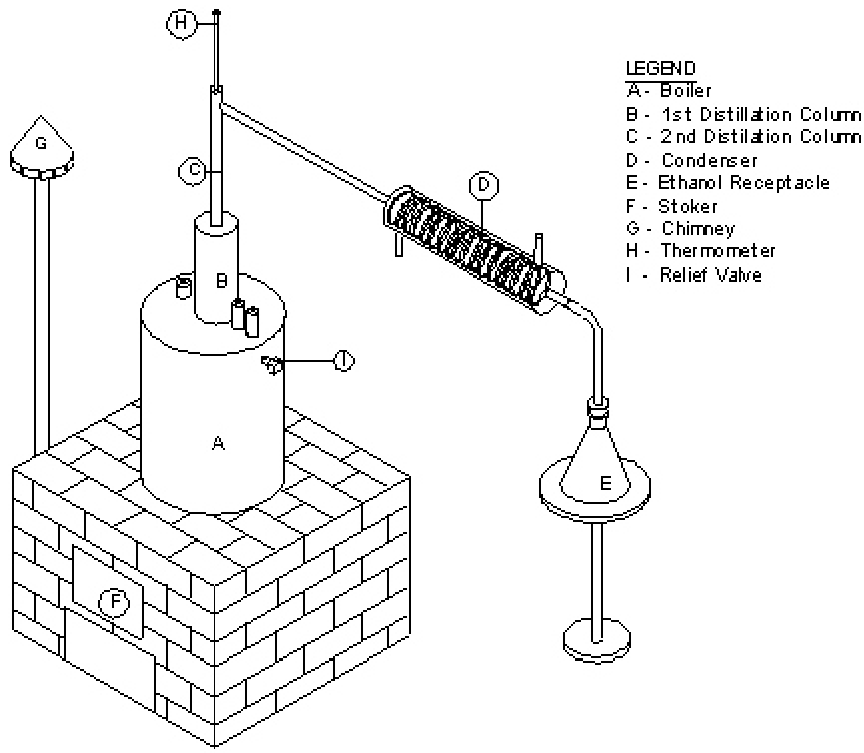

Fig. 2: The isometric view of the Ethanol plant

order to rake out the wood flinkers and to feed in the fuel (Obetta, 2007)

The combustion chamber was built of burnt bricks of 24 cm x 10 cm in order to minimize heat loss. It has two units, the stoker and the ash pit joined together with sandcrete. The total area of wall requiring bricks is 28065.01cm^2. And the number of pieces of bricks required is approximately 117 as calculated.

The stoker walls are made of high refractory materials (fired clay bricks) that can with stand high temperatures that is to say that they have high resistance to fusions. Fired brick, save time and quantity of fuel needed to generate desired heat besides, they reduce heat losses through conduction (Ehiem *et al.*, 2009). Expansion of bricks takes longer time to occur. Its coefficient of thermal expansion lies from 5 to 7×10^{-6} K (Baker, 1997).

The stoker is where fire is made with a metal cast door of 20 cm x15 cm. It has a loading opening of 30 cm x 20 cm which allows for charcoal and air to enter the stoker. A perforated sheet metal of 80cm x 80cm was placed 40cm above the ground in the stoker to facilitate easy separation of ash from the solid charcoal. This arrangement allows for continuous burning of the charcoal and easy collection of the ash. A chimney pipe of 7.5 cm x 55 cm is placed on the combustion chamber to remove smoke from the stoker and avoid choking.

The boiler is where heating and fermentation takes place. It is made of stainless steel to avoid corrosion during fermentation. The boiler is cylindrical with 45cm x 47cm x 0.1cm, width, height and thickness respectively. The cylindrical top 45 cm diameter has openings of 10cm, 6.4, 3 and 3 cm diameter for feeder opening where the feed stock enters the boiler, distillation column placed directly on the boiler and openings for inserting the thermometer and pressure gauge to monitor temperature and pressure changes. The boiler is placed directly on the perforated sheet metal on the stoker which was firmly sandcreted, leaving only a circular opening of 45 cm diameter for the boiler to sit on in order to prevent heat loss from the stoker and to enable heat to get to the content of the boiler. On the boiler there is a relief valve attached towards the top of the boiler to reduce pressure build up during fermentation and also to avoid explosion of the fermenting mash.

The distillation column is made up of stainless steel inserted and welded unto the boiler to allow gaseous ethanol during heating after fermentation to be properly channeled for collection. The unit is in two pieces, the first piece is a 6 cm x 20 cm column welded directly on the boiler while the second piece a 3.6 cm x 25 cm has a retainer welded at it's base with and packings of broken glasses packed to half of it's length to allow for adequate reflux. The two columns are properly lagged with cotton flux and foil to prevent heat loss and to allow for complete distillation of the gaseous ethanol from the boiler.

The condenser is a unit made of an outer jacket of 40 cm x 13 cm with two openings at opposite ends to allow water to enter and leave the jacket during cooling. While inside the jacket is a coil of soft copper pipe of diameter 0.8 cm with a total of 13 coils and a spacing of 1.5 cm in between. The copper coil is connected to a T-joint of 3 cm x 2 cm attached to the top of the distillation column to allow for the gaseous ethanol from the distillation column to be condensed as it passes through the copper pipe inside the outer jacket of the condenser for collection of the liquid ethanol. The condenser is also inclined at an angle of 45ºC for the liquefied ethanol to flow out easily and quicker.

Experiment Design follows a 2-way classification analysis as experimental design was adopted for the statistical analysis. This follows a 2-treatment effect (size and measured parameters) in a factorial design with RCBD (Randomized Complete Block Design) with no replications (because of the size of the experiment) per experimental unit (Obi, 1985). This experimental unit comprises 2 factors (three feedstock sizes) and 4 measured parameters (Volume of ethanol, Density, Ethanol Concentration and Refractive index) in each of the 3 varieties, giving a 36 treatment combinations for the three different experiments as follows:

- Cassava chips versus 4 measured parameters
- Grated cassava versus 4 measured parameters
- Sieved cassava liquor versus 4 measured parameters

The feedstock three sizes in any of the three variety combinations form the levels of factor A while the four measured parameters form the levels of factor B. These tests were carried out in Makurdi, Nigeria and completed early part of 2010.

RESULTS AND DISCUSSION

The data obtained from the different tests were organised for ANOVA statistical analysis as shown on Table 2.

From the results of the test runs on Table 2, it is observed that in all the three varieties, the test runs for cassava chips gave the least volume of ethanol sample produced due to the less exposed surface of the material. As a result, complete break down of all the starch in the sample was not achieved. The percentage of ethanol by volume (strength/concentration) was also the least among the three varieties used in the experimentation.

The percentage of ethanol by volume increased as the conditioned cassava when the experiment changed from the cassava chips to the sieved cassava liquor. This trend was also observed for the refractive index, showing that more cassava starch is exposed when completely grounded and sieved leaving out liquor than when grated and/or cut into chips.

The table similarly showed that Akpu, the local variety gave the highest yield of ethanol than the two exotic varieties. This may be as a result of the local variety (Akpu) being used solely as a source of starchy carbohydrate in food components which are predominantly consumed in Nigeria. While these other two varieties are improved hybrids used specifically for making "garri" and for the production of flour meant for baking purposes. Their choice for these roles is because they have less starch content.

For all the varieties, it was observed that the densities of the samples decreased as the percentage of ethanol by volume (strength) and refractive index increased.

In summary, the local variety known as Akpu yielded more ethanol when used as chips, grated or sieved cassava liquor than all the other varieties in their various size conditions. One remarkable development in this work to note is that, in whichever size condition the process is to be undertaken, the cassava feedstock must be processed fresh, else, the distillation yield will be adversely affected resulting in the waste of major experimental requirements like enzymes and yeast. Data were also generated when the configuration of the condenser and the packing size in the distillation column were changed.

Effect studies on the measured parameters: The effect of size and variety of cassava samples on the total volume of sample collected, density of sample collected, percentage ethanol by volume of sample collected and Refractive index are presented on Table 2 while the resulting analysis of variance (ANOVA) are summarized on Table 3 (A-D). Table 4 is the summary of data generated when the configuration of the condenser was changed as well as the 'packing size' in the distillation column.

Total volume of sample collected: The total volume of sample collected at different stages as shown on Table 2 indicate that for each of the varieties, there were variations on the quantity of ethanol collected at the end of the distillation. When these variations were subjected to analysis of variance (ANOVA), as on Table 3A, it showed no significant effect at both 5 and 1% levels of probability for the variety but conditioned cassava sample was found to be significant ($p<0.05$). This implies that the different varieties of the feedstock do not influence the quantity of ethanol to be obtained in the course of the distillation more than the way the cassava samples were

Table 2: Data arrangement for analysis of variance (ANOVA)

		Conditioned samples		
Parameters measured	Varieties used	3-5 mm cassava chips	Grated cassava	Sieved cassava liquor
Total volume of sample distilled (ml)	98/2205 Variety	620	1080	1256
	305070 Variety	620	950	1080
	Akpu Local Variety	585	1280	1985
Density of sample distilled	98/2205 Variety	0.9694	0.9596	0.9502
	305070 Variety	0.9705	0.9596	0.9431
	Akpu Local Variety	0.9641	0.9502	0.9352
Ethanol by volume (%) (Ethanol Conc.)	98/2205 Variety	19.50	27.00	32.00
	305070 Variety	19.00	27.00	36.00
	Akpu Local Variety	23.00	32.00	40.00
Refractive index	98/2205 Variety	51.68	67.00	73.60
	305070 Variety	51.68	67.00	82.80
	Akpu Local Variety	57.00	73.60	92.00

Table 3: The ANOVA tables for the effects of Cassava size and varieties on total volume, density, % ethanol and refractive index of samples collected during distillation

					F-tab	
Source	df	SS	MS	F-cal	5%	1%
A - Volume of sample						
Varieties	2	259208	129604	2.014393^{NS}	6.9443	18
Conditioned Samples	2	1050818	525409	8.16626*	6.9443	18
Error	4	257356	64339			
Total	8	1567382				
B - Density of Sample						
Varieties	2	0.000164	8.2E-05	10.7769*	6.9443	18
Conditioned Samples	2	0.000952	0.000476	62.4151**	6.9443	18
Error	4	3.1E-05	7.6E-06			
Total	8	0.001147				
C - % Ethanol						
Varieties	2	50.38889	25.19444	12.95714*	6.9443	18
Conditioned Samples	2	360.7222	180.3611	92.75714**	6.9443	18
Error	4	7.777778	1.944444			
Total	8	418.8889				
D - Refractive Index						
Varieties	2	161.1108	80.55538	5.7460^{NS}	6.9443	18
Conditioned Samples	2	1294.144	647.0722	46.1556**	6.9443	18
Error	4	56.07751	14.01938			
Total	8	1511.333				

NS: Not significant; *: Significant @ 5%; **: Highly significant @ 1%

conditioned. When however, the packing size in the distillation column was altered, the total yield of the ethanol was found to have increased significantly as shown on Table 4 subjected to Analysis of variance (ANOVA) as indicated on Table 5A, the cassava varieties were found to be highly significant ($p<0.01$) while the new packing was only significant ($p<0.05$). This implies that both parameters influenced the volume of ethanol collected not at equal strength.

Density of sample: On Table 2, the densities of the entire samples collected at each stage were taken and from the analysis of variance shown on Table 3B, it shows that there was a decrease in density as more samples were collected from the different sizes of a given feedstock which was also decreasing in size. And statistically, it was observed that there is a highly significant ($p<0.01$) effect of the size of the cassava samples on the density of ethanol distilled at 1%. That same analysis of variance on Table 3B however showed a significant ($p<0.05$) effect of the varieties of feedstock. The density decreases with the decrease in size of the feedstock, while the density of the varieties decreased from the improved hybrid stock of 305070 Variety, to 98/2205 Variety and then the least Akpu Local Variety. This is due to the fact that ethanol has lower density and as such will lower the density of the sample with more percentage of ethanol. In a similar trend, the values of density observed were decreasing as the sizes of packing in the distillation column were increasing. Statistically, packing size was found to be significant ($p<0.05$) as shown on the ANOVA results of Table 5B while the varieties were found not to be significant.

Percentage ethanol collected from sample: The percentage of ethanol in the entire samples collected (not dehydrated after collection) on Table 2 shows the percentage of ethanol in the sample increasing as the sizes of feedstock decreased from 3-5 mm Cassava Chips to Grated Cassava and then to Sieved Cassava liquor in that

Table 4: Data Arrangement for Analysis of Variance (ANOVA) when the distillation column packing and configuration of the condenser changed

Parameters measured	Varieties used	Size of packing used: 3-6 mm	6-8 mm	8-10 mm
Total volume of sample distilled(ml)	98/2205 variety	925	1256	1300
	305070 variety	936	1080	1120
	Akpu local variety	1580	1985	2010
Density of sample distilled	98/2205 variety	0.9571	0.9504	0.9392
	305070 variety	0.9504	0.9431	0.9072
	Akpu local variety	0.9392	0.9352	0.8865
Ethanol by volume (Ethanol Conc.) (%)	98/2205 variety	28.00	32.00	38.00
	305070 variety	32.00	36.00	53.00
	Akpu local variety	38.00	40.00	61.00
Refractive index	98/2205 variety	64.40	73.60	87.40
	305070 variety	73.60	82.80	121.90
	Akpu local variety	87.40	92.00	140.30

Table 5: The ANOVA tables for the effects of Cassava size and varieties on total volume, density, % ethanol and refractive index of samples collected during distillation with a new packing arrangement

Source	df	SS	MS	F-cal	F-tab 5%	1%
A - Volume of sample						
Varieties	2	1161398	580699	99.93386**	6.9443	18
Conditioned Samples	2	196044.7	98022.33	16.86889*	6.9443	18
Error	4	23243.33	5810.833			
Total	8	1380686				
B - Density of sample						
Varieties	2	0.001229	0.000615	5.343678^{NS}	6.9443	18
Conditioned Samples	2	0.002495	0.001247	10.84615*	6.9443	18
Error	4	0.00046	0.000115			
Total	8	0.004184				
C - Ethanol (%)						
Varieties	2	281.5556	140.7778	7.63253*	6.9443	18
Conditioned Samples	2	550.2222	275.1111	14.91566*	6.9443	18
Error	4	73.77778	18.44444			
Total	8	905.5556				
D - Refractive index						
Varieties	2	1489.429	744.7144	7.63253*	6.9443	18
Conditioned Samples	2	2910.676	1455.338	14.91566*	6.9443	18
Error	4	390.2844	97.57111			
Total	8	4790.389				

NS: Not significant; *: Significant @ 5%; **: Highly significant @ 1%

order, indicating that the size of feedstock has high significant effect ($p<0.01$) on the percent of ethanol in all of the samples. This was further confirmed from the analysis of variance carried out and reported of Table 3C. The ANOVA from Table 3C showed that Ethanol concentration obtained from the distillation is significant ($p<0.05$) with the different varieties. Similar trend was also observed when the packing size was changed in the distillation column as shown on Table 4. The ANOVA result of Table 5C confirmed this observation where both parameters were found to be significant ($p<0.05$).

Refractive index: Table 2 shows that Refractive index of the sample collected increased with decrease in size of feedstock. This was however not found to show any significant effect at both 5 and 1% levels of probability. The varieties were found to be highly significant ($p<0.01$) as shown on Table 3D. When the configuration was changed, increased values of refractive index were also observed as indicated on Table 4 while the ANOVA results on Table 5D showed a 5% significant effect on both parameters.

CONCLUSION

A 3.2 L per batch bio-ethanol plant was designed, fabricated, and tested. Quantitative analysis using refractor-metric method showed that the sieved cassava liquor contained more ethanol while the grated and cassava chips gave the least in that order. The local variety known as Akpu when compared with the 98/2205 improved variety and the 305070 exotic variety, in the three levels of processing showed that Akpu gave better yield of ethanol than the other two varieties. This trend of performance was also repeated when the configuration of the condenser and the packing size in the distillation were changed.

It is evident therefore that Nigeria has the capacity to produce bio-ethanol from cassava using local technology and therefore will be in better stead to empower the rural producers of Cassava.

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