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Modelling and Optimization of Ethanol Production from Cassava (*Manihot Esculenta*)

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ABSTRACT

The need for ethanol optimization from locally sourced material like cassava informed the use of cassava samples to produce ethanol. Two sets of micro-organisms were used for cassava fermentation: Yeast (*saccharomyces cerevisiae*) obtained from fresh palm wine and *zymomonasmobis* obtained from decaying oranges. A combination of both the yeast and *zymomonasmobis* was also prepared as a single solution. The organisms were inoculated into the cassava starch substrate to enhance fermentation for six days. The quantities of starch that were fermented ranged from 5g -25g and the highest volume of ethanol produced was 25cm^3 when 10g of starch was inoculated with *zymomonasmobis.* Distillation was used to determine the volume of ethanol that was produced. The densities obtained were compared to the density of standard ethanol and the results obtained agreed with the specification of standard ethanol. Design and model equations for ethanol production optimization were developed and the results obtained correlated with the experimental results.
Keywords : Cassava, Ethanol Production, Microorganism, Fermentation, Starch, Yeast, Optimization.

I. INTRODUCTION

Cassava (*Manihot esculenta*) that belongs to the Family of *Euphorbiaceae* is a perennial crop. In different geographical regions, it has other names depending on where it is found. It is called *Yaccu* in central America, while in India it is called *tapioca*, Brazil calls it mandioca and most Africa countries call it cassava. In Africa it is cultivated mainly in the tropical region, while it is cultivated at the equatorial belt in Latin America and Asia. The crop serves as edible starch-reserving roots for human and animal feed as staple food for millions [1] [Akande, 2009]. Cassava cultivation does not require much technicality as it is very easy to plant and requiring low input materials. Poor farmer are largely involved in its cultivation on marginal lands, as it is often called the crop of the poor. Cassava plays an important role in human's life as income generation crop and for food security. When cooked, it is tasteless, odourless and has high degree of whiteness. Cassava starch when extracted can be modified into food and non-food materials like textiles [2][3]. Cassava and other carbohydrates has also been used for Production of biofuel [4] e.g. bio-ethanol in adhesives such as Holt melt glues, envelopes etc, cosmetic production like dusting powders and make-up and soap fillers, in pharmaceuticals as tablet binders, coatings and dispersant for medicine, in biomass fuels as briquette binders, in the construction industry as concrete block material binder like binders in asbestos, clay/limestone binding, paint filler, Gypsum etc and in Paper industry for sizing.

Fermentation in most process industry and laboratory has been used for the chemical transformation of complex sugar and carbohydrate or organic substance into simple sugars or compounds by the action of

enzymes. This industrial process employs raw materials transformation by the controlled action of carefully selected strains of organism into definite products. Fermentation is classified as a biological process of ethanol production [3], where sugar is broken down into alcohol and carbon (IV) oxide in the presence of an enzyme as shown in equation 1 and 2.

$$2C_2H_5OH_{(aq)} + \ CO_{2(g)} \qquad (1)$$

Sugary juice including grapes, oranges, pineapple, paw-paw is extracted and fermented directly to ethanol using yeast. This may involve the conversion of the sugar to ethanol by the *zymase*, enzymes which are contained in the yeast. Ethanol is then collected by distillation at 78°C.

$$C_6H_{12}O_6 \xrightarrow{Zymase} 2C_2H_5OH_{(aq)} + \ CO_{2(g)} \qquad (2)$$

Other starch containing substances including potatoes, maize, rice, cassava, etc can also be used as feedstock. The starch $(C_6H_{10}O_5)_n$ is first extracted, by crushing and pressure- cooking the material and then the malt (partially germinated barley) is then added at 50-60°C for one hour. *Diatase* enzyme in malt converts the starch to maltose [n-($C_{12}H_{22}O_{11}$)] [5]. *Zymomonasmobilis* has also been used to ferment cassava to ethanol. This process has shown higher ethanol yield.

Ethanol form biological sources also known as, *Bio-ethanol* is a product of "microbiological way of sugar conversion into ethanol and carbon dioxide (CO_2). Ethanol is a high octane fuel and today has replaced lead as an octane enhancer in petrol [6] and currently adopted as principal fuel that can be used as petrol substitute for vehicles [7]. This makes Bio-ethanol a renewable energy as a product of fermentation of complex and simple sugar. Energy crops such as cane sugar, cassava and cassava products are feedstock of sugar required for ethanol production. Further, maize, wheat crops, sorghum, millet, crop husk and peels, waste straw and sawdust are materials for bioethanol production. Ethanol is also obtained by chemical process of reacting ethylene with hot steam.

This study shall focus on the raw material such as cassava, decaying oranges and palm wine for preparation of organisms and production of ethanol. The research is aimed at developing a model for the production of ethanol and optimizes it with objectives of starch production from cassava and to identify microorganism that would give the maximum yield of ethanol

II. METHODS AND MATERIAL

2.1 Preparation of organism

Freshly tapped palm wine was taken to the microbiology laboratory to prepare the yeast called *saccharomyces cerevisiae* from palm wine. Decaying oranges were also taking to microbiological laboratory in the University of Port Harcourt to obtained *zymomonasmobis*.

2.2 Peeling and Grinding of Cassava

The freshly harvested cassava tubers were obtained from Okro market, Iriebe, in Port Harcourt, Nigeria. The tubers were peeled, washed and grinded with a grinder; thereafter blended with an electrical blender in order to obtain the starch. The blended cassava mash was filtered to remove unwanted particles.

2.3 Hydrolysis

A set of 5g, 10g, 15g, 20g and 25g of the starch was weighed and sterilized. Distilled water was added to make it up to the mark of 100ml for each set. The flasks were covered with sterile cotton wool wrapped with aluminium foil to avoid contamination.

2.4 Sterilisation

The mixtures were sterilized in an autoclave at 121°C for 20 minutes. The mixtures were also allowed to

cool again and sterilized distilled water was added to make up the mark of 100ml due to water loss by evaporation.

2.5 Enzymes Hydrolysis and Fermentation

Two drops of freshly prepared yeast (*saccharomyces cerevisiae*) was inoculated into the set of 5g, 10g, 15g, 20g and 25g of each substrate mixtures. Two drops of *zymomonasmobis* were added to another set of the substrate mixtures 5g, 10g, 15g, 20g and 25g after water has been added to make up the mark of 100ml. Also two drops of the mixtures of yeast and *zymomonasmobis* were added to another set of the mixtures while one set of 5g of mixture was used as the control. All the sets of the mixtures were shaken to obtained homogeneous mixtures and they were inoculated at 26°C ± 2°C for six days.

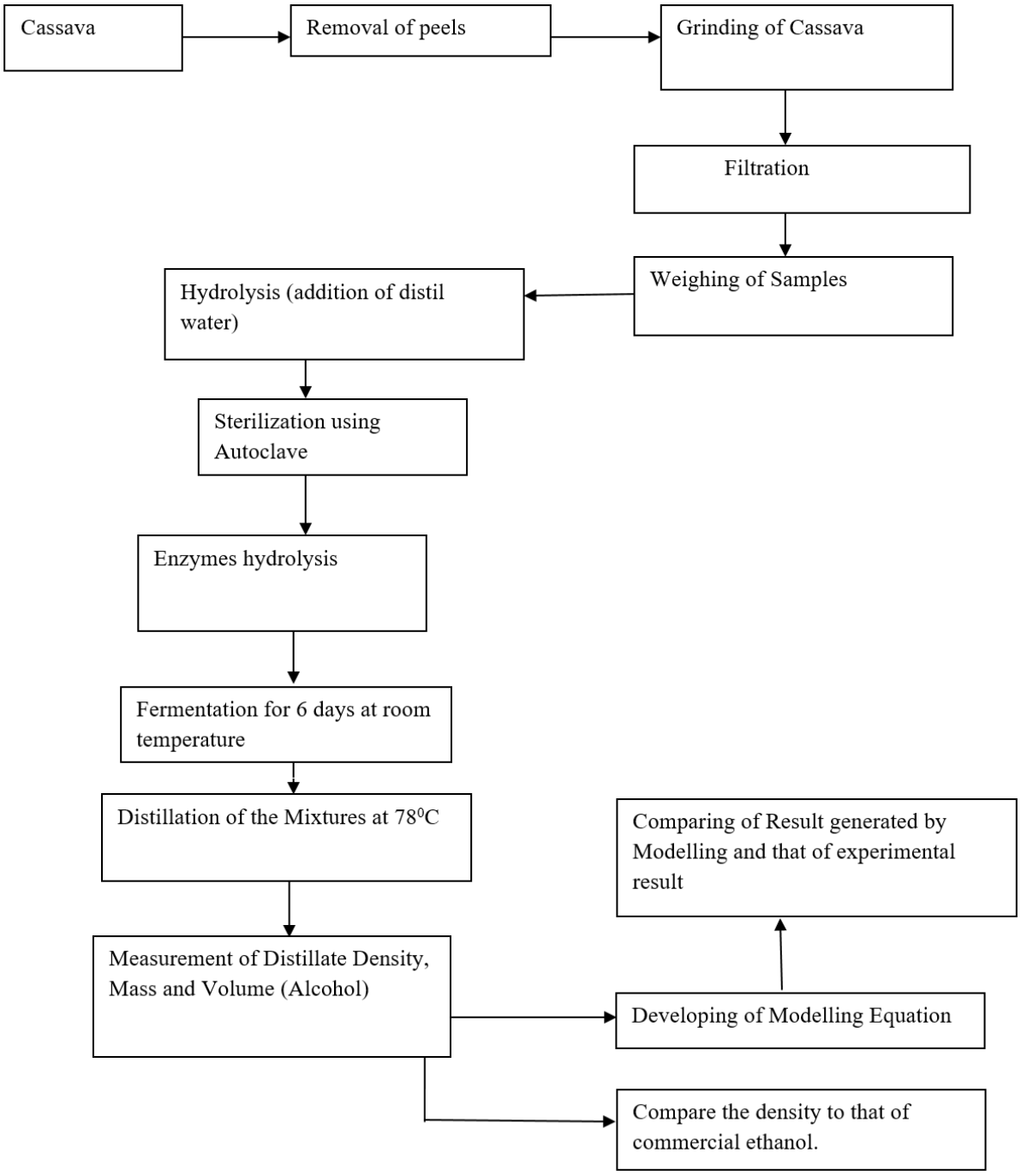

Figure 1: Process Block Flow Diagram

2.6 Distillation

The mixtures were taken to University of Port Harcourt Chemistry Laboratory for distillation. The fermented broth liquids were transferred into round bottomed flasks and placed on a heating mantle fixed to a distillation column fitted to running water taps. Other flasks were fixed to the distillate at 78^{0}C (standard temperature for ethanol production).Anti-bombing chips were dropped into the flasks to avoid explosion of the flasks. This was done for all samples of the fermented broth.

2.7 Determination of Quantity of Ethanol Produced

Molecular seeds were added to the distillate collected to absorb water that would have managed to escape with the distillate. The mass of the distillates were weighed and the volumes were measured with a measuring cylinder. The process is summarized with the flow diagram in Figure 1:

2.8 Modelling and optimization

Assumptions

(1) Unsteady state
(2) Constant Temperature
(3) Volume of CO_2 was negligible
(4) Initial concentration of starch is zero.

Modelling Equation

(Input material)- (output material) + (rate of reactant loss to chemical reaction) = Rate of accumulation (3)

$$C_6H_{10}O_5 + H_2O \rightarrow C_6H_{12}O_6 \quad (4)$$

$$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2 \quad (5)$$

$$rv = \frac{dN}{dt} \quad (6)$$

$$Where\ concentration\ (C) = Mole(n)/Volume(v)$$

$$r = \frac{dC}{dt} \quad (7)$$

For the irreversible kinetic reaction,

$$r = k\frac{[C_2H_5OH]^2[CO_2]^2}{C_6H_{12}O_6} \quad (8)$$

Neglecting the concentrating of CO_2

$$r = kC^2 \quad (9)$$

Where, C= ethanol concentration

$$kC^2 = {}^{dC}/_{dt} \quad (10)$$

$$dt = {}^{dC}/_{kC^2} \quad (11)$$

Integrating Eqn (11) $\Rightarrow \int dt = \int \frac{dC}{kC^2}$

$${}^{1}/_{C} - {}^{1}/_{C_0} = kt \quad (12)$$

$${}^{-1}/_{C} = kt \quad (13)$$

To determine the volume of ethanol, recall that

$$Conc. = \frac{mole}{volume}, \Rightarrow C = \frac{n}{V} \quad (14)$$

Substitute Equation (10) into Equation (9) thus,

$$\frac{V}{n} = -kt \quad (15)$$

$$V = -knt \quad (16)$$

Recall that

$$Mole(n) = \frac{mass}{molar\ mass} \quad (17)$$

$$\text{Thus, } V = \frac{-kmt}{molar\ mass\ of\ ethanol} \quad (18)$$

Unit of k which is slope is $mol^{-1}cm^3min^{-1}$.It is obtain by plotting the graph of (-1/C) against time.

$$k = \frac{change\ in\ (-1/C)}{change\ in\ time}$$

III. RESULTS AND DISCUSSION

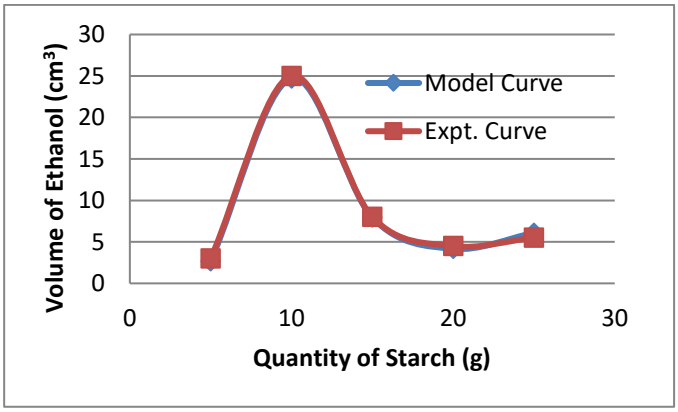

Figure 1: Experimental and Modelling Volume against quantity of starch using zymomonasmobis

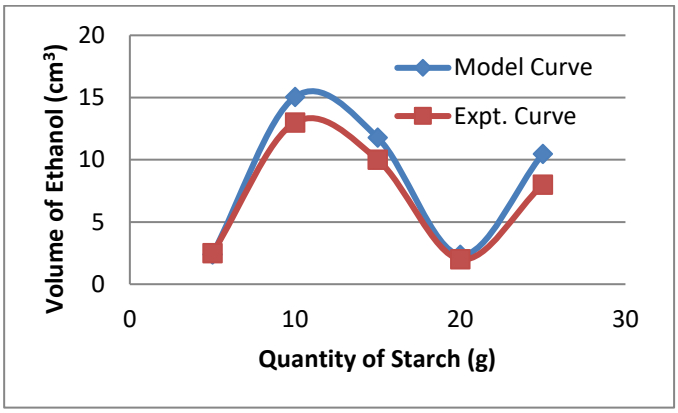

Figure 2: Experimental and Modelling Volume against quantity of starch using saccharomyces cerevisiae

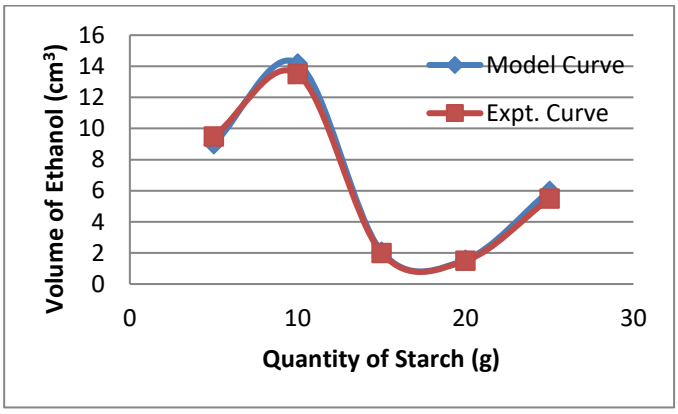

Figure 3: Experimental and Modelling Volume against quantity of starch using Z. M. & S. C

The results Figure 1shows that when two drops of *zymomonasmobis* was added to 10g of starch and 90ml of distilled water, the highest volume of ethanol of 25.0cm³ was obtained. This implies that to every two drops of *zymomonasmobis* added to 10g of starch, 90ml of water was the required volume. Also, the highest weight of ethanol was obtained at the same point in all the experiments. The density of ethanol obtained was 0.8971g/cm³ compared to the density of standard alcohol which is 0.801g/cm³. The error in density is 0.096g/cm³which is still acceptable. The increase in volume from 3.0cm³ to 25.0cm³ and subsequent decrease to 4.5cm³showed the optimum condition favourable for ethanol production using *zymomonasmobis* was 10g of starch in 90ml of water. Similarly, in Figure 2, the highest volume of ethanol of 13.0cm³ was obtained when two drops of *saccharomyces cerevisiae* (yeast) was added to 10g of starch in 90ml of distilled water. The density and weight of the ethanol at this point was 0.8786g/cm³ and 11.4222g respectively. The weight and density of the ethanol produced are 11.9051g and 0.8819g/cm³ respectively. The lowest volume of ethanol produced during the experiments was 1.5cm³ when two drops of *zymomonasmobis* and *saccharomyces cerevisiae* mixture was added to a mixture of 20g of starch in 80ml of distilled water. More so, when 5g of starch was mixed with 95ml of water, the density obtained was much closer to the density of standard ethanol. The control sample in Table 4.4 gave a perfect density of 0.8023g/cm³ which is close to that of standard alcohol of 0.801g/cm³.

Furthermore, Figure 1 to Figure 3 showed close relationship between the experimentally obtained values and the developed model equation. The plotted graphs of Figure 4.1 and Figure 4.3 almost superimpose unto the model equation values which revealed the degree of accuracy of the mathematical model developed.

Figures 1 to Figure 3 showed that the highest volume of ethanol produced is 25.0cm³ when *zymomonasmobis* was used as microorganism. Thus, *zymomonasmobis* is a good organism that can be used to optimize production of ethanol from cassava starch. Figures 4.1 to 4.3 show a close relationship between

the model equation developed and the experimental volume of ethanol produced.

IV. CONCLUSION

From the investigation on the fermentation of cassava using organisms from decaying oranges and palm wine for production of ethanol, following conclusions were drawn

- A good percentage of starch-wet base (35%-47%) was produced from cassava.
- When two drops of *zymomonasmobis* was added to 10g of starch in 90ml of distilled water, the highest volume of alcohol, 25cm^3 was obtained in the experiment.
- *Zymomonasmobis* is the microorganism that gave the optimum volume of ethanol.
- Ten grammes of starch in 90ml of distilled water are a good mixture and ratio that can produce the highest volume of alcohol when *saccharomyces cerevisiae* and *zymomonasmobis* are mixed together.
- The mathematical model equation developed had a good correlation with the experimentally.

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