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Production and characterization of bioethanol from cassava peel: alternative energy source

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ABSTRACT

This study is focus on the conversion and optimization of cassava peel to bioethanol. Classical optimization technique was employed in studying the process variables effect of temperature, acid concentration, cassava peel concentration and time of hydrolysis of cassava peel to glucose. Optimum glucose yield of 78mg/ml was obtained at the temperature of 100^{o}C, acid concentration of 0.40mole, cassava peel concentration of 2g/L and hydrolysis time of 45 minutes. After which the glucose obtained from hydrolysis of cassava peel was fermented to produce bioethanol using a classical optimization technique for the effects of pH, temperature, yeast concentration, glucose concentration and fermentation time on bioethanol yield. Results obtained revealed that the optimum yield of 45.50% of bioethanol was obtained at the pH of 5, fermentation temperature of 35^{o}C, yeast concentration of 10%, glucose concentration of 100g/L and fermentation time of 6 days. The bioethanol produced from cassava peel was characterized to determine the kinematic viscosity, specific gravity, flash point, refractive index, distillation property, sulphur content, octane number and water content. Results obtained on the properties of the bioethanol produced revealed that that the bioethanol produced shows corresponding fuel properties recommended by ASTM, thus providing a good alternative fuel of clean and renewable resource and establishing the potential for bioethanol commercialisation.

Introduction

The source of global energy have experienced transition for more than two decades initiating from wood as mankind had relied on burning wood either for cooking food or to keep warm, as a result highlighting the age long utilization of wood as biomass resources [1]. Demirbas (2003) [1] reported that transition from wood biomass led to coal, nuclear energy to oil and from oil to natural gas. It has been reported by Frauke and Mitchell (2011) [2] that the persistent utilization of energy, fundamentally of fossil based resource had characterized the perceived daily increase of carbon dioxide produced and emitted into the atmosphere. Douglas *et al.* (2008) [3] opined that the carbon dioxide emitted to the earth's atmosphere accumulates in excess over a lengthy moment in time and also reported that increase in carbon dioxide deposition content, leads to the increase on the warmth of the planet and global warming effect. A renowned modern remedy to global warming was proposed by Roger (2006) [4] who projected for an alternative energy to serve as a replacement and retrofit of the current fossil based energy technologies with renewable energy technologies that abound with comparable or better performance but do not emit carbon dioxide and other toxic gases. Abdulkareem *et al.* (2012) [5] made it clear that the search for an alternative energy resource is to ensure energy source with reduction in the emission level, enhanced recyclability, improved functionality and improved ability to get the environment rid of hazardous emissions. It was reported by William (2010) [6] that the utilization of biofuels significantly reduces the emission of greenhouse gases into the atmosphere and thus enhancing green technology actualization. Bioethanol and biodiesel are the two characteristic biofuels presently dominating global attention in ensuring clean and sustainable alternative energy efficiency [7-8]. Bioethanol which is the major product of fermentation is obtained through biochemical technological conversion of sugar, starch and cellulosic biomass feedstocks in the presence of an enzyme. Ball (2007) [9] considered the biochemical technology of bioethanol production method as the perfect route for alternative energy production. According to Mustafa et al., (2008) [10], most of the bioethanol are produced in the United States through the fermentation glucose from corn. Mustafa et al. (2008) [10] also reported that the production of bioethanol in Brazil is principally from sugar cane sucrose. Although bioethanol had been extensively acknowledged to be a perfect substitute to the present energy resource, the product is still commercially unavailable especially in the developing countries such as Nigeria. The non-availability of bioethanol at commercial quantities can be attributed to the production of bioethanol in the recent times from starchy and sugar feedstocks. These sugar and starchy feedstocks are very important in human nutrition. The high demand for these feedstocks both for feeding and bioethanol production led to the price increase of the feedstocks and the resultant increase in the price of bioethanol in the global market. An alternative feedstock to the edible feedstock must not only be a clean, renewable, abundant and environmentally friendly but be cost effective to enhance its viable competition in the global market.

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There is an increasing call by the civil societies on government to stop the production of bioethanol from food crops as a measure to avoid encroaching into global food crisis. Besides, these food crops are very essential for human consumption and the continued conversion of these food crops to bioethanol may not be sustainable.

The present research and development in the area of the production of bioethanol as an alternative energy resource to the existing fossil fuels therefore focussed on the utilization of agricultural waste such as cassava peel. The high starch content of cassava makes it an abundant source of starchy feedstock for bioethanol production [11]. Besides the use of starch obtained from cassava for the production of bioethanol which competes with cassava food chain supply, cassava peel waste rich in cellulose material is also an important raw material for the production of bioethanol [12]. Cassava peel often referred to as an agricultural waste had in recent times proven to be an abundant source of bioethanol production from its rich cellulosic materials [13]. The fact that cassava peel is an agricultural waste and cannot be utilized for nutritional purpose makes its use as a fuel source very attractive. The utilization of cassava peel as a feedstock in the production of bioethanol is also favoured by the abundant availability of the peel as a waste that is difficult to manage. The use of cassava peel in bioethanol production underscores the great contribution of converting biomass waste into wealth and enhancing waste management, cost efficiency and environmental sanitation [14]. Though cassava peel can be used to produce bioethanol, it however requires additional processing to breakdown the cellulosic materials into sugars [13]. Bioethanol produced from cellulose is referred to as cellulosic bioethanol, and it involves four basic steps, such as pre-treatment, hydrolysis, fermentation and distillation. Pre-treatment which is the first step in the process of converting cellulosic material into bioethanol is aimed at breaking the rigid structure of the lignocellulose for easy access to the lignin, hemicellulose and cellulose molecules inside the lignocellulose [12]. Second step entails the hydrolysis of the treated feedstock to convert the cellulose and hemicellulose to glucose chains [12]. This is followed by the fermentation of the hydrolyzed sample with yeast to produce bioethanol while the final stage of the process of converting the biomass material into ethanol is the distillation process [15]. Unlike the other renewable energy resources, biomass can be converted directly into liquid fuels called biofuels which are used for transportation purposes [16]. This present study is required to determine the optimal conditions such as pH, temperature, acid concentrations, enzyme concentrations, substrate concentrations and time for hydrolysis and fermentation processes of converting cassava peels to bioethanol.

Materials and Methods

Materials

The material utilized in this work includes cassava peel (locally sourced), acetone (M&B, England), distilled water (laboratory), diethyl ether (BDH, England), hydrochloric acid (BDH, England), sodium hydroxide (M&B, England), *Saccharomyces cerevisiae*. The equipments used are Abbe refractometer (Gallenkamp, England), autoclave (Citizen, India), batch improvised fermenter, Beakers (Pyrex, England), cooling bath (Citizen, India), digital pH meter (Rex pHs), digital weighing balance (Citizen, India), distillation set up (Setastill, Germany), distillation flask (Pyrex, England), erlenmeyer/conical flask (Pyrex, England), flash point tester, flat bottom flask (Argonne, USA), funnel (OK plastic, Nigeria), FTIR spectrophotometer (Shimadzu, Japan), hydrometer (Pyrex, England), incubator (Stuart, Germany), magnetic stirrer (Gallenkamp, England), magnetic heater (Gallenkamp, England), measuring cylinders (Pyrex, England), distillation tube (Pyrex, England), octane analyser (Stanhope seta), oven (Stanhope seta), sulphur analyser (Horea(SLFA-2800), thermometer (Pyrex, England), thermostatic hot plate (Gallenkamp, England), test tube (Pyrex, England), water bath (Stanhope seta), vacuum pump, viscometer (Stanhope seta), viscometer bath (Stanhope seta), viscometer holder (Stanhope seta)

Methodology

The effects of temperature, acid concentration, substrate concentration and hydrolysis time were studied using a classical optimization technique to ascertain the optimal experimental conditions for the production of glucose from cassava peel (cellulosic feedstock) for bioethanol production. The effect of temperatures on the hydrolysis process was investigated by varied the temperature between 30-110^{o}C with step increment of 10^{o}C. Acid concentration was also varied between 0.05-0.5moles with a step increment of 0.05mole. The effects of substrate concentration on the hydrolysis were also investigated in the range of 1.0-2.8g/L with a step increment of 0.2g/L. Hydrolysis was also varied between 5-50 minutes with step increment of 5 minutes. In each run, solutions contained 100ml of distilled water, diethyl ether and require concentrations of acid and substrate concentrations were placed in a 250ml conical flask. The hydrolysed sample was cooled and the hydrolysate filtered to separate suspended and unhydrolysed materials. The sample was neutralized with 2M of NaOH and the glucose yield measured and recorded.

The supernatants from the hydrolysis of cassava peel were transferred into another set of conical flask. The components were autoclaved at 121^{o}C for 15 minutes and were allowed to cool. The effects of the fermentation process variables such as pH, temperature, yeast concentration, glucose concentration and fermentation time were investigated. A classical optimization technique was employed to study the optimum conditions for bioethanol production using cassava peel. The sample of the fermented broth obtained from the various fermentation times was poured into a round bottom flask of a distillation set up. Distillation was performed and the distillate collected at 78^{o}C. The volume of the distillate was obtained and recorded. The produced bioethanol was then characterized to determine the kinematic viscosity, specific gravity, flash point, refractive index, distillation property, sulphur content, octane number and water content.

Results and Discussions

Optimization of Hydrolysis Process

Cassava peel was utilized as a feedstock for the conversion and optimization of bioethanol. The conversion and optimization of bioethanol involves the basic processes of hydrolysis and fermentation. The effects of the process variables on the yield of glucose produced via the hydrolysis process using cassava peel were investigated using classical optimization technique. The process variables investigated include temperature, acid concentration, substrate concentration and the period of hydrolysis. Results obtained are presented in Figures 1-4

It has been reported in literature that increase in hydrolysis temperature positively favoured the glucose yield [17-20]. However, Sathya et al (2008) [20] reported in their work that hydrolysis temperature of 105oC is the best temperature for hydrolysing cassava peel and the group opined that temperature variations will give a range of product yield depends on the type of catalyst utilized. In this present study, hydrolysis temperature was varied between 20^{o}C to 110^{o}C and the results obtained as

presented in Figure 1 indicate that the glucose yield increases from 15 mg/ml to 60 mg/ml. When the hydrolysis temperature was raised to 110°C, the yield reduced to 55 mg/ml. The reduction in the yield at this temperature can be attribute to thermal inactivation of the yeast. Hence hydrolysis temperature of 100°C gave the best yield of 60 mg/ml. Comparative study of the results obtained with the literature values indicate little variation, for instance Geetha and Krishman (2008) [21] in their work reported a best yield a best yield of 80.76 mg/ml at optimum temperature of 105°C. This variation could be attributed to the variation in the variety of cassava utilized as a feedstock and other operating parameters.

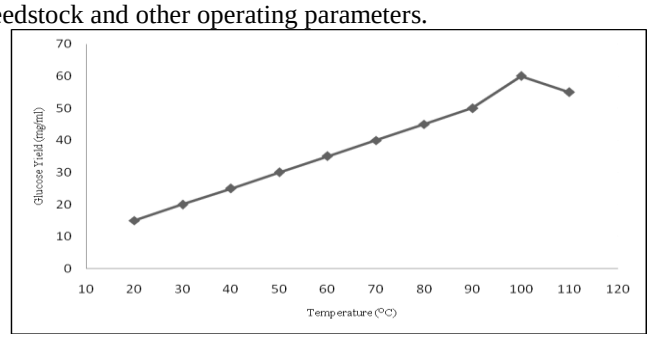

Figure 1: Effect of temperature on the yield of glucose

Also investigated in this study is the influence of acid concentration on the hydrolysis of cassava peel. For this purpose, the concentration of acid was varied from 0.05mole to 0.5mole, while the hydrolysis temperature was fixed at 100°C with substrate concentration of 2g/L and hydrolysis time of 30 minutes. Results obtained as depicted in Figure 2 shows that the glucose yield from hydrolysis of cassava increases with increase in acid concentration from 0.05mole to 0.40mole. Further increment in acid concentration beyond 0.40mole resulted into reduction in glucose yield, for instance when the concentration was increased from 0.40mole to 0.45mole, the glucose yield reduced to 55mg/ml. Further increment in acid concentration from 0.45mol to 0.50mole also resulted in reduction of glucose concentration from 55mg/ml to 50mg/ml. Reduction in the glucose yield at acid concentration above 0.45mole can be blame on the degradation and charring of glucose during the process of hydrolysis. Agu et al., (1997) [22] in their work also blame reduction of glucose yield above acid concentration of 0.40mole on the dehydrating effect of acid on cassava hydrolysis.

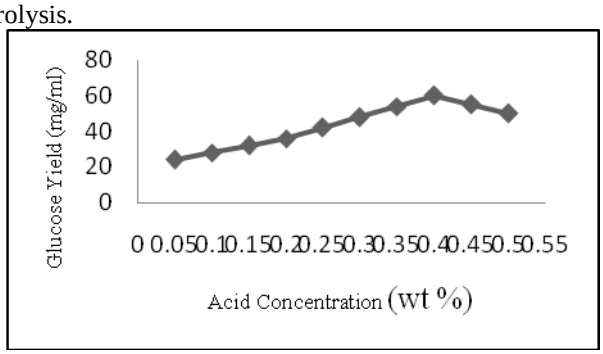

Figure 2: Effect of acid concentration on the yield of glucose

Since this study was aimed at establishing optimum conditions for hydrolysis of cassava peel, the influence of substrate concentration on the hydrolysis of cassava peel was studied and the results obtained are presented in Figure 3. The substrate concentration was varied from 0.8g/L to 2.8g/L while keeping other parameters constant. It can be observed from the results presented that increment in substrate concentration from 0.8g/L to 2.0g/L positively favoured the glucose yield, with optimum yield of 60mg/ml at substrate concentration of 2.0g/L. Results as presented in Figure 3 also revealed that increment in substrate concentration above 2.0g/L resulted in decrement in glucose yield. The optimum substrate concentration of 2.0g/L obtained in this study contradict optimum substrate concentration of 1.5g/L and 2.5g/L reported by Kanlaya and Jirasak (2007) [19] and Teerapatr et al., (2006) [18] respectively.

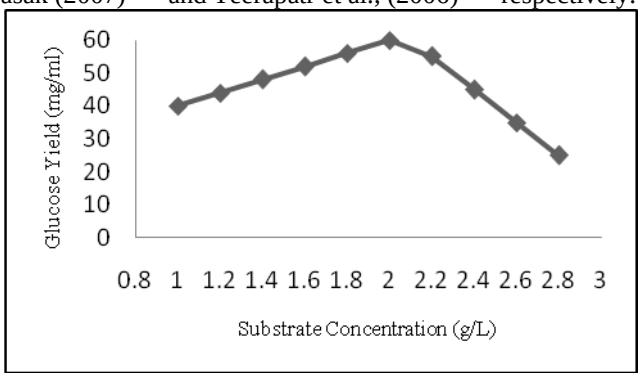

Figure 3: Effect of substrate concentration on the yield of glucose

The effect of time on hydrolysis of cassava was also study by varying the hydrolysis time between 5 minutes to 50 minutes, while keeping other parameters constant. Results obtained as presented in Figure 4 indicate that hydrolysis time of 45minutes gave the maximum glucose yield of 78mg/ml. The increment in glucose yield with time can be attribute to the glucose adaptability without degradation during this period of hydrolysis. Results also shown that glucose yield from hydrolysis of cassava peel decreased when the hydrolysis time was increased from 45minutes to 50minutes due to degradation of glucose. This pattern of results conforms to the result reported by Geetha and Krishnan (2008) [21] that reported that a sustained increase in hydrolysis time reduces glucose yield.

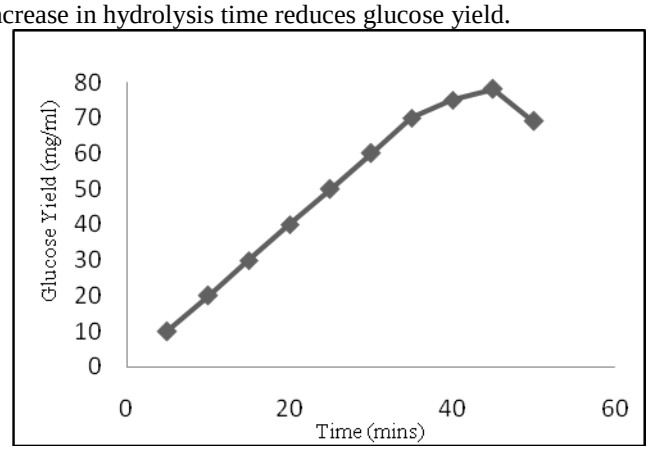

Figure 4: Effect of hydrolysis time on the yield of glucose

Kinetics of Hydrolysis Process

Theoretical yield kinetic of hydrolysis process was investigated by varying the hydrolysis temperature at different hydrolysis time and the results obtained are presented in Table 1. The data obtained were fit into first and second order reaction rate equation to determine the reaction rate that best described the hydrolysis of cassava peel.

The rate of hydrolysis of cassava peel at a constant volume in a batch reactor assuming first order reaction is;

$$\frac{dC_A}{dt} = -k_A C_A \quad (1)$$

Integrate Equation 1 with the limit of $C_A = C_{A0}$ at $t = 0$ gives

$$In\frac{C_{Ao}}{C_A} = -In\frac{C_A}{C_{Ao}} = kt \quad (2)$$

Equation can be written in terms of conversion as;

$$-In\,(1 - X_A) = kt \quad (3)$$

For second order reaction, the rate law is;

$$-\frac{dC_A}{dt} = k_A C_A^2 \quad (4)$$

Integrating Equation 4 with the limit of $C_A = C_{A0}$ at t = 0 gives

$$\frac{1}{C_A} - \frac{1}{C_{A0}} = kt \quad (5)$$

Equation 6 in terms of conversion gives

$$\frac{1}{C_A} = \frac{1}{C_{A0}} = \frac{1}{C_{A0}} \frac{X_A}{1-X_A} = kt \quad (6)$$

The data presented in Table 1were analysed to plot the values of $-In(1-X_A)$ versus time and $\frac{X_A}{1-X_A}$ versus time for first and second order reaction respectively to determine which of the order of the reaction best fit the data. The R^2 values obtained at different temperature are presented in Table 2. Results obtained indicate that the R^2 correlation coefficient values for the first order reaction are in the ranges of 0.883-0.968 while that of the second order is in the ranges of 0.842-0.872. Since the R^2 correlation coefficient for the first order reaction gave the best value above 90%, it can be theoretically inferred that the hydrolysis of cassava peel fit the first order reaction. This result agrees with the literature values, for instance Geetha and Krishnan (2008) [21], Zhisheng and Hongxun (2004) [17] and Teerapatr *et al.* (2006) [18] stated that the rate of hydrolysis varies linearly with the rate of glucose yield in their respective work and also confirms the hydrolysis process to be a first order reaction.

The slope of the plot of –ln(1-XA) against time at different temperature as shown in Equation 2 is equal to the reaction rate constant and the rate constant obtained at different temperature are presented in Table 2. The values of rate constant at different temperature were utilized to determine the activation energy (E_a) and the frequency factor (k_o) for cassava peel hydrolysis using the Arrhenius Equation (Fogler, 2008) [22].

The Arrhenius equation is given as

$$K = k_o e^{-\frac{Ea}{RT}} \quad (7)$$

Equation 7 can be linearized to obtain

$$In\ k = \left(-\frac{Ea}{RT}\right) + In\ k_o \quad (8)$$

Where

E_a, is the activation energy, R is the gas constant (J/mol.K), T is the temperature (K) and k_o is the frequency factor.

The slope and vertical intercept of the plot of lnK against 1/T as shown in Figure 5are equal to $–E_a/R$ and lnk_o respectively. From the plot, the slope is equal to -1941.8 and the intercept is equal to 1.635.

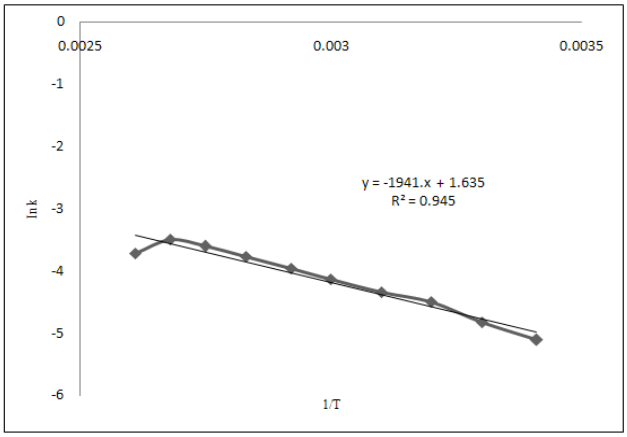

Figure 5: Plot of $In\ k$ against $\frac{1}{T}$ for Hydrolysis Process

$$Slope = -\frac{Ea}{R} = -1941.8$$

$$Ea = 1941.8 \times 8.314\ J/mol.K$$
$$Ea = 16.14\ kJ/mol$$
$$In\ k_o = 1.635$$
$$k_o = 5.13$$

The activation energy (Ea) and the hydrolysis reaction frequency factor (k_o) were found to be 16.14kJ/mol and 5.13 respectively. The value of activation energy (Ea) obtained in this study fall within the range of 8.8-44.03kJ/mol reported in literature [23-26]

Optimization of Fermentation Process

The main focus of this study is to convert cassava peel to bioethanol; the next stage of this study therefore is to convert the glucose obtained from hydrolysis of cassava peel to bioethanol through fermentation process. Classical optimization technique was utilized to study the influence of pH, temperature, enzyme concentration, glucose concentration and fermentation time on the yield of bioethanol and the results obtained are presented in Figures 7-11.

The influence of pH of the medium on the fermentation of glucose to bioethanol was studied and the results obtained are presented in Figure 6. Fogler (2008) [22] reported that the enzymes usually catalysed reactions at the mild condition of pH range of 4-9. In this study, the pH was varied between 4 to 5.8 and the results obtained as presented indicate that the bioethanol yield increases with increase in pH. However, pH of 5 gave the optimum yield of bioethanol. This result closely agrees with the results reported by Muhammad et al., (2011) [27] and Akpan et al., (2011) [28] who reported an optimum yield of bioethanol at pH of 5.12 and 5 respectively. Further increment in pH above 5 led to reduction in the yield of bioethanol. The increment observed in the yield of bioethanol from pH of 4 to 5 can be attributed to the fact that the enzymes that facilitates the metabolism of the glucose functions effectively in acidic condition.

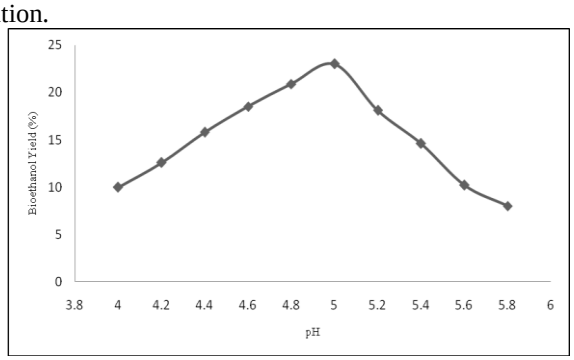

Figure 6: Effect of pH on the yield of bioethanol

Presented in Figure 7 is the influence of temperature on the yield of bioethanol. Results as presented indicate that bioethanol yield increases with increase in fermentation temperature from 13°C to 35°C. As the fermentation temperature was raised from 35°C to 60°C, results obtained as presented revealed that the yield of bioethanol was reducing. This pattern of results could be attributing to the fact that enzymes does not perform well at high temperature due to stress induced on the activity of enzymes by high temperature and low microbial activity. Literature also revealed that fermentation process above 45°C could lead to destruction of yeast cells which enhances reduction in the activity of the yeast cells. Hence, temperature of 35°C is the optimum temperature for production of bioethanol from cassava peel. It is also worth of mentioning that the results obtained fall within the values reported in literature which is in the range of 30-37°C [27, 29-33].

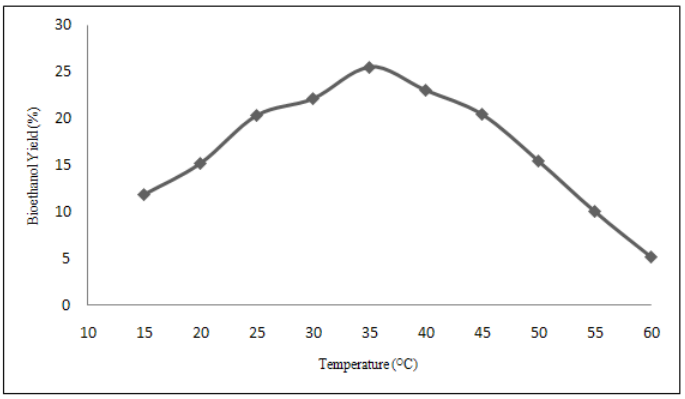

Figure 7: Effect of Temperature on the yield of bioethanol

The influence of yeast concentration on the fermentation of glucose to produce bioethanol was also studied and the results obtained are presented in Figure 8. It can be seen from the results presented that yield concentration of 10% gives the optimum bioethanol yield of 25.5%. Result also indicates that as the yeast concentration increases; bioethanol production also increases until the yeast concentration of 10%. Beyond this concentration, there is a reduction in the yield of bioethanol. The reduced percent yield of bioethanol at low yeast concentration vividly shows that low yeast concentrations were overwhelmed by the high glucose concentration in the fermentation system. The optimum yeast concentration of 10% obtained in this study shows proximity with the work of Yadav *et al.* (1997) [34], Mohammed *et al.* (2011) [27] and Kadambini and Anoop (2006) [31] who reported optimum bioethanol yield with 15 %, 10 % and 5 % respectively of yeast concentration.

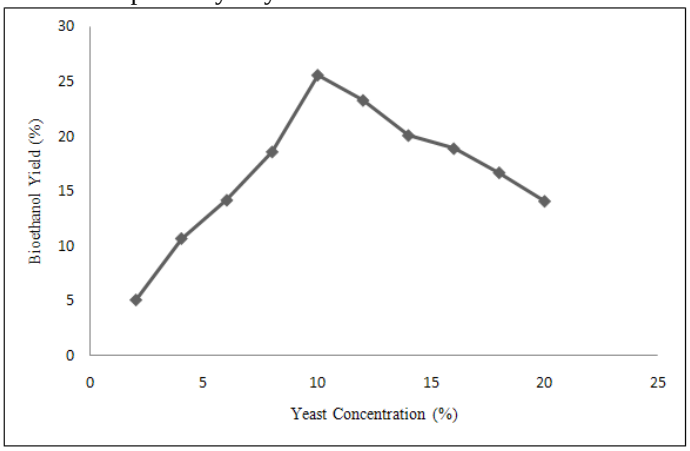

Figure 8: Effect of yeast concentration on the yield of bioethanol

Also investigated was the effect of glucose concentration on the fermentation process and the results obtained are presented in Figure 9. The glucose concentration was varied between 20g/L to 100g/L with step increment of 10g/L. Results as presented also show that yield of bioethanol increased from 8.5% at the glucose concentration of 20g/L to 25.5% at the glucose concentration of 100g/L. It can also be observed from the results presented that the yield of bioethanol reduced to 19.5% when the glucose concentration was increased from 100g/L to 120g/L. The reduction in the bioethanol yield beyond glucose concentration of 100g/L can be attribute to the possibility of hinders in the activity of the yeast at high concentration of glucose. The effects of fermentation period on the yield of bioethanol were also investigated and the result obtained is as presented in Figure 10. The fermentation period in this study was varied from 1 day to 10 days.

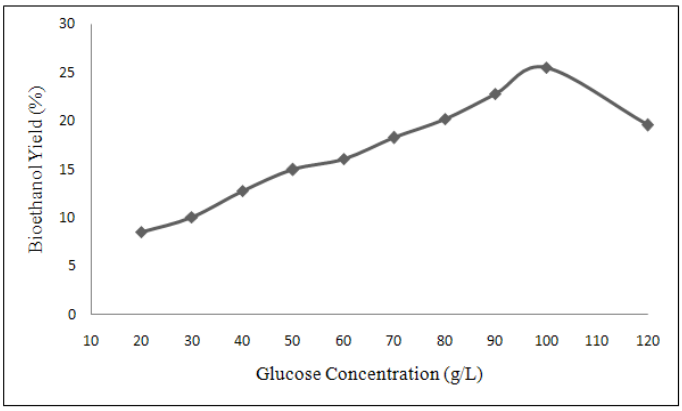

Figure 9: Effect of glucose concentration on the yield of bioethanol

It can be seen from the result presented in Figure 14 that the optimum percent yield of bioethanol was obtained at 6 days of fermentation process. The yield of bioethanol is low on the first day of fermentation and increases gradually up to the sixth day of fermentation, this can could be as a result of the fact that the yeast cells progress from the adaptability period to the exponential period of fermentation. The yield of bioethanol was equally constant at 45.50 % on the seventh days of fermentation but declines rapidly on the 8th to 10th days of the fermentation process. The result obtained in this work falls within the literature values which recommend fermentation process to be in the range of 1 – 10 days.

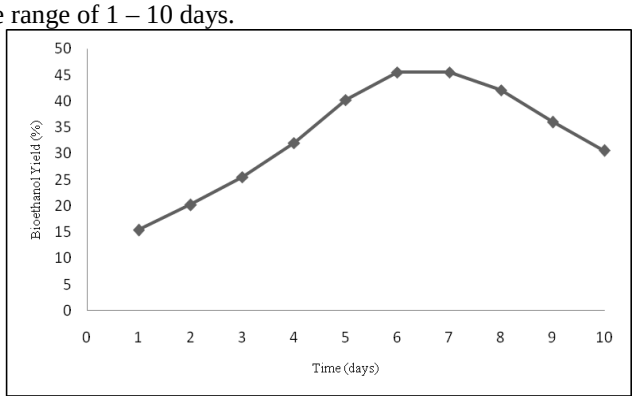

Figure 10: Effect of fermentation time on the yield of bioethanol

The result of this study equally shows similarity to the log mass plot of a biomass against the time of microbial culture obtained from the literature. Figure 10 shows that on the first day of fermentation, the yeast cells were at the lag phase where very little or no reaction occurs. Between the first and second day of fermentation, the yeast cells are at the accelerated growth stage. The third and fourth day of fermentation marks the exponential growth phase where the growth of yeast cell increased along with the yield of bioethanol. The fifth and sixth days of fermentation marks the apex of yeast growth and production of bioethanol. Between the sixth and seventh days of fermentation, the process was at the stationary phase of the fermentation. While the last stage of the fermentation process is called the decline phase during which the yeast experience stress, death and consequently results to the low yield of bioethanol. Hence the best bioethanol yield of 45.50% was obtained at the optimum experimental conditions of the pH of 5.0, fermentation temperature of 35°C, enzyme concentration of 10%, glucose concentration of 100g/L and fermentation time of 6 days

Characterization of Bioethanol

The bioethanol produced from cassava peel via the hydrolysis and fermentation process using yeast as a catalyst was analysed to determine the basic properties and compared

with the standard values of the bioethanol. Results obtained on the various analyses conducted are presented in Table4.

One of the properties of the produced bioethanol tested for was the kinematic viscosity, which is described as the opposition to flow by the liquid fuel. It is also a key factor for the correctivness of the mass transport metering necessities of engine operation (Ajayi and Akingbehin, 2002) [35]. Hence the efficient functionality of fuel engine depends on the viscosity of fuel; it also aids engine functionality in enhancing fuel flow through the injection nozzles and reducing drag and incomplete combustion of fuel fuel. Results presented in Table 4 indicate that the produced bioethanol kinematic viscosity are 1.21×10^3cst at 20°C, 0.83×10^3cst at 40°C and 0.6×10^3cst 60°C. Results obtained also indicate a decreasing trend of viscosity as the temperature was increased from 20°C. The kinematic viscosity quality of the produced bioethanol from cassava peel conforms to the set standard for bioethanol and that of the gasoline. Specific gravity (SG) is also an important property of fuel engine because of the functionality of the fuel engine is based on a volume metering system. Specific gravity measures the mass of a known volume of bioethanol at a standard temperature and compare to mass of an equivalent volume of water at that same temperature. Specific gravity of bioethanol produced were 0.750kg/L and 0.785kg/L respectively at room temperature of 27°C and standard temperature of 15°C. The specific gravity of bioethanol obtained in this work falls within the range of the specific gravity of 0.750kg/L and 0.850kg/L recommended by the ASTM standards. Results obtained also show appreciable similarity with the bioethanol specific gravity of 0.794kg/L and 0.790kg/L respectively reported by El-Dossoki (2007) [36], Tangka *et al*. (2011) [37] and Bromberg and Cohn (2008) [38], it also falls within the standard fuel range as shown in Table 4. Also tested for is the flash point of the produced bioethanol, which is described as a physical parameter that measures the potential of fuels to catch fire and explosion hazards in liquids and is also utilized for the classification and labeling of dangerous liquids [39]. Hence, flash point is the smallest temperature at which bioethanol forms lightable mixture in air near the liquid surface and a smaller flash point value makes the bioethanol simple to ignite. Flash point is also the lowest temperature during which bioethanol gives off vapor in sufficient concentrations to support ignition [37]. Liquids with flash points which are less than 37.8°C are referred to as flammable and combustible liquids (ASTM, 2011). Result obtained as presented in Table 4 shows that the flash point of the produced bioethanol is 14.2°C, which falls within the range of ASTM standards for combustible and flammable liquids but higher than the flash point of 12.5°C reported by Tangka *et al*. (2011) [37]. Another property tested for is the refractive index of the produced bioethanol which is used for the identification and the determination of the purity of bioethanol. Refractive index of bioethanol depends on the density of the sample and also affected by its temperature. Refractive index decreases as the density of the substance decreases with an increasing temperature. Refractive index of the produced bioethanol in this study is 1.362 as presented in Table 4 which is within the range specified by ASTM. Result obtained also conforms to the literature values of 1.361, 1.3614 and 1.364 respectively reported by Pradhan et al. (2008) [40], Longtin and Fan (2000) [41] and El-Dossoki (2007) [36]. The distillation property of bioethanol defines the behaviour of the product at various boiling range. The boiling point of the produced bioethanol was investigated at the initial boiling point (IBP) and end boiling point (EBP) and the results obtained are presented in Table 4. The result of this study shows similarity with the distillation values reported by Bromberg and Cohn (2008) [38]. The distillation property of bioethanol provides information about the fuel with respect to its boiling range, performance effect, storage and handling. The result of this work shows appreciable agreement with literature values and the standards of ASTM. A pure bioethanol is supposed to have a very low quantity of sulphur so as to maintain its established quality as a fuel free from sulphur. The result of the sulphur content of the produced bioethanol presented in Table 4 is 0.0003%. This value is quite negligible compared to the ASTM maximum standard fuel sulphur content of 0.05%max. High sulphur content in fuel is not encouraging because it is the fundamental proponent of green house gases emission which causes global warming and climate change. The 0.003wt% of sulphur obtained in this study can be considered as negligible sulphur content which shows the considerable consistency of the product as an alternative, clean and renewable fuel that ensures green technology especially in the present era faced with the multivariable effects of global warming and climate change. Octane number of bioethanol is defined as the resistance of the product in the ignitable detonation engine to knock and an unnecessary ignition causing harm to the engine. Octane number of bioethanol fuel shows its capability to oppose pre- ignition and flame uniformly [37]. Research octane number (RON) relates to low engine speed operation of the octane number analyzer while Motor octane number (MON) relates to the high engine speed operation of the octane analyzer. Though, the results obtained for RON and MON fall within the range specified by ASTM standard for bioethanol, it is however higher than that of gasoline. The research octane number of 112 and motor octane number of 104 obtained in this work also show considerable consistency with the literature values but differed from the work of Tangka *et al*. (2011) [37]who reported bioethanol research octane number of129 and motor octane number of 106 respectively. The differences could be traced to the source of the material used for the production and the analytical method utilized. The octane number obtained in this work shows a high octane value compared with that of the gasoline low octane numbers of 90 and 80 for the research and motor octane number respectively. This high octane rating of the bioethanol indicates that the bioethanol produced has a high resistance to knock compared to gasoline with a low octane rating. The water content of the produced bioethanol is 0.0021ppm as shown in Table. The value of the water content of bioethanol obtained in this study is very low compared to the maximum ASTM standard water content tolerance of 0.05wt%. This result confirms the cleanliness of the bioethanol and authenticates its effectiveness as an alternative fuel in the combustion chamber of the car for the provision of maximum power to the engine. The trace of water obtained in this study shows that the produced alternative fuel cannot cause corrosion of the fuel tank owing to its trace water content.

Conclusions

The production of bioethanol from cassava peel was reported in this study through optimized processes of hydrolysis and fermentation respectively. Based on the results obtained it can be inferred that temperature, acid concentration, substrate concentration and time affects the optimal yield of glucose via the hydrolysis of cassava peel. The optimum glucose yield of 78mg/L was obtained at the optimum temperature of 100°C, acid concentration of 0.402t%, cassava peel concentration of 2g/L and hydrolysis time of 45 minutes. Results also revealed that fermentation parameters of pH, temperature, yeast concentration, glucose concentration and time of fermentation affect the optimum yield of bioethanol. The optimum bioethanol yield of 45.5% was obtained at the optimum pH of 5,

temperature of 35°C, yeast concentration of 10wt%, glucose concentration of 100g/L and fermentation time of 100g/L and fermentation period of 6 days. The properties of the bioethanol produced from cassava peel also conform to the set standard. Hence, cassava peel can be utilized as a feedstock for the production of bioethanol as alternative energy source.

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Table 1: Influence of temperature on the yield of glucose at different hydrolysis time.

Time $(mins)$	Glucose Yield at Various Temperature (mg/ml)									
	20 °C	30 °C	40 °C	50 °C	60 °C	70 °C	80 °C	90 °C	100 °C	110 °C
5	2	3	4	5	6	7	8	9	10	15
10	4	6	8	10	12	14	16	18	20	22
15	6	9	12	15	18	21	24	27	30	34
20	8	12	16	20	24	28	32	36	40	42
25	11	15	20	25	30	35	40	45	50	51
30	15	20	25	30	35	40	45	50	60	55
35	18	24	30	36	42	49	56	63	70	62
40	25	29	35	40	46	52	60	68	75	66
45	30	36	42	50	56	62	68	74	78	60
50	34	39	46	54	58	65	71	75	73	52

Temperature (°C)	$k\ (min^{-1})$	R^2	$\frac{1}{T}$	$In\ k$
20	0.006	0.883	0.00341	-5.11600
30	0.008	0.930	0.00330	-4.82831
40	0.011	0.951	0.00320	-4.50986
50	0.013	0.947	0.00310	-4.34281
60	0.016	0.964	0.00300	-4.13517
70	0.019	0.966	0.00292	-3.96332
80	0.023	0.968	0.00283	-3.77226
90	0.027	0.966	0.00275	-3.61192
100	0.030	0.938	0.00268	-3.50656
110	0.024	0.903	0.00261	-3.72970

Table 4: Properties of the Produced Bioethanol

S/N	Properties	Units	Experimental Results	ASTM Standard for bioethanol	ASTM Standard for gasoline
1	Kinematic Viscosity @ 20 °C @ 40 °C @ 60 °C	cst cst cst cst	 1.21×10^3 0.83×10^3 0.60×10^3	 0.5×10^3- 1.5×10^3	 0.1×10^3- 1.0×10^3
2	Specific Gravity @ 27 °C @ 15 °C	kg/L kg/L kg/L	 0.750 0.785	0.750-0.850	0.700-0.800
3	Flash Point (Open Cup)	°C	14.2	10-16	-5-10
4	Refractive Index	-	1.362	1.360-1.364	1.350-1.355
5	Distillation Property IBP 5 % 10 % 30 % 50 % 70 % 90 % 100 % EBP Total Recovery = 100	 °C °C °C °C °C °C °C °C °C	 74 74 74 74 75 76 77 78 79 79	 70-80	 40-200
6	Sulphur Content	$\%\ wt$	0.0003	0.05max	0.05max
7	Octane Number RON MON	-	 112 104	 110-130 95-110	 85-90 80-85
8	Water Content	ppm	0.0021	0.05max	0.05max

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