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Determination of Calorific Value and Rate of Combustion of Biodiesel Generated from *Jatropha Curcas* Seed Oil

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Abstract

Jatropha curcas Seeds were collected and processed. 200.00g of the processed seed were subjected to soxhlet extraction using methanol at 85^oC for 5 hours. The extract (*Jatropha curcas* oil) was removed from the extracting solvent (methanol) by rotary evaporation and concentrated to a constant weight using sterilizing hot air at 60^oC. Biodiesel was produced from a solution mixture (40.00cm³ concentrated *Jatropha curcas* oil and 360.00cm³ methanol) by base catalysed trans- esterification at 65^oC. The percentage of the biodiesel collected was evaluated and recorded. The calorific value, the percentage combustion, the combustion time and the rate of combustion of the biodiesel were determined. The work showed that the amount of biodiesel collected, the calorific value, the percentage combustion, the combustion time and rate of combustion of the biodiesel were 202.00 cm³, 86.00 %, 1.19 second and 54.20 cm³/ second, respectively.

Keywords: *Jatropha curcas* seeds, biodiesel; base catalysed transesterification; calorific value; rate of combustion.

Introduction

Energy has been recognised as the bedrock of any industrial and overall national development. The operations of technological society today depend largely on the production and utilization of huge amount of energy. It is therefore, not surprising that any nations of the world are facing problems of dwindling energy supplies, energy distribution and numerous environmental effects of various methods of energy production and utilization (Ndana and Manko, 2010). As nations develop industrially and in status, more individuals own vehicles, power generating plants and other forms of mechanical devices, which utilize different forms of fuels which on the other hand, have adverse effects on the environment and substances of value in the environment (Yaro, 2015). The source of fuels used now adays in most mechanical devices are fossils fuels, such as crude oil, natural gas and coal (Ndana and Manko, 2010). Fossil fuels are practically non-renewable in nature, hence there is the need for generating renewable energy resources from locally sourced abundant renewable sources, which are cheaper and environmentally-friendly to replace completely or minimize the use of the existing non-renewable fossils fuels, which have detrimental effects on the environment and its content. Production of biodiesel, which is nontoxic and renewable in nature now adays is making road into the world market due to environmental acceptance (Ndana and Manko, 2010).

Biodiesel is a clean burning fuel derived from biological sources by catalytic reaction of long chain fatty acid with a short chain aliphatic alcohols (usually methanol or ethanol) through a process called transesterification or alcoholysis (Garba *et al*, 2012). Chemically, biodiesel is a mixture of monoalkylesters of long chain fatty acids derived from renewable lipid feedstock such as vegetable oil or animal fat, and short chain alcohol, primarily methanol or ethanol (Demirbas, 2008). The physical and chemical properties advantages of methanol over ethanol, such as polarity and short chain, as well as the cheapness of methanol make it more preferable used for commercial scale production of biodiesel than ethanol (Demirbas, 2008). As alternative to petro as alternative to petro diesel, biodiesel is technically feasible

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economically competitive and environmentally acceptable (Demirbas and Demirbas, 2007). Additionally, biodiesel has high flash point. This makes the use of biodiesel safer in vehicles in the event of vehicle crash and, spillage of biodiesel does not present any risk or hazard to the environment (Ndana and Manko, 2010). Biodiesel has wide variety of feedstock such as riped seeds oil, soya bean oil, palm oil, adulterated vegetable oils, animal fat among several others (Garba *et al*, 2012). The available known method through which biodiesel can be generated from oil reach seeds are: base catalysed transesterification and conversion of oil to fatty acid and subsequently to biodiesel (Yaro, 2015)

Jatropha curcas is a perennial and drought resistant plant, which strives well in most types of terrain. It is cheap and easily cultivated through seeds and cuttings. The plant can be inter cropped with other plants and, it takes about 9 month to mature. *Jatropha curcas* is not edible to human and animals, therefore, it does not suffer from direct competition with food crops and, can remain economically viable for 30-50 years. The seed of *Jatropha curcas*. Have high oil content of 35-42% and other valuable economic products, such as glycerine, which is used in cosmetic and pharmaceutical industries and; seed cake which is an excellent fertilizer (Garba, et al, 2012)

This work reports studies on biodiesel production from *Jatropha curcas* oil by base catalysed transesterification method. The work also report studies on calorific value and combustion of the biodiesel using food/fuel calorimeter.

Materials and Methods.

Collection and Processing of Experimental Sample

C seeds were collected from a group of *Jatropha curcas* plants located along Dilimi river side, near permanent site, University of Jos, Plateau state- Nigeria. The pods of the seed were cracked and, the seeds were air dried for 2 weeks under sun, pulverized using pestle and mortar and sieved to a particle size of less than 250x 10⁻⁶ m.

Extraction of *Jatropha Curcas* Seed Oil

Two hundred gram (200.00 g) of the pulverized *Jatropha curcas* seeds were subjected to soxhlet extraction for 5 hours at 85 °C using methanol (as extracting solvent) under steady flow of running tap water through a condenser. The extract (*Jatropha curcas* seed oil) was recovered from the extraction solvent by evaporation using rotary evaporated according to the method described by Yaro, (2015) with few adjustments. The oil was concentrated using hot air sterilizing cabinet at 60°C according to the method described by Bulama *et al* (2014) with few adjustments.

Production of Biodiesel

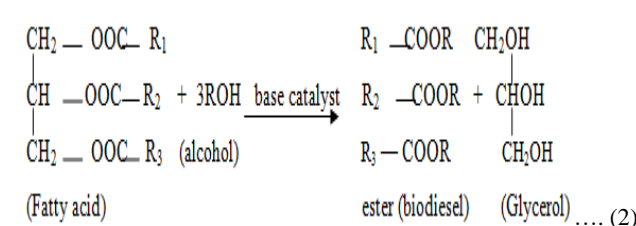
A solution mixture made up of 40 cm³ concentrated *Jatropha carcus* seed oil and 360 cm³ methanol containing IM KOH solution (as catalyst) was placed in a reactor (500 cm³ round bottomed flask) and heated at 65°C along with stirring using magnetic stirrer at the rate of 450 rpm. The volume ratio of the solution mixture, the concentration of the catalyst, the heating temperature and the rate of stirrings used were based upon the findings of Garba *et al* (2012). The heating and stirring were stopped when two (2) distinct liquid phases were formed. The liquid phases were allowed to settle and, the top layer (top phases) containing the ester of fatty acid (biodiesel) was separated from the bottom

layer, which contained glycerol by separation using separating funnel. The excess methanol in the top layer was removed by distillation leaving behind the biodiesel. The volume of the biodiesel collected was measured and, the percentage by volume of the biodiesel collected was evaluated using the following relation

$$\% \text{VBD} = \frac{\text{VBD}}{\text{VSM}} \times 100 \dots \dots \dots (1)$$

Where VBD = Volume of biodiesel
 VSM = Volume of solution mixture
 (See Appendix 1 for more details)

The base catalyst Tran’s esterification reaction involved in the process was based on the reaction below as reported by Ndana and Manko



Determination of Calorific Value

The calorific value of the biodiesel was determined using food/fuel calorimeter (Fig 1). The flat form of the calorimeter was lowered a few centimetres below and, the igniter holder was pushed up to the maximum position and swung around to touch the inside of the calorimeter. 75 cm³ of the biodiesel was placed in a 100 cm³ beaker and placed in the recess on top of the platform and, a moderate sunction was supplied by the filter pump. The platform was raised to support the calorimeter. The water in the calorimeter (50cm³) was stirred and, a steady temperature was attained and recorded (as initial temperature of the water). An igniter coil was carefully positioned and touched the biodiesel in the beaker. A gentle stream of oxygen gas was released from oxygen cylinder and, an electric current (2.5 amps and 240 volt) was briefly switched on, which ignited the biodiesel in the beaker after which the igniter coil was immediately raised and swung out of the beaker. The pressure of the oxygen gas was carefully increased and, the biodiesel burnt quickly without sputting and loss of weight. The water in the calorimeter was stirred continuously throughout the combustion period. After complete combustion, the filter pump and the supply of oxygen were turned off and, stirring continued until maximum temperature was observed and recorded (as final temperature of the water). The beaker was removed and the volume of the biodiesel was ascertain after cooling (Garba, 1998)

The percentage combustion of the biodiesel was evaluated as follows:

$$\% \text{Combustion} = \frac{\text{VBD}_B - \text{VBD}_A}{\text{VBD}_B} \times 10 \dots \dots \dots (3)$$

Where V_{B,D} B= Volume of biodiesel used in calorimeter before

Where V_{B,D} A= Volume of biodiesel after burning

(See Appendix 2 for more details)

Estimation of Calorific Value

The calorific value (Cv) of the biodiesel was estimated in J/Kg from the mass (m), specific heat capacity (C) and the

change in temperature ($\Theta_2 - \Theta_1$) of the water in the calorimeter using the equation below as adopted by Okeke *et al* (2009).

$$Q = MC (\Theta_2 - \Theta_1) \dots\dots\dots (4)$$

Where Q is the quantity of heat gained by the water in the calorimeter, which is equal to the heat generated by the biodiesel during combustion (ie. the calorific value of biodiesel)

Thus, $Q = CV \dots\dots\dots (5)$

From (4) and (5), $CV = MC (\Theta_2 - \Theta_1) \dots\dots\dots (6)$
(See Appendix 3 for more details)

The mass, m of the water used in the calorimeter was estimated from the volume V and density, ρ of the water by the following equation:

$$\rho = \frac{M}{V} \dots\dots\dots (7)$$

Estimation of Combustion Time

The time taken for the complete combustion of the biodiesel was estimated using the following energy calculations as reported by Ezeonu (1997):

The electrical energy supplied in a given time during combustion of the biodiesel in the calorimeter was evaluated as follows:

$$E = IVT \dots\dots\dots (8)$$

Where E = electrical energy supplied

I = Electric current used

V = Potential difference across the circuit

t = Time taken (in second)

But in the calorimeter, the electrical energy supplied in a given time is equal to the heat gained by the water, hence

$$IVt = MC (\Theta_2 - \Theta_1) \dots\dots\dots (9)$$

From (9), $t = \frac{MC (\Theta_2 - \Theta_1)}{IV} \dots\dots\dots (10)$

But from (6), $MC (\Theta_2 - \Theta_1) = CV$,

Therefore, (10) can be expressed as;

$$t = \frac{CV}{IV} \dots\dots\dots (11)$$

Let for combustion, to be Ct , $\iff Ct = \frac{CV}{IV} \dots\dots\dots (12)$

(See Appendix 4 for more details)

Estimation of the Rate of Combustion

The rate, r of combustion of the biodiesel was estimated using the following relation:

$$r = \left(\frac{V_{BDB} - V_{BDA}}{Ct} \right)$$

(See Appendix 5 for more details)

Results and Discussion

Results

The results of all the experiments and estimation carried out in this work are presented in Tables 1 and 2 below. Table 1 shows the amount (cm^3) and the percentage of biodiesel generated from a solution mixture of $40 cm^3$ *Jatropha curcas* oil and $360 cm^3$ methanol. Table 2 shows the percentage combustion, calorific value, combustion time and rate of combustion of $75 cm^3$ of the biodiesel generated.

Table 1: Amount (cm^3) and Percentage of Biodiesel Generated from $40cm^3$ *Jatropha Curcas* Oil and $360cm^3$ Methanol.

Volume of <i>Jatropha curcas</i> oil	Volume of methanol	Volume of biodiesel collected	Percentag of biodiesel collected
40.00 cm^3	360.00 cm^3	202.00 cm^3	50.50%

Table 2: Evaluated Percentage Combustion, Calorific Value, Combustion Time and Rate of Combustion of $75 cm^3$ of the Biodiesel Generated.

Percentage combustion	Calorific value	Combustion time	Rate of combustion
86.00%	714.00J	1.19 sec	54.20 cm^3 /sec

Discussion

The amount ($202.00 cm^3$) of the biodiesel collected from a solution mixture used was presented in Table 1. The result indicated that *Jatropha curcas* seed could be used for large scale biodiesel production since appreciable quantity ($202.00 cm^3$) was collected from $400.00 cm^3$ solution mixture of *Jatropha curcas* oil and methanol. The appreciable production of biodiesel observed may be connected to the suitable volume ratio (1:9) of *Jatropha curcas* oil to methanol, the reaction temperature ($65^{\circ}C$) and the optimum concentration of KOH used during base catalysed transesterification. This is in accordance with the findings of Garba *et al* (2012). The result of the energy analyses carried out on the biodiesel using experiments and estimations are presented in Table 2. From the result it could be seen that the percentage combustion and calorific value of the biodiesel generated are 86.00% and 714.00J/ $75 cm^3$, respectively. The high combustibility and calorific

value observed may be associated with the long chain of carbon atoms in the fatty acid components of the biodiesel. Because diesel oil from crude oil contains between C_{12} - C_{25} per molecule as reported by Ababio, (1985). The moderate rate of combustion of the biodiesel ($54.20/cm^3$) indicated that the biodiesel has an auto anti knocking quality due to branch nature of the fuel (biodiesel), which helps to regulate the rate at which the biodiesel burns in an internal combustion engine during combustion. The auto anti-knocking quality of the biodiesel will also makes the fuel to be environmentally-friendly because during combustion of the fuel (biodiesel), the effluent gas is pollutant free. In addition, the auto anti-knocking quality of the biodiesel also make the fuel to have high octane rating. Beside environmental protection and high octane rating, the findings of the present work will also help to save a lot on cost of production because the fuel obtained (biodiesel) does not require the addition of lead tetra ethyl ($Pb(C_2H_5)_4$)

as anti-knock and need not to undergo cracking process for a high octane number (i.e. octane rating). This is of course, an added advantages over the production of fuel from crude oil, which requires the addition (Pb(C₂H₅)₄) as anti-knock and cracking process for the formation of fuel (gasoline) with increase octane number as reported by Ababio (1985).

Conclusion

From the findings of the present work, it could be said that combustion of 1dm³ of biodiesel generated from *Jatropha curcas* seed oil using an electric current of 2.5 amphere and a potential difference of 240 volt could generate 9520.00 J of energy (heat) in 1.19 seconds. The work also proved the importance of *Jatropha curcas* seed oil as important raw material for the production of biodiesel, which is environmentally friendly at low cost.

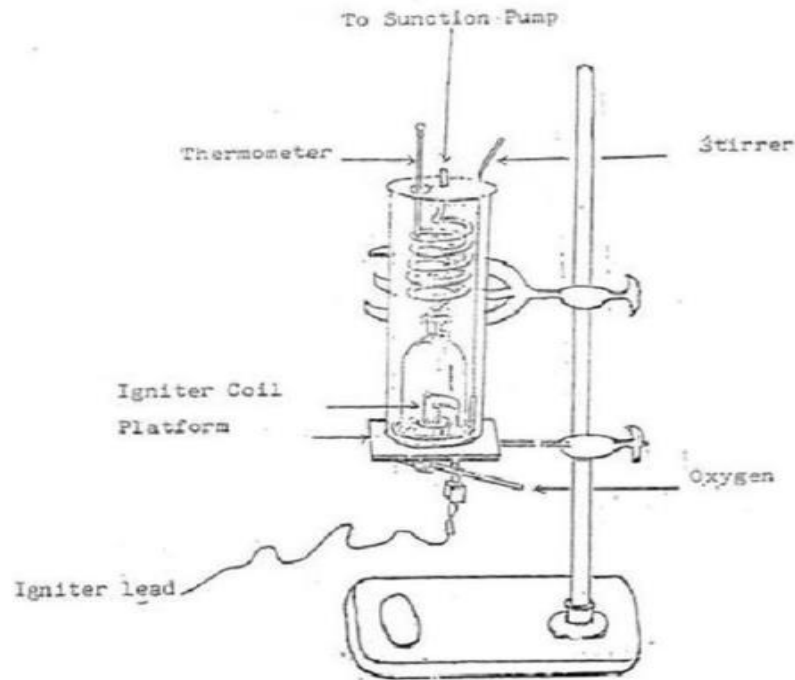


Fig.1 Fule/ food Calorimeter: apparatus for measuring calorific value

Appendices

Appendix 1: Evaluation of biodiesel collected

Volume of *Jatropha* (VJ) = 40.00 cm³
 Volume of Methanol (Vm) = 360.00 cm³
 Volume of Solution mixture (V_s) used for transesterification reaction was obtained as follows:

VS= VJ+ VM
 Vs= 40.00 cm³+ 360.00 cm³= 400.00 cm³
 Volume of biodiesel (VBD) collected = 202.00 cm³
 Percentage of biodiesel collected (%BD) was obtained as follows:

$$\% \text{VB.D} = \frac{\text{VBD}}{\text{VS}} \times 100 \Rightarrow = \left(\frac{202.00}{400.00} \right) \text{cm}^3 \times 100 = 50.50\%$$

Appendix 2: Determination of the percentage combustion of the biodiesel

VBDB = Volume of biodiesel used in calorimeter before combustion= 75.00 cm³
 VBDA = Volume of biodiesel remained in calorimeter after combustion= 10.50 cm³

$$\text{The percentage of biodiesel } \% \text{CB.D} = \frac{\text{VBD}-\text{VBDA}}{\text{VBDB}} \times 100 = \left(\frac{75.00 - 10.50}{75.00} \right) \text{cm}^3 \times 10 = 86.00\%$$

Appendix 3: Determination of calorific value of the biodiesel

CV = calorific value = Q
 But Q = MC (Θ₂-Θ₁)
 ⇒ CV = MC (Θ₂-Θ₁)

$$0.05\text{kg} \times 4200\text{J/kg}^{-1}\text{K}^{-1}(29.60-26.20) \text{K} = 714.00 \text{ J}$$

Since 75.00 cm³ of biodiesel 714.00 J →
 1000cm³ of biodiesel x →
 ⇒ X = $\frac{1000\text{cm}^3 \times 714.00\text{J}}{75.00 \text{cm}^3} = 9520 \text{ J/dm}^3$ of the biodiesel

Appendix 4: Estimation of combustion time of the biodiesel

$$\text{Combustion time, Ct} = \left(\frac{\text{CV}}{\text{IV}} \right)$$

$$= \left(\frac{714.00}{2.500 \times 24.00} \right) = 1.19 \text{ sec}$$

Since 714.00 J combusted in 1.19 sec
 9520J will be combusted in:
 $\frac{9520.00 \text{ J} \times 1.19 \text{ sec}}{714.00 \text{ J}}$

$$= 15.87 \text{ second}$$

Appendix 5: Estimation of the Rate of Combustion of the Biodiesel

$$\text{Rate of combustion Rc} = \left(\frac{\text{VBDB}-\text{VBDA}}{\text{Ct}} \right)$$

$$= \left(\frac{75.00 - 10.50 \text{ cm}^3}{1.19 \text{ sec.}} \right) = 54.20 \text{ cm}^3/\text{second}$$

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