



COMPARATIVE CALORIFIC EVALUATION OF BIOMASS FUEL AND FOSSIL FUEL

C. O. Osueke

Mechanical Engineering Department, Landmark University, Omu-Aran Kwara State

T. M. A. Olayanju

Agricultural and Bio-Systems Engineering Department, Landmark University, Omu-Aran Kwara State

C. A. Ezugwu

Mechanical Engineering Department, Landmark University, Omu-Aran Kwara State

A. O. Onokwai

Mechanical Engineering Department, Landmark University, Omu-Aran Kwara State

I. Ikpotokin

Mechanical Engineering Department, Landmark University, Omu-Aran Kwara State

D. C. Uguru-Okorie

Mechanical Engineering Department, Landmark University, Omu-Aran Kwara State

F.C. Nnaji

Chemical Engineering Department, Landmark University, Omu-Aran Kwara State

ABSTRACT

In recent years, fossil fuels have been preferably used both for domestic and industrial purposes. Fossil fuels are highly flammable and effective but are very hazardous to the human environment. It is also one of the causes of the ozone layer depletion which humanity is battling presently. Biomass fuels are majorly agricultural waste materials which have good properties that aid combustion, less hazardous and are effective for some domestic activities and in small-scale industries. This paper presents the calorific evaluation and analysis of fossil fuel and biomass fuel. It also highlights the effects of fossil fuels in terms of the dangers of increasing CO₂ concentration in the atmosphere. It presents biomass fuel as a potential substitute for fossil fuel as a renewable energy by comparing the calorific values of various combustible samples such as: rice husk, petrol, diesel, corn cob using a C200 bomb calorimeter at the Landmark University energy laboratory to determine the calorific values and to examine if biomass can be used as a suitable replacement for fossil

fuels. Results show that corn cob has a higher calorific value than rice husk, but both corn cob and rice husk have sufficient energy to be used as substitutes for petrol and diesel and other fossil fuels to reduce the dangers of CO₂ concentration in the atmosphere and societies over-reliance on fossil fuel.

Keywords: Biomass, Energy, Calorific value, Briquette.

Cite this Article: C. O. Osueke, T. M. A. Olayanju, C. A. Ezugwu, A. O. Onokwai, I. Ikpotokin, D. C. Uguru-Okorie and F.C. Nnaji, Comparative Calorific Evaluation of Biomass Fuel and Fossil Fuel, *International Journal of Civil Engineering and Technology (IJCIET)* 9(13), 2018, pp. 1576–1590.

<http://www.iaeme.com/ijciet/issues.asp?JType=IJCIET&VType=9&IType=13>

1. INTRODUCTION

Energy is vital to human existence. Its application cannot be over emphasis, because its activities range from and not limited to domestic appliances, transportation, industrial machines, including sophisticated industrial, and commercial applications, etc. Renewable energy is a form of energy that comes from resources which are naturally replenished on a human timescale. It is one of the means of tackling the global challenges of climate change [1].

Biomass is any organic matter from animals and plants used as energy source, in order words it has stored energy which can be harvested. When such energy is harvested or released it is known as biomass energy. In Nigeria wood fuel is used for cooking and in some areas due to the shortage of wood, dried cow dungs serve as a substitute for wood. The use of agricultural by-products, wood, and its dust briquetted to generate energy for drying and cooking has been investigated and found feasible. The use of biomass to produce energy is a process of recycling waste which might be hazardous to man and the environment or plants remains after harvest. However, the conversion of raw biomass into source of fuel through direct combustion is an old method of waste materials utilization, which has led to the development of gasification and biomass briquette. Biomass briquettes offer a comparative advantage over the fuel wood, which is not limited to easy of collection, longer burning interval, higher heating values, lower cost, and reduced environmental impact. [2].

Biomass fuels are different from fossil fuels since fossil fuels are non-renewable energy which includes but not limited to coal, gas, and gasoline. The burning of fossil fuels by automobiles and industrial plants have caused air pollution, invariably causing harm to humans'. Biomass fuels do not release SO₂ which are harmful to man [3,4,5]. Owing to the effects of fossil fuels on climate change and its environmental impact, there is a higher demand for cleaner and more renewable sources of energy both locally and globally, among these are energy from sunlight, wind turbines, hydro-powered turbines and biomass; although not as profoundly tractive as others [6]. Biomass is more practical than all other forms of renewable energy in most regions of Africa including Nigeria. Its relative availability at low cost makes it ideal for developing countries, whereas high cost of solar panels, turbines may pose a constraint to the implementation and development of clean energy.

Briquettes, compressed block of sawdust, rice husk, etc, are important alternative fuel source for rural dwellers and small-scale industries [7,8]. Other than sawdust, there are biomasses with high energy potential such as rice and coffee husks, straw, wood chip, and bark. Forest residues account for 65% of the biomass energy potential and are in abundance in Nigeria, this can serve as an alternative to fossil fuel in certain sectors, and this can eventually be used to meet needs [9]. Irrespective of the high generation of agricultural residues, it is

what noting that in Nigeria its utilization as fuel is low. This is attributed to sufficient information concerning biomass fuel utilization technologies [10].

The use of biomass as a biofuel will lead to the reduction of CO₂ emissions and Ozone layer depletion and its palletization has an economic advantage. The pelletizing process will involve the use of binders such as starch, molasses, heavy oil or phenolic resin [11,12]. Also, hardeners such as sulphuric acid (H₂SO₄), potassium hydroxide (H₃PO₃) and sodium hydroxide (NaOH) can be added to the biomass materials to improve their mechanical properties. In the formulation of Biomass feedstock, it consists of, but not limited to glucose polymers. The Chemical and Physical composition Biomass varies depending on species, growing conditions, and location.

The intensive growth of emissions from the fossil fuels combustion causes air quality deterioration. Fossil fuels replacement with biomass can be of fundamental importance for the protection of public health. The aim of this project is to compare the calorific values of agricultural wastes (biomass) and fossil fuel and determine if biomass material can be used to replace fossil fuel.

2. MATERIALS AND METHODS

2.1. Materials

2.1.1. Material Selection

The following criteria were taken into consideration;

- Renewable waste materials.
- Cost of materials.
- Material availability in Landmark University.

2.1.2. Materials utilized

The materials used for the experiment include:

- Corn cobs.
- Rice husks.
- Diesel.
- Petroleum.

2.1.3. Sources of Raw Materials

The Corn cobs and rice husks were obtained from Landmark University Teaching and Research Farm, Omu-Aran, Kwara State, Nigeria. Materials such as diesel and kerosene were sourced from a petrol station at Omu-Aran, Kwara state. The preparation and analysis of the samples were carried out in Landmark University energy research laboratories.

2.1.4. Preparation of the materials

Solid samples of the biomass were milled using an industrial milling machine at the Landmark University Teaching and Research Farm.

Table 1. Calorific Value Analysis

Calorific Value Analysis	Gross calorific Value Kj/kg
Diesel	44,800
Petrol	48,000
Corn cobs	12,255
Rice husk	12,005

The calorific values of each biomass and fossil fuel were determined using a bomb calorimeter that utilizes benzoic acid and is powered by oxygen.



Plate 1. Bomb Calorimeter setup

2.2. Experimental Procedure

2.2.1. Charge Weight Calculation

Before the bomb was opened, we ensured that the samples were weighed and potential calorific value did not exceed the 7000 cal (2900 Joules) allowable maximum. Which is designated as;

$$GCV = \frac{44800}{1000} = 44.8 \text{KJ/KG}$$

$$m_f = \frac{29300}{44.8} = 0.65 \text{g}$$

2.2.2. Procedures for the preparation and charging of fuels

The preparation and charging procedures are fundamentally identical for all fuels. The only variations are between solid and liquid fuels.

- Preparation of the Water Jacket and Calorimeter Vessel:-The water jacket was filled with water in advance of testing so that it has time to reach ambient temperature. The calorimeter vessel locator is at the bottom of the water jacket, which was filled with a measured volume of (2 litres) water. The calorimeter vessel was then placed inside the water jacket.
- Preparation of Solid Samples: The solid samples were weighed (m_f) based on charge weight calculation and then pelletized, thereafter put into the calorimeter for analysis.

Comparative Calorific Evaluation of Biomass Fuel and Fossil Fuel

- Preparation of Liquid samples: The liquid samples were weighted in a known crucible weight, ensuring that the charge weight didn't exceed the maximum weight calculated in the charge weight calculation.
- Preparation of the bomb vessel: The bomb vessel was cleaned. Then 55mm nichrome wire was cut and weighed, and its weight recorded as m_w . The wire was slid into bomb electrodes and tied around the electrodes. The rings on the electrodes were then used to lock the wire so as to ensure effective electrical contact. Thereafter 100mm Cotton thread was weighed and recorded as m_c , and this was tied to the centre of the wire with some of it dangling. Next was to load the sample into the crucible holder ring while ensuring the dangling thread came in contact with the sample (liquid and solid). The top section with the crucible was placed into the base of bomb calorimeter and firmly locked.
- Oxygen Charging: The bomb was charged with pure oxygen. It was fitted with an oxygen bottle regulator. Other components like the pressure gauge, safety bursting disc, oxygen bottle regulator and bomb vessel were connected to each other and the hoses inlets and outlets were tightened. The pressure regulator knob was turned and the bottle valve opened and the pressure was recorded. The pressure regulator knob was turned slowly making sure it did not exceed 25bar. After the recommended pressure was released, the bottle valve and pressure regulator knob were closed. The hoses were detached from the bomb vessel.



Plate 2. Labtech BL20001 Electronic Compact Scale measuring the mass of Biomass.



Plate 3. Formation of pellet with the press.



Plate 4. Bomb Electrode slots to accept the use of screw microchrome wire.

2.2.3. Conducting A Calorimetric Test

The bomb was charged with the correct weight of fuel and the vessels pressurized with pure oxygen to a maximum of 25bar, thereafter the bomb vessel was placed inside the calorimeter vessel filled with 2 litres of water. The ignition terminals, temperature sensor and the stirrer were connected and positioned properly. The stirrer and the sensor were in contact with the water inside the calorimeter vessel. The other end of the ignition cables were connected to the corresponding bomb ignition sockets at the rear of the control console.

The procedure was to monitor the temperature at 1-minute intervals until there is no change.

Once the rising temperature was stable, the time of the last reading was recorded and the bomb firing button was pressed. We continued monitoring and recording the temperature every minute. The initial rise in temperature was rapid, but slowed down and continued for a while after firing. The rise in temperature is considered to have reached maximum temperature once the temperature rise starts to progressively fall or remain constant for typically 5 successive minute readings.



Plate 5. Bomb Vessel



Plate 6. Bomb vessel placed inside calorimeter vessel

3. RESULTS AND DISCUSSION

This aspect of the work analyses and discusses the various experiments and results obtained.

3.1. Bomb calibration procedure

When the bomb was charged with fuel and oxygen and ignited, it heats the sample, however, the heat generated also heats the mass of water of known weight in the calorimeter vessel and the heavy stainless steel bomb vessel. Therefore to account for the heat gained by the bomb material a calibration was done using benzoic acid of calorific value of 6319 cal/g (or 26450 J/g).

Since the mass of water in the calorimeter vessel was kept constant, so the effective heat equivalent ε generated was calculated as:

$$\varepsilon = [m_{ba} \times q_{vba} + Q_{fuse} + Q_{ign}] / \theta \quad (3.1)$$

Where,

M_{ba} = benzoic acid (g)

q_{vba} = gross calorific value of benzoic acid (J/g)

Q_{fuse} = heat attributed to the cotton thread (J)

Q_{ign} = heat attributed to the nichrome ignition wire (J)

θ = corrected temperature rise of the calorimeter vessel (K)

3.1.1. Procedure

- A pellet of Benzoic acid was prepared with a weight of 1g, then the solid sample testing procedure was followed.

The weight (m_{ba}) of benzoic acid = 0.981 g

- The bomb was prepared for firing with the pellet following stated testing procedures.

m_w , mass of nichrome wire = 0.005g

m_c , mass of cotton thread = 0.010g

- The bomb was charged with oxygen.
- A calorimetric test was carried out and data was recorded.
- Sample data is shown below:

m_c , Mass of cotton thread = 0.010g

m_w , mass of nichrome wire = 0.005g

m_{ba} , mass of benzoic acid = 0.981g

Mass of water in calorimetric vessel = 2kg

Mass of wire left after firing = 0.0g

Initial water temperature = 18.2°C

Cotton fuse is assumed to have a calorific value of $q_c = 4180$ cal/g (17496.6 J/g)

Nichrome wire is assumed to have a heating effect of $q_w = 0.335 \times 10^{-3}$ cal/g (1402.2 J/g)

Temperature rise data for Benzoic Acid can be seen from the figure below, the maximum temperature rise $\theta = 2.33$ K.

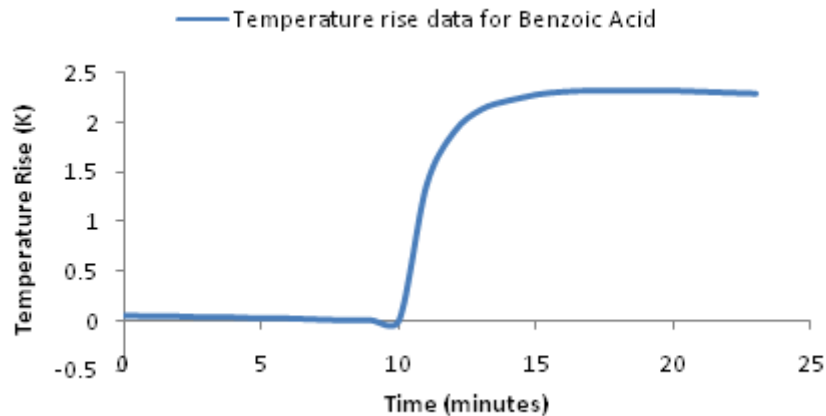


Figure 1. Temperature rise with respect to time for Benzoic Acid

3.1.2. Sample Calculations

For the cotton thread

$$\begin{aligned} Q_{\text{fuse}} &= m_c \times q_c & (3.2) \\ &= 0.010 \times 17496.6 \\ &= 174.966 \text{ J} \end{aligned}$$

$$\begin{aligned} Q_{\text{ign}} &= m_w \times q_w & (3.3) \\ &= 0.005 \times 1402.2 \\ &= 7.011 \text{ J} \end{aligned}$$

For the bomb,

$$\begin{aligned} \varepsilon &= \frac{m_b a x q_v b a + Q_{\text{fuse}} + Q_{\text{ign}}}{\theta} & (3.4) \\ &= \frac{0.981 \times 26450 + 174.966 + 7.011}{2.33} \\ &= 11214.346 \text{ J/K} \end{aligned}$$

This is the constant value for the bomb assuming no components are changed and the mass of water in the calorimeter vessel remains 2kg. The factor ε is used in subsequent calorimetric calculations as follows.

3.2. Fuel Testing

Having calibrated the bomb, the procedure for testing fuel and calibration is almost identical.

3.2.1. Diesel Test

In this case, the fuel being tested is diesel.

- The charge (liquid charge) was prepared following the procedure of testing for calorific value of liquid samples and the weight was recorded.

From u

m_f , mass of diesel = 0.585g

- We prepared the bomb for firing with the liquid fuel following the stated procedure.

m_w , mass of nichrome wire = 0.040g

m_c , mass of cotton thread = 0.085g

- The bomb was charged.
- A calorimetric test was carried out

The data is shown below;

m_w , mass of nichrome wire = 0.040g

m_c , mass of cotton thread = 0.085g

m_f , mass of diesel = 0.585g

mass of water in calorimeter vessel = 2kg

mass of wire after firing = 0.0g

initial water temperature = 19.0°C

Cotton fuse is assumed to have a calorific value of $q_c = 4180 \text{ cal/g}$ (17496.6 J/g)

Nichrome wire is assumed to have a heating effect of $q_w = 0.335 \times 10^{-3} \text{ cal/g}$ (1402.2 J/g)

Temperature rise data for Diesel Sample can be seen from the figure below. The maximum temperature rise $\theta = 0.01-0.55 = 0.54\text{K}$

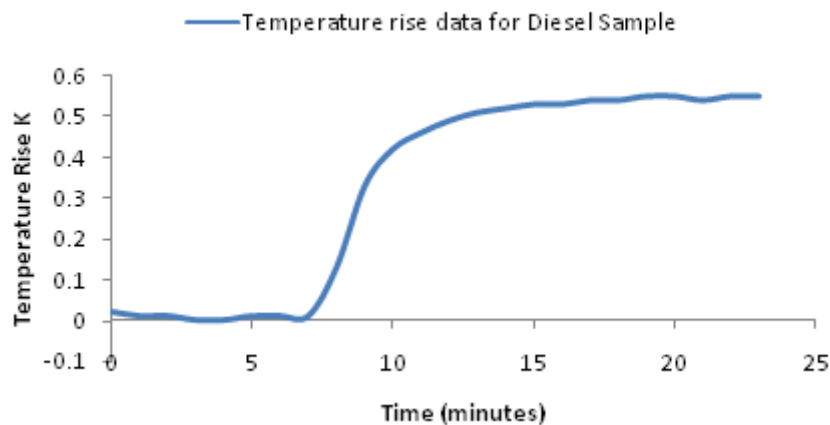


Figure 2. Temperature rise with respect to time for Diesel Sample

The gross calorific value of the sample q_{vf} can be calculated from.

$$Q_{vf} = \frac{(ex\theta) - Q_{fuse} + Q_{ign}}{m_f} \quad (3.5)$$

where;

m_f = fuel sample (g)

q_{vf} = calorific value of benzoic acid (J/g)

Q_{fuse} = heat contributed from the cotton thread (J)

Q_{ign} = heat contributed from the nichrome ignition wire (J)

θ = temperature rise of the calorimeter vessel (K)

Sample calculation

For the cotton thread

$$Q_{fuse} = m_c \times q_c$$

$$= 0.085 \times 17496.6$$

$$= 1487.2 \text{ J}$$

$$Q_{ign} = m_w \times q_w$$

$$= 0.040 \times 1402.2$$

$$= 56.1 \text{ J}$$

For the bomb,

$$\epsilon_d = 11214.34 \text{ J/K}$$

For the diesel sample,

$$q_{vf} = \frac{(\epsilon x \theta) - Q_{fuse} - Q_{ign}}{m_f}$$

$$= \frac{(11214.34 \times 0.54) - 1487.21 - 56.1}{0.585} = 7713.56 \text{ J/g}$$

3.2.2. Petrol Test

m_w , mass of nichrome wire = 0.005g

m_c , mass of cotton thread = 0.010g

m_f , mass of petrol = 0.30g

mass of water in calorimeter vessel = 2kg

mass of wire after firing = 0.0g

initial water temperature = 27.6°C

bottle pressure gauge = 80bar

outlet pressure gauge = 24.5 bar

Cotton fuse is assumed to have a calorific value of $q_c = 4180 \text{ cal/g}$ (17496.6 J/g)

Nichrome wire is assumed to have a heating effect of $q_w = 0.335 \times 10^{-3} \text{ cal/g}$ (1402.2 J/g)

Temperature rise data for Petrol Sample can be seen from the figure below. The maximum temperature rise $\theta = 0.26 - 0.07 = 0.19\text{K}$.

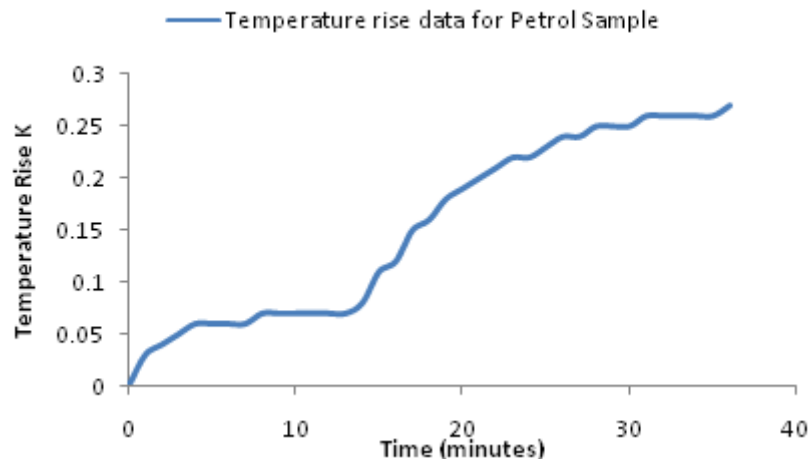


Figure 3. Temperature rise with respect to time for Petrol Sample

$$Q_{vf} = \frac{(\epsilon x \theta) - Q_{fuse} - Q_{ign}}{m_f}$$

m_f = fuel sample (g)

q_{vf} = calorific value of benzoic acid (J/g)

Q_{fuse} = heat contributed from the cotton thread (J)

Q_{ign} = heat contributed from the nichrome ignition wire (J)

Sample calculation

For the cotton thread

$$\begin{aligned} Q_{\text{fuse}} &= m_c \times q_c \\ &= 0.010 \times 17496.6 \\ &= 175.0 \text{ J} \end{aligned}$$

$$\begin{aligned} Q_{\text{ign}} &= m_w \times q_w \\ &= 0.005 \times 1402.2 \\ &= 7.01 \text{ J} \end{aligned}$$

For the bomb,

$$\epsilon_p = 11214.34 \text{ J/K}$$

For the diesel sample,

$$\begin{aligned} q_{\text{vf}} &= \frac{(\epsilon x \theta) - Q_{\text{fuse}} - Q_{\text{ign}}}{m_f} \\ &= \frac{(11214.34 \times 0.19) - 175 - 7.01}{0.30} \\ &= 6500 \text{ J/g} \end{aligned}$$

3.2.3. Rice husk Test

m_w , mass of nichrome wire = 0.005g

m_c , mass of cotton thread = 0.010g

m_f , mass of rice husk = 1.20g

mass of water in calorimeter vessel = 2kg

mass of wire after firing = 0.0g

initial water temperature = 27.3°C

bottle pressure gauge = 80bar

outlet pressure gauge = 24.5 bar

Cotton fuse is assumed to have a calorific value of $q_c = 4180 \text{ cal/g}$ (17496.6 J/g)

Nichrome wire is assumed to have a heating effect of $q_w = 0.335 \times 10^{-3} \text{ cal/g}$ (1402.2 J/g)

Cotton fuse is assumed to have a calorific value of $q_c = 4180 \text{ cal/g}$ (17496.6 J/g)

Nichrome wire is assumed to have a heating effect of $q_w = 0.335 \times 10^{-3} \text{ cal/g}$ (1402.2 J/g)

Temperature rise data for Rice husk Sample can be seen from the figure below. The maximum temperature rise $\theta = 0.46 - 0.12 = 0.34\text{K}$.

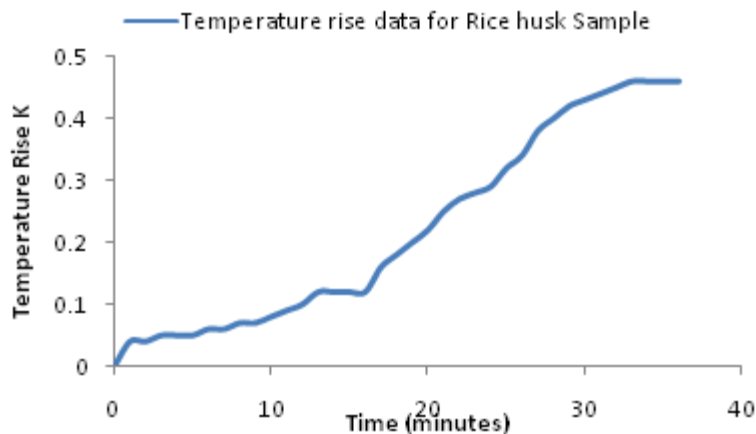


Figure 4. Temperature rise with respect to time for Benzoic Acid

Sample calculation

For the cotton thread

$$\begin{aligned} Q_{\text{fuse}} &= m_c \times q_c \\ &= 0.010 \times 17496.6 \\ &= 175.0 \text{ J} \end{aligned}$$

$$\begin{aligned} Q_{\text{ign}} &= m_w \times q_w \\ &= 0.005 \times 1402.2 \\ &= 7.01 \text{ J} \end{aligned}$$

For the bomb,

$$\epsilon_{\text{th}} = 11214.34 \text{ J/K}$$

For the rice husk sample,

$$\begin{aligned} q_{\text{vf}} &= \frac{(\epsilon x \theta) - Q_{\text{fuse}} - Q_{\text{ign}}}{m_f} \\ &= \frac{(11214.34 \times 0.34) - 175 - 7.01}{1.2} \\ q_{\text{vf}} &= 3035 \text{ J/g.} \end{aligned}$$

3.2.4. Corn cob Test

m_w , mass of nichrome wire = 0.005g

m_c , mass of cotton thread = 0.010g

m_f , mass of maize cob = 1.22g

mass of water in calorimeter vessel = 2kg

mass of wire after firing = 0.0g

initial water temperature = 27.8°C

bottle pressure gauge = 80bar

outlet pressure gauge = 24.5 bar

Cotton fuse is assumed to have a calorific value of $q_c = 4180 \text{ cal/g}$ (17496.6 J/g)

Nichrome wire is assumed to have a heating effect of $q_w = 0.335 \times 10^{-3} \text{ cal/g}$ (1402.2 J/g)

Temperature rise data for Corn cob Sample can be seen from the figure below. The maximum temperature rise $\theta = 0.62 - 0.19 = 0.43 \text{ K}$.

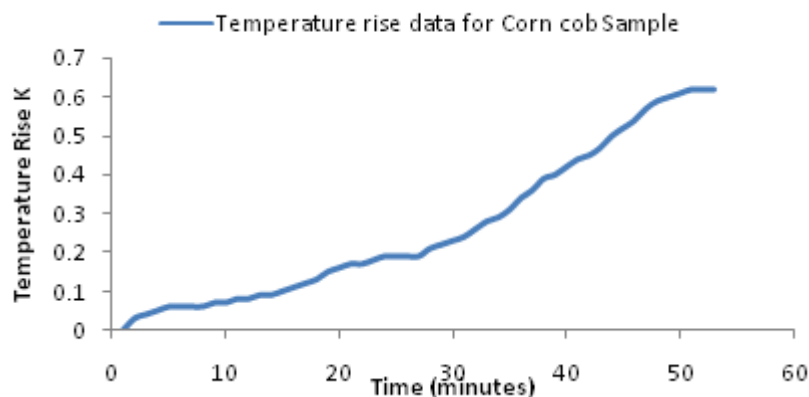


Figure 5. Temperature rise with respect to time for Corn Cob Sample

Sample calculation

For the cotton thread

$$Q_{\text{fuse}} = m_c \times q_c$$

$$= 0.010 \times 17496.6$$

$$= 175.0 \text{ J}$$

$$Q_{\text{ign}} = m_w \times q_w$$

$$= 0.005 \times 1402.2$$

$$= 7.01 \text{ J}$$

For the bomb,

$$\epsilon_{\text{cc}} = 11214.34 \text{ J/K}$$

For the maize cob sample,

$$q_{\text{vf}} = \frac{(\epsilon_{\text{cc}}\theta) - Q_{\text{fuse}} + Q_{\text{ign}}}{mf}$$

$$= \frac{(11214.34 \times 0.43) - 175 + 7.01}{1.22}$$

$$q_{\text{vf}} = 3850 \text{ J/g}$$

Table 2 Physical and Chemical Composition of Rice husk and Maize cobs. Agbongiarhuoyi, A. (2015).

SAMPLE	UNITS	RICE HUSK	MAIZE COB
CARBON	%	20.93	19.73
HYDROGEN	%	17.22	15.00
SULPHUR	%	3.82	4.48
MOISTURE CONTENT	%	48.51	42.98
GROSS CALORIFIC VALUE	J/g	12300	12255
NET CALORIFIC VALUE	J/g	3035	3850

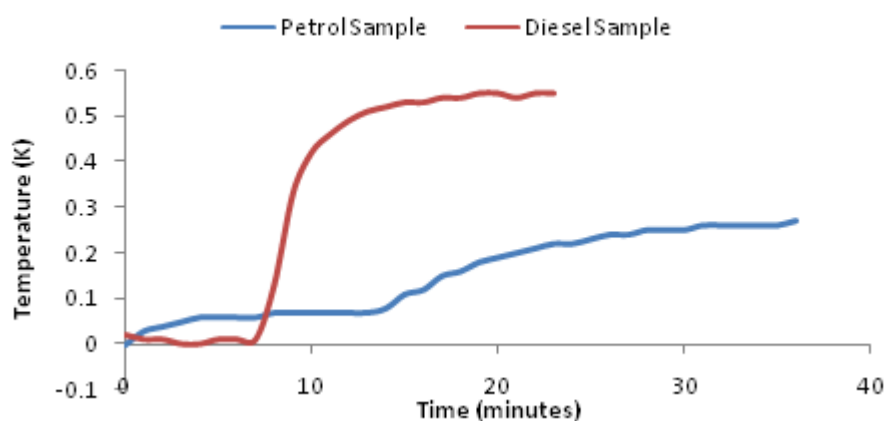


Figure. 6. Comparative analysis of diesel and petrol

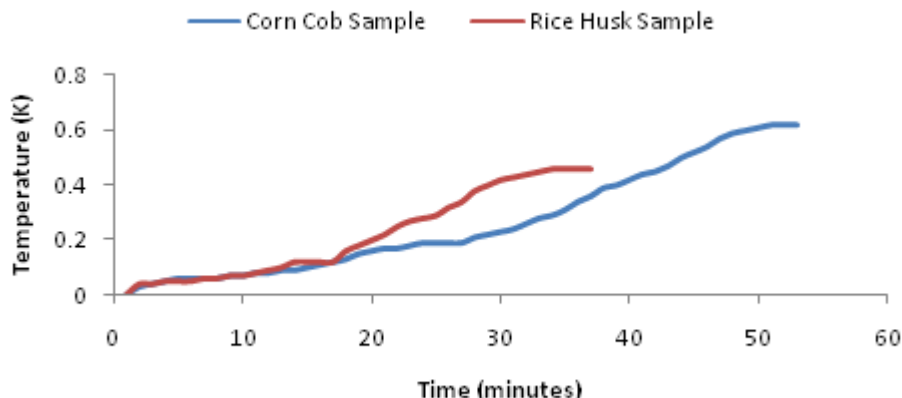


Figure. 7. Comparative analysis of rice husk and corn cob

3.3. Discussion

The graphs above show that the temperature of the combustible matter increases with respect to time. Figure 6 shows that petrol is more combustible than diesel fuel. Figure 7 indicates that corn cob has a higher calorific value than rice husk which means that corn cob is more combustible than rice husk and is a viable substitute for fossil fuels. The petrol combust faster than diesel while diesel burns at a higher temperature.

4. CONCLUSION

A sustainable energy source was produced by pelletizing rice and corn cobs into strong pellet fuel without a binder. The pellets have lightweight (1-2g), genuinely solid and can withstand compressive drive of no less than 800N, this ensures easy of transportation. The gross calorific values of these fuels; rice husk, corn cob, diesel, and gasoline have been determined experimentally with the C200 bomb calorimeter. The project showed that corn cob has a higher calorific value than rice husk which means that corn cob is more combustible than rice husk and is a viable substitute for fossil fuels. The petrol combust faster than diesel while diesel burns at a higher temperature.

RECOMMENDATION

The project has established that pellet fuel can be produced from corn cobs and rice husk without the addition of binder. However further research can be on the design of portable pellet machine and pellet stove.

ACKNOWLEDGMENTS

Authors are grateful to the management of Landmark University for all their effort towards the achievement of this research. We are also grateful to the laboratory staff and students of the university who played different roles in this work.

REFERENCES

- [1] Sami, M., Annamalai, K., Wooldridge, M., 2001. Co-firing of coal and biomass fuel blends. *Prog. Energy Combust. Sci.* 27, 171–214.
- [2] Huda, A., Mekhilef, S., and Ahsan, A. (2014) Biomass Energy in Bangladesh: Current Status and Prospects. *Renewable Sustainable Energy Review*, 30, 504–17.
- [3] Cocchi, A., Andreini, P., Cassitto, L., Del Zotto, L., Tallini, A., Di Simone, G., Molinari, G., Cedola, L., 2015. 69th Conference of the Italian Thermal Engineering Association, ATI 2014 Energy enhancement of solid recovered fuel within systems of conventional thermal power generation. *Energy Procedia* 81, 319– 338.
- [4] Velis, C.A., Longhurst, P.J., Drew, G.H., Smith, R., Pollard, S.J.T., 2010. Production and quality assurance of solid recovered fuels using mechanical—biological treatment (MBT) of waste: a comprehensive assessment. *Crit. Rev. Environ. Sci. Technol.* 40,979–1105.
- [5] Wu, H., Glarborg, P., Frandsen, F., Dam-Johansen, K., Jensen, P.A., Sander, B., 2009. Co-combustion of coal and SRF in an entrained flow reactor: a preliminary study. In: 4th European Combustion Meeting.
- [6] Buchanan, S., Burt, E., Orris, P., 2014. Beyond black lung: Scientific evidence of health effects from coal use in electricity generation. *J. Public Health Policy* 35, 266–277.
- [7] Henderson, J.E., Joshi, O, Parajuli, R., Hubbard, W.G., 2017. A regional assessment of wood resource sustainability and potential economic impact of the wood pellet market in the U.S. South. *Biomass Bioenergy* 105, 421–427. <https://doi.org/10.1016/j.biombioe.2017.08.003>.
- [8] Sikkema, R., Steiner, M., Junginger, M., Hiegl, W., Hansen, M.T., Faaij, A., 2011. The European wood pellet markets: current status and prospects for 2020. *Biofuels Bioprod. Biorefining* 5, 250–278. <https://doi.org/10.1002/bbb.277>.
- [9] IEA-ETSAP and IRENA Technology, 2013. Biomass co-firing: Technology Brief. IEA-ETSAP and IRENA.
- [10] Awasthi, M., Deepika, K. (2013). Biochemical Characterization of Agricultural Residues for Utilization in Gasification Process: A Necessity for Rural Sector. *International Journal of Sustainable Development and Green Economy* 2 (1-2) 22–26.
- [11] Kaliyan, N., Morey, R.V., 2010. Natural binders and solid bridge type binding mechanisms in briquettes and pellets made from corn stover and switch grass. *Bioresour. Technol.* 101, 1082. <https://doi.org/10.1016/j.biortech.2009.08.064>.
- [12] Ruscoe, I.M., Jones, C.M., Jones, P.L., Caley, P., 2005. The effects of various binders and moisture content on pellet stability of research diets for freshwater crayfish. *Aquac. Nutr.* 11, 87–93. <https://doi.org/10.1111/j.1365-2095.2004.00324.x>.