ENERGY ANALYSES OF BRIQUETTES PRODUCED FROM TORREFIED GROUNDNUT SHELL AND RICE HUSK

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ABSTRACT

In this work, the energy analyses of Briquettes produced from locally sourced Groundnut shell and Rice husk was determined. The proximate and ultimate analysis of the torrefied Groundnut shell and Rice husk samples were carried out.In the preparation of the briquettes (Groundnut shell and Rice husk briquette), cassava starch was used as a binding agent. The concentration of the binder was varied between 20 – 60 wt% while a constant mass of 70g of the two samples were used throughout the experiment. briquettes of Groundnut shell and Rice husk were produced according to the number of runs (20) generated by the Design Expert Software and their calorific values determined respectively using Oxygen Bomb Calorimeter. Design Expert Central Composite Design Tool was used in the design of experiments and Response Surface Methodology (RSM) was used to optimize the calorific values of Groundnut shell and Rice husk briquettes. The Design Expert Software gave optimized values of 39.525 wt% binder concentrations, 57.512 seconds and 4.316 MPa compaction pressure for Groundnut shell briquette and 33.706 wt% binder concentrations, 61.678 seconds and 4.595 MPa compaction pressure for Rice husk briquette. The result showed that the Groundnut shell briquette gave 19.754MJ/kg calorific value while Rice husk briquettes gave the calorific value of 17.869 MJ/kg. The Rice husk briquette gave the water boiling test, ignition time and burning rate of 15.82 min, 15min, 0.22 g/min respectively while the Groundnut shell briquette gave the water boiling test, ignition time and burning rate of 19.64 min, 17min, 0.16 g/min respectively. This shows that Groundnut shell and Rice husk can be recommended as raw materials for large scale production of energy.

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CHAPTER ONE

1.0 INTRODUCTION

1. Background to the Study

Decrease in the availability of fuel for domestic and cottage industries coupled with the ever-rising prices of non-renewable energies in developing countries such as Nigeria have necessitated alternative energy sources. Briquette is a good example of an alternative source of energy. This is because briquettes are very cheap and affordable (Ogwu *et al.*, 2014).

Briquettes are produced from biomass. Biomass is a natural material of biological origin which is in abundance. Its abundance in nature makes it the best alternative energy source which is good for the mitigation of greenhouse gas emissions. Biomass is usually plant based and popularly called cellulosic biomass (Shukla and Vyas, 2015). Therefore, Biomass Briquettes are formed by different agricultural wastes. Some of the briquettes formed are from date palm, sawdust, plastic wastes of different types, groundnut shell, coffee husk and pulp, rice husk and several other biomasses (Onukak *et al.*, 2017).

Over 40years ago, researchers have looked towards the area of biomass for its renewability, abundance and positive environmental impacts. Felling of trees poses serious danger to the environment which should be highly discouraged and room be given to other sources of renewable energy like agricultural waste materials (Mba, 2018; Olowoyeye, 2021). The abandonment of agricultural wastes causes water pollution when the rain water washes the decomposed biomass into close water bodies. When this water is taken, people become victims of cholera and other water borne diseases (Thliza *et al.*,2020). Biomass in its original state is hard to sustain, convey and gets spoilt during storage due to high moisture content, shapes and sizes are not regular and bulk density is extremely low. In order to solve these challenges, the process called densification is applied. Densification is the process whereby the particles of the biomass having uniform shapes and sizes after undergoing grinding is compressed with the aid of hydraulic press making it easier to be handled, stored and transported with ease. Densification is a process that brings about cost reduction and durability of the briquettes (Kumar *et al.,* 2017).

In developing countries, most agricultural wastes are dumped into water bodies or left in an open air thereby resulting to environmental pollution. However, these agricultural wastes have resources such as nutrients and energy that can be harnessed to become valuable products. The choice of agricultural wastes to be used as briquettes is solely dependent on the biomass dominant in a particular environment (Shahapur *et al.,* 2017).

The choice of rice husk and groundnut shell was necessitated by the abundance of rice and groundnut in Niger State. Rice and groundnut being the most popular food is linked with so much solid wastes such as the rice husk and groundnut shell. However, there rice husk and groundnut shell if properly harnessed and utilized could be a source of energy that can be used both at domestic and industrial levels. The most efficient way to utilize their energies is to convert them to briquettes.

There are several factors associated with the need to explore other energy sources. Some of those factors are: Overdependence of the household sector on energy which is seriously causing scarcity of wood and charcoal in the rural and urban areas, the ever rising prices of kerosene and cooking gas in Nigeria, insecurity of the forest where the coal and woods are sourced from is a major challenge in the northern part of Nigeria (Igbe *et al.,* 2022).

Many Researchers have done a lot on the production of briquettes from Rice Husk and groundnut shell but have not done optimization of their calorific values. Calorific value is the most important in energy industries because it is a basic requirement for fuel that is used to assess the competitiveness of market situation. This research is set to perform the optimization of the calorific value of rice husk and groundnut shell briquettes.

1.2 Statement of the Research Problem

The demand for energy at domestic and industrial level has increased due to increase in population. These agricultural wastes are left in an open field to decompose, therefore causing environmental pollution (Shahapur *et al.,* 2017). Calorific values of most agricultural waste materials have not been optimized. Optimization of the calorific value is very important because it is the basic requirement of a fuel that is used to assess competitiveness (Sharma *et al.,*2015).Among the biomass being investigated for briquettes production by many researchers, calorific values of groundnut shell and rice husk are yet to be optimized using Design Expert Software (Chukwuneke *et al.,* 2020).

1.3 Justification of the Study

- Agricultural wastes are sources of renewable and sustainable energy.
- They are also readily available and cheap.
- There is a need to explore alternative source of energy such as briquettes made from agricultural waste materials.
- Gives cleaner energy and mitigates greenhouse effects.
- Going into the use of these briquettes will minimize deforestation in rural and urban areas.

- Many agricultural waste materials have been used for the production of briquettes and as such calorific value which is a measure of its energy content have not been optimized for groundnut shell and rice husk briquettes.

1.4 Aim and Objectives of the Study

The aim of this work is to determine the energy content of briquettes produced from torrefied locally sourced agricultural waste materials. This aim was achieved through the following objectives:

I. Treatment and characterization of groundnut shell and rice husk.

II. Torrefaction of groundnut shell and rice husk.

III. Optimization of the calorific value from produced briquettes using Design Expert Software.

IV. Performance evaluation of the produced briquettes.

1.5 Scope of the Study

The scope of this work is to determine the energy content of the following prepared briquettes from torrefied agricultural waste materials: Rice husk and groundnut shells.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Biomass

The need for alternative energy sources aside crude oil has been on the increase due to increase in population, giving rise to increase in demand. It is also anticipated that crude oil will deplete over time due to its un-sustainability. The major source of global energy had been fossil fuels and as such, large quantities of hydrocarbon oils, gas and coal were tapped from the ground. These fossil fuels are used largely in transport engines, for heating, generating electricity and feedstock to petrochemical industries. Amidst its advantages, there are so many challenges associated with it. This brought about a shift to a more sustainable energy sources (Kumar, 2017; Ismaila *et al.*, 2013).

Biomass is biological in nature and gotten from living organisms. It is usually plant based and popularly called cellulosic biomass. They serve as energy sources and could be used directly by burning; this is to produce heat or it is usually converted to other forms of biomass fuels (Shukla and Vyas, 2015).

Biomass wastes otherwise known as organic materials are produced as a by-product during harvesting and process of agricultural crops. Biomass waste accounted for about 12.2% of global primary energy consumption which constitute 73.1% of the world's renewable energy. It is also the third largest source of energy after oil and coal (Tumuluru *et al.*, 2010).

Biomass has several advantages, which are: it is inexpensive than coal, it has no fly ash when burning, it has high burning efficiency and it is a renewable energy source that improves the environment. Looking at its advantages, it is the main energy source in developing countries like Indonesia, India and Brazil. Biomass in its original state is hard to sustain, convey, gets spoilt during storage due to high moisture content, shapes and sizes are not and has extremely low bulk density. In order to solve these issues, densification is applied. Densification is the process whereby the particles of the Biomass with uniform shapes and sizes are compressed by hydraulic press, making it easily handled, stored transported easily. Densification brings about cost reduction and makes the Biomass durable (Kumar *et al.,* 2017). Biomass briquettes have been proven to generate energy from waste. Some of the briquettes formed are from date palm, sawdust, plastic wastes of different types, groundnut shell, coffee husk and pulp, rice husk and several other biomasses (Onukak *et al.,* 2017).

2.2 Environmental Impacts of Agricultural Wastes

Agricultural wastes (AW) can be defined as the residues from the growing and processing of raw agricultural products such as vegetables and crops. Agricultural wastes can be in form of solid, liquid or slurries depending on the nature of agricultural activities. In this research, the focus is on solid wastes. Agricultural wastes are significant environmental burdens that may lead to ground and water pollution if not utilized properly. It was said by the Federal Ministry of Environment in 1989 that Nigeria loses about US$750 Million annually due to depletion in forest cover. It was also forecasted that in 2030, the country will lose its potential revenue and unemployment will be on the increase. Some of the advantages of forests are; erosion prevention, flood prevention, proper water management, fisheries protection. Felling of trees poses serious danger to the environment (Mba, 2018; Olowoyeye, 2021). For example, the burning of agricultural wastes results in air pollution and emission of the greenhouse gases(GHG). Agricultural wastes such as Rice husk, Groundnut shell, Date palm, Paper wastes, Corn cobs, Sawdust, Soybean husk, Sugarcane, Tobacco wastes, Tea wastes, Palm husk, Wheat straw, Wood chips, Bagasse, Coffee husk and Bamboo dust are produced in large quantities. The conversion of agricultural wastes into biochar is an efficient waste management strategy than are the conventional waste management methods. Biomass waste utilization for the synthesis of biochar through pyrolysis is a promising environmental waste management approach, which reduces the environmental challenges caused by agricultural waste disposal (Shahapur *et al.*, 2017).

2.3 Health Impact of Agricultural Wastes

In developing countries like Nigeria, there is over dependence on solid fuels such as Fuel-wood and Charcoal. As a consequence, little attention is given to agro-waste. Most of the agro-waste are heaped in one place and abandoned causing their decay which poses danger to the society. When rain falls, it washes these heaps in the stream or river which usually is the source of water. The polluted water is taken and people become victims of cholera and other water borne diseases (Thliza *et al.*,2020).

2.4 Energy Sources

Energy is a major factor in the developmental process of a nation. The level of wellness and quality of life of a nation is attributed to it per capital energy consumption. The provision of a reliable and affordable energy is the key to life improvement and sustainable development.

In developing countries, wood is the most common energy source followed by animal dung and crop residues. The realization of the fact that wood may not be readily available shifted the focus of many researchers to find alternatives. According to many researches, agricultural wastes have been discovered to be a very good alternative if converted to briquettes (Shahapur *et al.,* 2017). Some of the agricultural wastes explored are: rice husk, groundnut shell, saw-dust, cotton stalk, cashew shells, bagasse, palm fibre, corn cob, eucalyptus bark, coconut shell, rice straw, cane trash and so on.

2.5 Calorific Value

The major energy term in analyzing briquettes is the Calorific Value. The Calorific Value is the most important characteristics of fuel in a market situation (Boroswki, 2014). It is the amount of energy per kilogram it exudes during combustion. Calorific Values are considered to have high thermal energy when it is high. This implies that the bigger the Calorific Value of a substance, the more thermal energy is expected from it during combustion (Olga *et al.,* 2017). According to Onuegbu *et al.* (2012), the Calorific Value of spear grass and elephant grass were 16.13MJ/kg and 15.98MJ/kg respectively after briquetting while the Calorific Values were 15.12MJ/kg and 14.66MJ/kg before briquetting. This shows that briquetting increases the Calorific Values of biomass due to reduction in moisture content and the use of cassava starch as a binder.

Some materials have better calorific value than others although the choice of feedstock is dependent on the availability in a geographical area. There is a need to look at the availability of feedstock in order to minimize cost (Jekayinfa *et al.,* 2020).

Converting rice husk into useful solid fuel briquette is a welcome technology that would serve many purposes which include providing cheap energy and environmental pollution control by reducing wild dumping of rice husk by rice millers in rice growing region in Nigeria (Sani *et al.,* 2019).

Agricultural wastes have different calorific value as a result of feedstock and compaction pressure. The table below shows the calorific value of some selected agricultural waste briquette with compaction pressure of 18 MPa and dwelling time of 60 seconds (Akpenpuun *et al.,* 2020).

Table 2.1: Calorific Value of Some Agricultural Wastes

Biomass Material	Calorific Value of Briquette (MJ/kg)
Bagasse	18.3260
Bamboo dust	17.4054
Castor seed shell	16.1586
Coffee husk	16.9243
Coir pitch	17.3469
Jute waste	18.5268
Groundnut shell	18.9284
Paper	20.2547
Paddy straw	14.5143
Palm husk	16.3176
Rice husk	13.3888
Sawdust	16.3092
Sunflower stalk	17.9912
Soybean husk	17.4473
Sugarcane	16.7193
Tobacco waste	12.1754
Tea waste	17.7276
Wheat straw	17.1544
Wood chips	20.0204

Source: (Food and Agricultural Organization (FAO, 1996))

2.6 Briquettes

Briquettes are solid materials that are highly flammable used to ignite and sustain fire. There are different Briquettes which are the briquettes from wood called Charcoal Briquettes and Briquettes from Biomass such as date palm trunk, plastic of different types, groundnut shell, coffee husk and pulp, rice husk, corn cob and so on (Onukak *et al.*, 2017). A typical example of briquettes is the briquettes made from wood and it is obtained by transforming low density pulverized carbonaceous matter from Briquettes to a high density and energized Briquettes from wood (Lamido *et al.*, 2018). The production of briquettes from any agro-based material requires the use of a binder. The process flow of corn cobs briquetting operation is illustrated below (Zubairu and Gana, 2014). Briquette production from rice husk using mold and press briquetting method requires more binder aside water. The most commonly used binder for rice husk briquetting are clay, starch, cow dung, molasses and resins. This is to agglomerate rice husk for better and effective combustion (Sani *et al.*, 2019). Briquetting improves the physical, chemical and combustible properties of the raw materials (Olaoye and Kudabo, 2017).

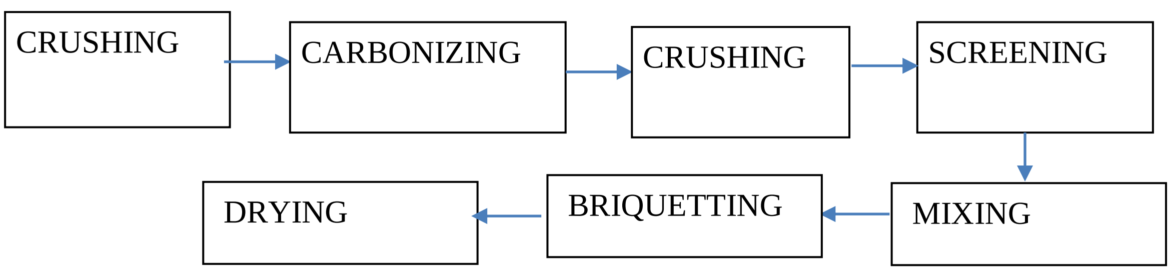

Figure 2.1: Briquetting Operation

2.6.1 Advantages of using briquettes over other solid fuel

The usage of briquettes has several advantages over solid fuel which are as follows: They are very cheap as compared to coal, thermal value is higher in biomass briquettes as a result of their low moisture and higher density, they give higher boiler efficiency, they have higher combustion uniformity as compared to coal, they have higher ash content as compared to coal and its environmental pollution is very minimal since it has no sulfur content (Suryaningsih *et al.*, 2017).

2.6.2 Advantage of setting up briquettes plant project

The setting up of a briquetting plant project comes with several advantages such as: There is no fly ash when briquettes are burnt, they have consistent quality, Sulfur content of coal or oil normally pollutes the environment while burning of briquettes does not pollute the environment when carbon dioxide captured is incorporated, they are easy to convey, store and hygienic to handle and since they have low moisture and higher density they have higher boiler efficiency when compared to firewood and loose biomass.

2.6.3 Briquetting process

Agricultural wastes burn so rapidly that it difficult to maintain a steady fire due to difficulty in controlling the combustion process. Also, wastes do not fit in form and structure for traditional coal pots and stoves. While recycled wood wastes had found some use as fuel by burning them directly in retrofitted industrial boilers, direct burning of loose bulky agricultural wastes is inefficient. They have low energy value per volume and hence are uneconomical; they also cause problems for collection, transportation, storage, and handling. One of the approaches that is being pursued in some parts of the world, for improved and efficient utilization of agricultural residues is their densification into solid fuel pellets or briquettes. This involves reducing the size by pressing the bulky mass together. The ease of storing and transporting such an improved solid fuel briquette of high specific weigh makes them attractive for use at home and in industries. Unlike the loose and the bulky form, combustion of briquettes can be more uniform. This could make is possible for briquetted materials to be burned directly as fuel in somewhat similar fashion as the fuel wood and coal in domestic stoves and ovens. Some developing countries like India, Thailand and few places in Africa have had experience of substituting fuel briquettes for fuel wood and coal to reduce the problems of firewood shortage and farm waste disposal (Bhattacharya *et al.,* 2000).

2.6.4 Binder

Binders are very important materials in the production of briquettes. Most of the materials used in making briquettes are loose and as such a sticky material is needed to keep them together. After the binder must have been added, the formed briquettes are oven dried to remove water so as to make it strong enough to be used in burning apparatus. Binders are required to be combustible for effective usage however; a binder at low concentration can also be suitable. Some of the examples of binders are: starch, clay, lime, plaster of Paris popularly known as POP, magnesia, tar, pitch from coal distillation, asphalt, sulphite liquor residue, molasses, resins and cement. The best binder for application is dependent on the locality and the briquetted material. In general briquetting operation, starch is widely advised because it is the most effective material known (Zubairu and Gana, 2014). Briquette binders are categorized into three: Organic, in-organic and composite binders (Zhang *et al.*, 2018). Briquettes can be replaced with conventional fuels such as: kerosene, diesel, furnace oil, lignite, coal, firewood and have the following advantages (Sharma *et al.*, 2015):

2.7Factors Affecting Biomass Waste Compaction Process

Regulating densification system requires some influential variables. These variables are important in obtaining the required density, stability and superiority. The quality of briquettes can be manipulated by controlling the process variables such as formulation, and the use of additives. The variables include the process variables, feedstock variables and biomass compaction variables. Extensive study was done on densification of biomass and the finding expressed the contribution of these variables in determining the quality of briquettes.

2.7.1 Process variables

Process variables are those factors that are set and carried out on biomass materials by the briquetting machine. The process variables include temperature, compaction pressure, retention time (dwelling time), concentration of the binder and the die geometry.

2.7.1.1 Temperature

Temperature was found to play a major role in the density of the briquettes. Increasing temperature of compressing operation will entail the use of fewer loads (Mani *et al.,* 2003). This however, would use lesser power for densification thus produces briquettes of desired density. This confirms Hall and Hall research as reviewed by Tumuluru *et al.*, (2010) who discovered that increasing temperature in wafer die would reduce pressure at any given moisture content. In like manner, heat addition at increased moisture content at a particular pressure would produce specific wafer density adding heat, increased the moisture content at which a certain pressure was able to produce a specific wafer density.

When temperature is increased, the materials tend to resist against the load applied (Sokhansanj *et al.*, 2005). On investigating briquetting of wheat straw, Tumuluru *et al.*, (2010) reviewed smith's work on compaction process and found out that for a given pressure, at a temperature range of 60 – 140 ºC, there is great degree of compaction and stability of the briquettes produced. The report also stated that the time required for the briquettes to expand was less when the die temperature is between 90 and 140 ºC. The report however observed that for wheat straw briquettes, there are external charred at the surface and a slight discoloration at temperature above 110 ºC. This is due to chemical degradation as the walls of the briquettes are building up. In a study that evaluated the densification potential of corn stover and switch grass using temperature as key parameter, it was observed that there is transition from hard to a soft, rubbery material (glass transition temperature). Kaliyan and Morey (2006) also studied compaction activities of corn stover and switchgrass and found that at 10, 15 and 20% moisture content, the recorded temperature was 75 ºC. The summary of the findings indicates that increasing moisture content generally reduce the glass transition temperature to the end point of 100 ºC. Consequently,75ºC and 100 ºC were chosen as optimum processing temperatures for briquettes. At 150 ºC, it was observed that there was moisture migration resulting in a lower durability than 100 ºC briquettes. The toughness of briquettes produced at 100 ºC was higher than those produced at 75 ºC.

2.7.1.2 Compaction pressure

Pressure is another variable that distinguishes briquettes quality significantly. The selection of compacting pressure at optimum value but obtaining the optimum value has been a major challenge because materials are different in behavior during pressure application. Supposedly, briquetting pressure increases the mechanical strength of the briquettes as a result of plastic deformation. However, above an optimum briquetting pressure, fracture may occur in the briquettes due to an unexpected expansion on the briquettes (Yaman *et al.,* 2000).Once amaximum pressure is attained, further increase in pressure will amount no significant increase in the cohesion of the briquettes (Ndiema *et al.,* 2002).

Compressing Oat sawdust at 10.3 % moisture content and applying pressure at rates 0.24 - 5.0 MPa/s has significant effect on the dry density. In the study of compression of biomass waste materials like waste paper, it was observed that increasing the pressure from 300 to 800 MPa at about 7% moisture content, increased the density of the material from 0.182 to 0.325 g/ml. For material at 18% moisture content at the same pressure, the briquettes densities were increased up to 0.278 and 0.836 g/ml respectively (Li and Liu, 2000). A contradicting report on the effect of pressure on final briquettes quality shows compacting pressure has minor influence in analyzing effect of compaction on briquette quality

2.7.1.3 Holding time (Dwelling time)

Dwelling time in briquette is the total number of time (sec) the compacting die is left on the briquette after operation. The dwelling time of biomass material in the die influences the quality of briquettes produced. It was observed that the dwelling time for Oak sawdust had more effect at lower pressure than at higher pressures. At 138 MPa, the influence of dwelling time became unnoticeable. Its influence on expansion rate is very small such that time greater than 40 seconds had a minor effect on density (Li and Liu, 2000). Dwelling time between 5 and 20 seconds do not usually have a significant effect on the olive cake briquette toughness and steadiness.

2.7.1.4 Die geometry

Die geometry refers to the dimensions of the die that affects briquetting operation of a given amount of material. This geometry are shape, size and configuration of the briquetting die. These configurations determine the energy required for compression and so on. In a review, it was observed that for a given quantity of a biomass material, increasing the surface area of the briquetting die can increase the density of the briquettes at a given pressure. It was also observed that height of briquettes produced with smaller chambers using a constant mass of material will be higher thus there will be a resultant smaller percentage in expansion (Tumuluru *et.al.*, 2010).

2.7.1.5 Binder concentration

The concentration of binder in any biomass briquettes is an important factor. However, low concentration of binder is suitable because it enhances combustion while high concentration of binder slows combustion process due to high moisture content (Zubairu and Gana, 2014).

2.7.2 Biomass waste variables

Biomass waste variables are those variables that affect the composition and properties of the biomass material. Biomass variables are also referred to as process variable which earlier mentioned. Some of the biomass variables are: particle size, heating rate, gas flow rate and feed rate.

2.8 Briquetting Machine Components

According (Gajbhiye and Raut, 2018), the briquettes making machine has several components which are as follows:

2.8.1 The main frame

The main frame serves as support to other parts of the machine and is usually made of mild steel during fabrication (Gajbhiye and Raut, 2018)

2.8.2 The hoper

This is conical shaped part of the machine through which the raw-material is introduced into the machine and it is made of mild steel. In order to attain maximum production rate, the hopper is designed is designed to accommodate large amount of the raw-material (Gajbhiye and Raut, 2018).

2.8.3 The v-belt

In order to transmit power between the motor and the shaft, the V-belt is used. The belt can be used to connect two or more rotating shaft mechanically. The V-belt has some basic advantages amongst other belts which are: It provides longer life; it can be easily installed and can be easily removed. The Plate below shows the V-belt (Gajbhiye and Raut, 2018).

2.8.4 The pulley

The machine works properly when two pulleys are used. One of the pulleys is driven by an electric motor while the other is driven on screw. The pulleys are usually made of cast iron. The drive element could be a rope, cable, belt or a chain (Gajbhiye and Raut, 2018).

2.8.5 Horse Power motor

The HP motor is used to cover electrical energy to mechanical energy (Gajbhiye and Raut, 2018).

2.8.6 Bearing

The bearing is a machine element that supports another moving machine element in order to reduce friction between the moving parts. As it carries load, it allows a relative motion between contact surfaces of the members. The classification of bearing is based on three things which are: the type of operation involved, the motion allowed and the direction of the load (Gajbhiye and Raut, 2018).

2.8.7The screw

The screw is basically used to transmit power from one part to the other. It is usually power driven and the pulleys/gears are mounted on it.The aforementioned components of the briquettes making machine has the following descriptions: the main frame (M.S. plate) is 4.5mm, the V-belt is B-65, the pulleys (cast iron) 10inch section B and 2inch section B, I HP Motor rotates at 14rpm, the bearing of N 6210 and Screw (cast iron) is 2inch in diameter (Gajbhiye and Raut, 2018).

2.8.8 How the briquette making machine works

The raw-materials which could be rice husk, soybean husk, bagasse, sugarcane wastes and so on are fed into the hoper in the right proportion to get the a closely packed briquette. The briquette machine is then operated by the motor which is coupled with the screw by the help of the V-belt and pulley (Jasiczek and Kwasniewski, 2020). As the screw moves forward, it exerts pressure on the plate which presses the raw-materials in the chamber and as a result, the briquette is formed. As soon as the briquettes are formed, it moves backward to its original position. In order to ensure a continuous operation, the process is repeated again (Gulhane and Handa, 2017).

2.9 Application of Briquettes

I. Briquettes are used in boilers for steam generation and heating.

II. Briquettes are used in foundries for metal heating and melting.

III. Briquettes are used in brick kilns for firing of furnace.

IV. Briquettes are used for residential heating like Hotels, Canteens and for winter heating in cold areas.

2.10 Type of Wastes Used for Briquettes Production

According to Prasityousil and Muenjina, (2012), there are various types of wastes used in the production of briquettes which are as follows:

2.10.1 Municipal solid waste

They are organic wastes that are generated by sectors such as residential area, industries, markets and institutions. Economic development and urbanization have led to the increase in the quantity and complexities of municipal wastes in cities of developing countries leading to serious concerns over the proper waste management in local communities.

The availability and abundance of these wastes makes it very suitable as raw material for briquettes production. Some good examples of municipal solid wastes are: agro-residue, banana rachis, cartons and textiles, charcoal dust/fines, coffee husk, wood residues, lignite, plastics, sawdust, sorghum stalks, corn Stover, wheat straw, sugarcane bagasse, coconut shells, switch and hey grass, and vegetable wastes (Young and Khennas, 2003).

2.10.2 Industrial waste

Sludge waste from refined palm oil industries, recycled plastics such as Polyethylene with high density (HDPE) and polypropylene (PP) are very good for the production of briquettes. When these plastics are added, high densification and high calorific value are obtained due to the presence of lignin.

2.10.3 Sludge

There are several materials used in producing briquettes of which sludge is one of them. Sludge is mostly a by-product of both domestic and industrial wastewater treatment. In treating wastewater, biological means is usually employed in achieving that because of its high moisture content. There are six steps in converting raw sludge to briquette. These steps are; dewatering and treatment, drying, carbonization, blending and binding, extruding and molding. The final step is usually followed by drying to complete the process.

2.10.4 Agricultural waste

Agricultural waste refers to all organic materials that are produced as the by-product from agricultural activities. They constitute the major part of thr total annual production of biomass residue and are very important source of energy (Sugathapala and Chandak, 2013). In developing countries like Nigeria, large amount of agricultural wastes are wasted through open dumping or burning indiscriminately (Kpalo *et al*., 2020).

Agricultural wastes are generally wastes usually obtained from agricultural processing plants. Groundnut shells are obtained when Groundnut is being processed. Rice Husk is obtained when paddy rice is being milled (Oyelaran *et al*., 2018). Several other agricultural wastes like date palms, corncob, orange peels, rice stalks and so on are product of processing. Agricultural waste has been considered one of the versatile for cooking and heating purposes due to its renewability and sustainability (Oyelaran, 2015).

2.11 Torrefaction

Torrefaction is the pre-treatment of the biomass in order to improve the hydrophobicity, the grindability, energy density and durability (Portilho *et al.*, 2020). In some literatures, it is referred to as a partial pyrolysis of biomass in an environment with no oxygen and with temperature range from 200 ^{o}C to 300 ^{o}C. Torrefied biomass are usually dark brown and condensable gases rich in organics and non-condensable such CO and CO_2 are produced. Torrefaction is divided into two: dry torrefaction and wet torrefaction (Okot, 2019). The dry torrecfaction is a thermal decomposition of biomass in inert environment at a temperature between 200 ^{o}C to 300 ^{o}C. The wet torrefaction is carried out at a temperature range of 180 to 250^{o}C. During wet torrecfaction, sub-critical water acts as a solvent/catalyst and reagent enhancing dehydration and breaking down of biomass (Dhital and Bajaracharya, 2016).

Torrecfaction being the partial pyrolysis gives rise to three products which are: Solid, gas and liquid. The gaseous products are mainly CO, $CO_{2,}$ and hydrocarbons and small amount of $H_{2.}$ The liquid products are usually acidic with very high water content of 63 to 86% giving rise to low heating value. The solid product is the main product of torrefaction.

2.12 Key Characteristics of the Feedstock Used in Making Briquettes

The proximate analysis of the feedstock plays an important role in determining the quality of the Briquettes that will be formed and as such, the following properties must be examined (Asamoah *et al.*, 2017).

2.12.1. Total carbon content

This is carried out in order to determine the quantity of carbon inside a material regarded as waste. This amount of carbon is what must be used up through burning in order for heat to be released.

2.12.2. Volatile matter

The volatile matter is a part of the biomass that is usually released during carbonation, therefore the amount of this volatile matter is of importance because too much of it leads to emissions when the biomass is burned. Low volatile matter is mostly preferred.

2.12.3. Fixed carbon

This is the amount of solid remaining after complete carbonation of the feedstock which is used to produce briquettes. When the carbon content of the feedstock is high, it gives durable and strong carbonized briquettes.

2.12.4. Ash content

When a material is burned, the powdery residue left is called ash which is made up of non-combustible materials. The amount of ash left is of high importance because if the amount left is high, ash slagging will occur. This has great effect in the combustion process causing over-heating of the Biomass stove which in turn leads to corrosion. However, an optimum quantity of ash is needed in order to have control of the burning process as well as avoid corrosion of the parts.

2.12.5. Moisture content

Moisture acts as binder in a briquetting process. The action of moisture is achieved by reinforcing and simulating bonding via van der waal forces by increasing the contact surface area of the particle (Mani *et al.,* 2003). Moisture present in the biomass accelerates starch gelatinization, protein denaturation and fibre solubilization process during briquetting. As a general rule, higher moisture content lowers the density of the briquettes. Investigation of the effect of moisture on briquette quality was carried out. Increasing the amount of moisture content of material from 7 – 15% of pulping residues and spruce wood sawdust resulted in stronger briquettes (Demirbas *et al.,* 2004). It was also reported that low moisture content (5 – 10%) of corn stove resulted in a more stable, durable and denser briquettes than at higher moisture contents of 15% (Mani *et al.,* 2006).

Optimum moisture content for densification is different for different types and species of materials which makes the set individual biomass waste process conditions also different. However, processing of briquettes at moisture content range of 8 – 15% will not have much effect on the durability of the briquette (Theerarattananoon *et al.,* 2011: Arzolar *et al.,* 2012).

The moisture content of the feedstock has great effect on the production cost of when energy is involved. Production can be highly minimized through drying and densification of Biomass. Very low moisture content will lead to the flakiness of the raw material. This implies that an optimal level of moisture is needed to ensure proper bonding of the feedstock.

2.12.6 Bulk density

A very high bulk density will lead to high durability which has resistance to shear stress. A high bulk density will increase the transportation cost due to high weight or volume of the raw material (Hibane *et al.,* 2018).

2.12.7 Particle size

Generally, the briquette quality is inversely proportional to the particle size. Particle size distribution has an effect on pellet quality (Mani *et al.,* 2003).

The bonding ability of the raw material used in the production of briquettes is enhanced when the particle size is small. However, different particle size will also enhance the bonding ability of the raw material because the smaller ones will fill up the spaces caused by larger ones in order to keep them together.

2.12.8 Ultimate analysis of the raw material

The ultimate analysis of the raw material (waste) is very essential which involves the quantifying of the elemental content of the wastes. The elemental content has great effect on the combustion property of the materials which has to do with the level and types of emissions that will be generated during the usage of the briquettes. The ultimate analysis gives the opportunity of knowing the gases that should be monitored since the briquettes are largely used indoors. Such gases are: carbon monoxide, fine particulate matter, nitrogen oxide, hydrogen, oxygen, and chlorine and sulfur oxide.

According to (Onukak *et al.*, 2017), the proximate analysis to determine the chemical elements (carbon, hydrogen, oxygen, nitrogen and sulfur) of the produced briquettes was carried out. Also, the following energy evaluation analysis of the produced briquettes was carried out:

2.13 Energy Evaluation Analysis of Produced Briquettes

2.13.1. Thermal fuel efficiency (TFE) test

When looking at the energy evaluation of produced briquettes, the thermal fuel efficiency test is usually conducted to check the quality of the briquettes while burning. Briquettes with good thermal efficiency will burn effectively at a very short time, reduces carbon footprint and reducing our dependence on fossil fuel (Hersztek *et al.*, 2019).

2.13.2. Burning rate

The burning rate was determined using insulated Biomass Stove, stop watch and a fire source. Burning rate is the rate at which a known mass of briquette is allowed to burn completely in the presence of oxygen. The Briquette was placed in a biomass stove and lighted until it started burning. The time taken by the briquette to burn completely was recorded using the stop watch as adopted by (Ameh *et al.*,2019).

2.13.3. Ignition time

This is the time taken by a known mass of fuel to ignite. The easiness of briquettes to ignite leads to proportionate increase in the flame length. Ignition time is also a function of the surface area of the briquettes exposed to burning. Larger surface area will take longer time to ignite unlike smaller surface area. Moisture content of produced briquettes affects the ignition time. Briquettes with very low moisture content tend to ignite easily unlike briquettes with relatively high moisture content. Combustibility of the materials used in producing briquettes plays a very vital role in igniting a briquette. High combustible briquetting materials will ignite easily.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

Rice husk was sourced from Zaworo Rice Mills, Bida Niger State and Groundnut Shell was sourced from Sonmazhiko, Gbako Local Government of Niger State, Cassava Starch and distilled water.

3.2 Equipment

Table 3.2: List of Equipment and Apparatus used

S/N	Equipment	Model	Manufacturer	Source
1	Briquetting Rig		Metallurgical and Material Engineering	ABU, Zaria
2	Oxygen Bomb Calorimeter	GD ISO1716	China	NAPRI, ABU Zaria
3	Grinding Machine		KMT Production Machinery India private Limited	NCRI Badeggi Bida, Niger State
4	Measuring Cylinder			ABU, Zaria
5	Analytical Balance			ABU, Zaria

Briquettes Rig, Oxygen Bomb Calorimeter, Grinding Machine, Measuring Cylinder and Analytical Balance.

3.3 Methods

3.3.1 Treatment of the Groundnut shell and Rice husk

The initial treatments of the agricultural wastes (Rice husk and Groundnut shell) were carried out through: sorting, drying, size reduction. The sorted feedstock was sun dried for 14 days and then taken for characterization.

3.3.2 Characterization of the Groundnut shell and Rice husk

The following methods of analyses were used to characterize the briquettes: Proximate and Ultimate Analyses.

3.3.2.1 Proximate analysis of the pre-treated Groundnut shell and Rice husk

The proximate analysis was carried out to determine percentage volatile matter; percentage moisture content; percentage ash content and percentage fix carbon.

(a) Percentage volatile matter (PVM): The percentage volatile was determined using the standard method CEN/TS 15148. Two grams of briquette sample was pulverized and oven dried at 105ºC until its weight was constant. The sample was then heated at 550ºC for 10 min and weighed after cooling. The percentage volatile matter was calculated using:

$$PVM = \frac{A-B}{A} \times 100 \qquad (3.1)$$

Where A is the weight of the oven dried sample and B is the weight of the sample after 10 min in the furnace at 550ºC.

(b) Percentage Moisture Content on dry basis: The percentage moisture content (PMC) was determined using standard CEN/TS 14774. Three grams of briquette sample was oven dried at 105 ± 2 ºC until a constant mass was obtained. The change in weight (D) after 16 – 24 hours was then used to determine the sample's PMC using:

$$PMC = \frac{\mathrm{D}}{\mathrm{E}} \text{ x } 100 \quad (3.2)$$

where D is change in weight and E is the initial weight before drying.

(c) Percentage Ash Content: Percentage Ash Content (PAC) was determined using standard CEN/TS 14775. Two grams of the briquette was heated in a furnace at 450 ºC for 1 hour and weighed after cooling to get the weight of the ash (C). PAC was determined using:

$$PAC = \frac{\mathrm{C}}{\mathrm{A}} \text{ x } 100 \quad (3.3)$$

where C is the weight after cooling and A is the weight of the oven dried sample.

(d) Percentage Fixed Carbon: The Percentage Fixed Carbon (PFC) was computed by subtracting the sum of PVM, PAC and PMC from 100

$$PFC = 100\% - (PVM + PAC + PMC) \quad (3.4)$$

3.3.2.2 Ultimate analysis of the Groundnut shell and Rice husk

National Cereal Research Institute has a low – power miniature neutron source reactor (MNSR) located at Badeggi Niger State, Nigeria was used to determine then concentration of elements in each of the raw samples using neutron activated analysis. Neutron Activated Analysis is based on the principle that stable isotopes become radioactive after exposure to a neutron source. While these isotopes decay, having half lives varying from seconds to years, they emit beta- radiation of certain energy which is unique in characterizing most elements.

Counting of induced gamma rays in the activated products was carried out using a PC-based gamma ray spectrometry set-up, which consists of horizontal dipstick High-Purity Germanium (HPGe) detector. As different isotopes have half lives, counting was delayed for three weeks to allow interfering species to decay. This technique provides multi element analysis with minimum detection limits in sub-ppm range. Sample size for testing was kept below 1 mm and no pretreatment was carried out on the samples to avoid destruction of composting materials.

3.4 Torrecfaction of the Treated Groundnut shell and Rice husk

The agricultural wastes (Rice husk and Groundnut shell) was torrefied at a temperature range of 240 – 260 ^{o}C using muffle oven for a period of an hour at NCRI Badeggi, Bida Niger State.

3.5 Briquetting of Pre-Treated Groundnut shell and Rice husk

According to (Ameh *et al.*, 2019), a biomass mixture was prepared for briquettes production using a constant mass of biomass (Rice husk and Groundnut shells) of 70g and different concentration of binder; (20 to 60 wt.%), 145 ml of distilled water was used. Based on the design Expert used (CCD), twenty runs of briquettes of Rice Husk were produced and twenty runs of briquettes of Groundnut Shells were also produced respectively. Binders in form of paste were prepared using hot water of temperature 100^{o}C (20 to 60 wt % binder + 145 ml of hot water). At the start of the production of the briquettes, a hot water starch binder in the form of paste was added to biomass (torrefied Rice Husk and Groundnut shells), stirred thoroughly for uniform mixture, the prepared mixture was charged into a laboratory hydraulic press machine. The briquettes mould consists of 12 dies arranged in three rows, each with dimension of 11cm height and 7cm diameter. The mould was covered with a top plate and compressed manually at varying pressures of (2 – 5 MPa) and at varying dwelling time of (40 – 120 seconds) for briquette formation. The briquettes formed were sun dried for 14 days before further analyses (Bogale, 2009). The briquetting machine used is shown in plate 1

Plate I: Briquetting Rig

3.6 Determination of the Calorific Values of the Produced Briquettes

The calorific value of the groundnut shell and rice husk briquettes was determined using Cussons-bomb Calorimeter in the Laboratory of NCRI Badeggi Niger State as recommended by Namadi *et al.*,(2018). The following materials were used; Cussons-bomb Calorimeter, Beckman Thermometer, (0 – 6 ºC), Magnifying eye piece, Crucibles, Vices, Spanners, Oxygen Cylinder, Digital Weighing Balance, Syringe (50 ml), Cotton Thread, Ignition Fuse Wire, Stop Watch and 0.50/0.51 g of groundnut shell sample.

The groundnut shell and rice husk samples to be tested were ground into very small fine particles, clean and empty crucible was weighed using Digital Weighing Balance and later filled with 0.50/0.51 g of groundnut shell sample. The Cussons-bomb Calorimeter was properly cleaned before starting and 10 ml of distilled water was pipette into the bomb. A Fuse Wire of length 6 cm was connected across the terminals of the bomb along with some Cotton Thread linked with the groundnut shell sample placed into the crucible. The bomb was carefully closed using the Vice and Spanner and connected to the Oxygen Cylinder where it was charged carefully with oxygen up to about 25 atm.200 ml of distilled water was added into the Calorimeter Vessel and bomb was carefully submerged into it and checked to ensure no oxygen leakage. The Beckman Thermometer and Stirrer were arranged so that they do not touch the bomb or the vessel; the Stirrer was then switched on. Having the Stirrer running successfully and the temperature was noticed to be rising steadily; a series of reading at one minute interval was taken for 3 minutes and then uniformly over a period of one minute by unscrewing the bomb. The bomb was opened, observed for proper combustion, rinsed out, cleaned and dried. The same procedure was repeated for the rice husk sample.

The calorific value of the groundnut shell sample was calculated using equation 3.1 – 3.4 as shown below;

$$RC = \mathrm{n}V' + [\frac{-v+v}{2}] \tag{3.5}$$

where;

RC = Radiation Correction; n = Number of minutes between the ignition time and attainment of maximum temperature.

V' = Rate of temperature fall in degrees per minute at the end of the test

v = Rate of temperature rise in degrees per minute at the beginning of the test

The actual temperature rise T_{rise} during the test is given by

$$T_{rise=}\ T_{max} - T_{min} \tag{3.6}$$

where;

T_{rmax} = maximum temperature attained during the test

T_{min} = initial temperature at the ignition point (IP) of the test

Corrected temperature rise (Δt) during the test is given by RC + T_{rise}

And the water value W of the apparatus can be calculated using the equation below;

$$W = \frac{\mathrm{W_b x\ CV_b}}{\Delta \mathrm{t}} \tag{3.7}$$

where;

M_b = mass of the benzoic acid

CV_b = calorific value of the benzoic acid

Hence, the calorific value of the groundnut shell sample can be determined by the eq 3.4

$$CV = \frac{\Delta \mathrm{t\ x\ W}}{\mathrm{M_s}} \tag{3.8}$$

Equation 3.4 was used to determine their various calorific values.

3.7 Optimization of the Calorific Value of the Produced Briquettes Using Design Expert

Design Expert Software was used for the optimization of the calorific value obtained from the briquettes which was produced from torrefied agricultural wastes. The Central Composite design (CCD), the experimental design in Response Surface Methodology (RSM) was used to obtain a second-order (quadratic) model. The design resulted into 20 Runs with Binder proportion, compaction pressure and dwelling time as independent variables and Calorific Value of the briquettes as the response. Four replication of center points were used to predict a good estimation of errors and experiment were done in a randomized order. The actual and coded levels of each factor are shown in Table 3.1. The coded values were designated by -1(Minimum), 0 (Centre) and +1(Maximum) was used as adopted from (Ameh *et al.*, 2019).

Table 3.1: Factors for Central Composite Design for Briquettes Production

Factors	Units	-1(Low level)	0 (Mid)	+1(High level)
Binding Ratio (A)	wt%	20	0	60
Dwelling Time (B)	Seconds	40	0	120
Compaction Pressure (C)	MPa	2	0	5

3.8 Determined Parameters of the Produced Briquettes

The following analyses were carried out:

3.8.1 Burning rate

The specific mass of fuel burnt in air is known as the burning rate. It was determined by using insulated wire gauze of known weight. 100g of the produced briquettes was placed on it and the burner ignited. For every 10s using a stop watch, the weight of the wire gauze was taken until the briquettes were completely exhausted and a constant weight retained.

The Burning Rate of the samples was determined using Eq. 3.1

$$BurningRate = \frac{Total\ weight\ of\ the\ burnt\ Briquettes}{TotaltimetakenbytheBriquettes} \quad (3.9)$$

3.8.2 Ignition time

The method used by (Onuegbu *et al.*, 2011) was adopted where 100g of the groundnut shell and rice husk briquettes was placed on a wire mesh grid in between two fire retardant bricks to allow free flow of air. A bursen burner was placed underneath the setup until the flame became blue. The burner was kept lighted until the briquettes were ignited. The ignition time was determined using Eq. 3.10

$$IgnitionTime = Timethebriquetteisignited - Timetheburnerwaslighted \tag{3.10}$$

3.8.3 Water boiling test

Water boiling test entails the time taken by a known mass of briquette to boil water. A biomass stove was loaded with a known mass of briquette and allow to heat water in a pot until it started boiling. The time taken by the briquettes to boil water was recorded (Yahaya and Ibrahim, 2012).

3.9 Evaluation of the Produced Briquettes Performance

The produced briquettes were evaluated in order to examine its performance using biomass stove to cook. Five 100 g of groundnut shell briquettes was placed on a biomass stove and ignited until it lighted up. Four cups of rice was cooked for a period of 40 min. the same was done for rice husk briquettes but cooked the same cups of rice for 30 min.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Proximate Analyses of Groundnut shell and Rice husk

The proximate analyses of the two samples (Groundnut shell and Rice husk) are presented in the Table 4.1.

Table 4.1: Proximate Analyses of Groundnut shell and Rice husk

Samples	Moisture Content	Ash Content	Volatile Matter	Fixed Carbon
Groundnut shell (%)	10.41	2.525	62.140	24.925
Rice husk(%)	12.02	15.400	68.920	3.660

Table 4.1 indicates the percentage of moisture content, Ash content, volatile matter content and fixed carbon content. The table shows that rice husk has more moisture content than groundnut shell which is 12.41% and 10.41% respectively. The table shows that rice husk is higher in volatile matter than groundnut shell which implies that the higher the volatile matter, the faster the combustion as well as the burning temperature. The groundnut shell has a very high fixed carbon content of 24.925% as compared to rice husk which is 3.66 %. This suggests that groundnut shell can be more exposed to solid combustion. Rice husk has ash content of 15.40% while that of the groundnut shell is 2.525%. This implies that rice husk produces high amount of ash relative to groundnut shell. Therefore, groundnut shell is highly reactive and has high carbon conversion efficiency. This agrees with the findings of (Chukwuneke *et al.*, 2020).

4.2 Ultimate Analyses of Groundnut shell and Rice husk

The Ultimate analyses of the two samples (Groundnut shell and Rice husk) are presented in the Table 4.2.

Table 4.2: Ultimate Analyses of Groundnut shell and Rice husk

Samples	Carbon	Hydrogen	Nitrogen	Oxygen	Sulfur
Groundnut shell (%)	62.337	5.920	1.892	27.328	0.275
Rice husk (%)	44.949	5.542	1.860	32.249	0.300

Table 4.2 indicates the percentage of Carbon, Hydrogen, Nitrogen, Oxygen and Sulfur content. The amount of Carbon and Hydrogen content in the samples signify that the samples have high combustibility and can be used to produce briquettes.

4.3 Statistical and Optimization of the Calorific Value of Groundnut shell Briquettes.

The design plan in Table 4.3 was employed for the statistical analysis and optimization of the calorific value of Groundnut shell and Rice husk briquettes. The variables: binding ratio (A), dwelling time (B) and compaction pressure (C) with calorific value as the response were optimized using the coded values of the test variables.

Table 4.3: Results of Experimental Design Matrix for Optimization of Calorific Values for Groundnut shell Briquettes

			Factor 1	Factor 2	Factor 3	Response
Std	Run	Space	A: Binding Ratio Wt %	B: Dwelling Time Seconds	C:Compaction pressure MPa	Calorific Value MJ/kg
18	1	Center	40	80	3.5	18.7048
10	2	Axial	74	80	3.5	20.2376
11	3	Axial	40	40	3.5	15.5013
13	4	Center	40	80	3.5	18.6558
3	5	Factorial	20	120	2	17.7652
2	6	Factorial	60	40	2	19.2005
1	7	Factorial	20	40	2	12.9054
14	8	Axial	40	80	6	19.6422
5	9	Factorial	20	40	5	15.8764
20	10	Center	40	80	3.5	18.7048
15	11	Center	40	80	3.5	18.7048
7	12	Factorial	20	120	5	22.0926
6	13	Factorial	60	40	5	18.5959
19	14	Center	40	80	3.5	18.7048
17	15	Center	40	80	3.5	18.7048
12	16	Axial	40	147	3.5	18.9167
4	17	Factorial	60	120	2	18.5689
16	18	Center	40	80	3.5	18.7048
8	19	Factorial	60	120	5	18.5689
9	20	CentEdge	20	80	2	16.0987

The energy value depends on the significance of the variation of the results from process parameter combinations. The quadratic regression equation developed from the software is seen in Eq 4.1. This equation gives the optimum calorific value by relating it with the actual value.

$$y = -0.023911 + 0.268939A + 0.176056B + 1.74973C - 0.001834AB - 0.033082AC + 0.004085BC + 0.000396A^2 - 0.000506B^2 - 0.030206C^2 \qquad (4.1)$$

where A = Binding Ratio; B = Dwelling Time; C = Compaction Pressure; Y = Calorific Value

The quadratic model shows how the three factors (A, B and C) affect the response (Calorific values). It comprises of one factor and multi-factor coefficients, which gives the effect of a single factor and combined effects of different factors respectively. The positive and negative terms represent synergistic and antagonistic effects respectively. The synergistic effects improves the model while antagonistic effects reduces the model adequacy

4.4 Parametric Analysis of Groundnut shell Briquette Produced

Figure 4.1 show how the factors (Binding Ratio, Dwelling Time and Compaction Pressure) affect calorific value of the groundnut shell briquettes. Figure 4.1 show that the predicted calorific value (Ypred) deviates very little from the experimental calorific value (Yreal) which implies that the model is adequate. The combining factors were doubled to see their effects on the calorific value. It was observed that the increase in binding ratio had great effect on the calorific value as well as the dwelling time. The compaction pressure also had effect on the calorific value but not as much as the binding ratio and dwelling time. So in this experiment, binding ratio and dwelling time had the greatest effect and should be put into consideration while producing groundnut shell briquettes.

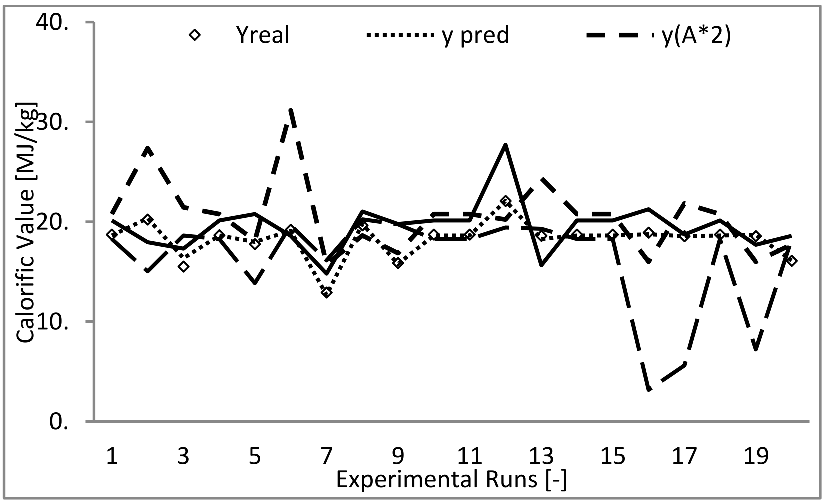

Figure 4.1: Graph of Calorific Value of Groundnut shell against Experimental Runs

In Table 4.4, the sequential model sum of squares gave a model F-value of 69.09 which implies that the model is significant. This level of significance justifies the fact that the proposed quadratic model is adequate. The Model is adequate since the statistic gave test of regression coefficient of $R^2 = 0.9842$ with adjusted R^2 value of 0.9699 and predicted R^2 value of 0.9071. The Coefficient of Variation (CV) obtained was 1.83% which is less than 5% shows that the level of dispersion of data is small and suggests linear model best fits. Since the Adeq Precision of 39.9650 is greater than 4, the signal is thus adequate; hence the design space can be navigated with the model (Chukwuneke *et al.*, 2020). Using the 5% significance p-value level for the analysis of variance (ANOVA), it can be seen from Table 4.4 that the terms A, B, C (Linear), AB, AC (Interactive) and B^2 (quadratic).

Table 4.4: Significance of Regression Coefficients of Calorific Value for Groundnut shell Briquettes

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	69.23	9	7.69	69.09	< 0.0001	Significant
A-Binding Ratio	5.60	1	5.60	50.31	< 0.0001	
B-Dwelling Time	22.01	1	22.01	197.65	< 0.0001	
C-Compaction Pressure	6.37	1	6.37	57.25	< 0.0001	
AB	17.21	1	17.21	154.60	< 0.0001	
AC	8.53	1	8.53	76.63	< 0.0001	
BC	0.4807	1	0.4807	4.32	0.0644	
A^2	0.1996	1	0.1996	1.79	0.2102	
B^2	5.66	1	5.66	50.88	< 0.0001	
C^2	0.0351	1	0.0351	0.3156	0.5866	
Residual	1.11	10	0.1113			
Lack of Fit	1.11	4	0.2778	810.01	< 0.0001	Significant
Pure Error	0.0021	6	0.0003			
Cor Total	70.35	19				

From Table 4.4, the model equation is reduced to the following:

$$y = -0.023911 + 0.268939A + 0.176056B + 1.74973C - 0.001834AB - 0.033082 - 0.000506B^2 \qquad (4.2)$$

4.5 Diagram of 3D Surface Plots for Groundnut shell Briquette

Fig 4.2 shows the combined effect of two independent variables on the Caloric value as shown in the 3D surface plots. The strong convergence of the dwelling time and binding ratio shows the interactive effect on the calorific value but as the convergence reduces, the interactive effect on the calorific value reduces until an optimum point was reached. This could be attributed to the particle size of the briquettes and compaction pressure. Smaller particle size and higher compaction pressure gives higher calorific value and larger particle size and lesser compaction pressure gives smaller calorific value. Therefore, binding ratio and dwelling time have great effect on the calorific value. This conforms to the findings of (Chukwuneke *et al.,* 2020).

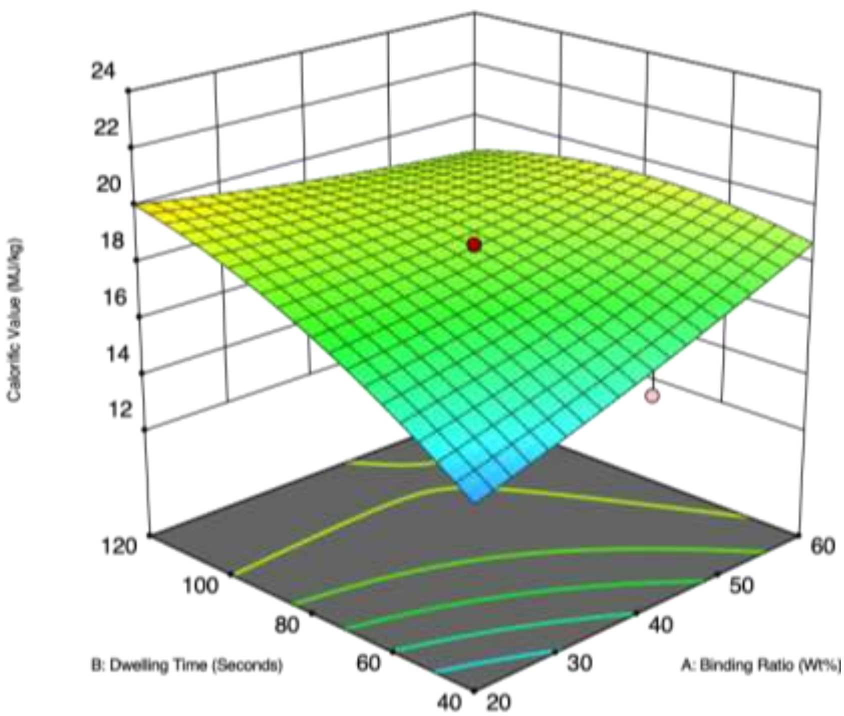

Figure4.2: Interaction effects of factors Dwelling Time and Binding Ratio

4.6 Diagram of Perturbation Plot for Groundnut shell Briquette

Fig 4.3 shows the perturbation plot where the dwelling time, binding ratio and compaction pressure influences the calorific value. It was observed that the three factors (dwelling time, binding ratio and compaction pressure) have great effect on the calorific value until an optimum point was reached where the curves started decreasing (Svatek *et al*., 2009). This could be attributed to many factors such as non-uniform particle size of the groundnut shell, the hydraulic jack which presses the mixed sample and how closely the particles are packed together. The combinations of these factors give rise to high calorific value and also allow the briquettes to burn efficiently. This conforms to the study of Ameh *et al.*, (2019);Wilson *et al.*, (2017).

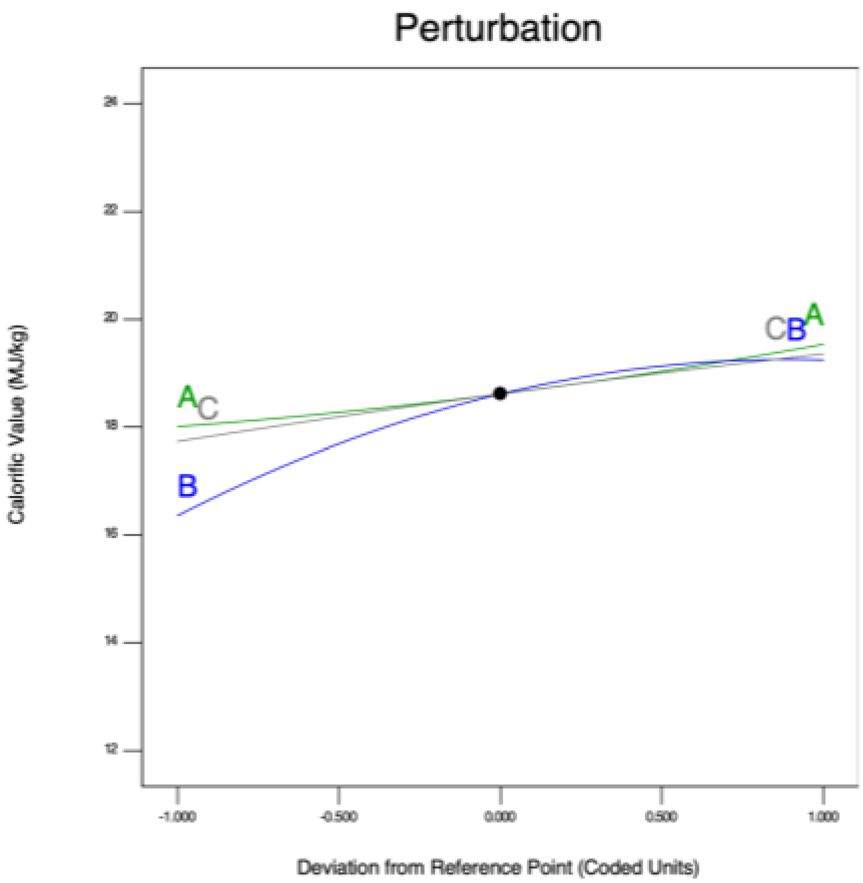

Figure 4.3: Perturbation Graphs Showing the Effects of the 3-factors on Calorific Value

4.7 Relationship between Predicted Energy Value and the Actual Energy Value of Groundnut shell Briquettes

Fig 4.4 shows the relationship between predicted calorific value and actual energy value as given by the Design Expert software. Figure 4.6 gives a close distribution of the point along the straight line which implies agreement between the experimental and predicted energy values hence the developed quadratic model is justified.

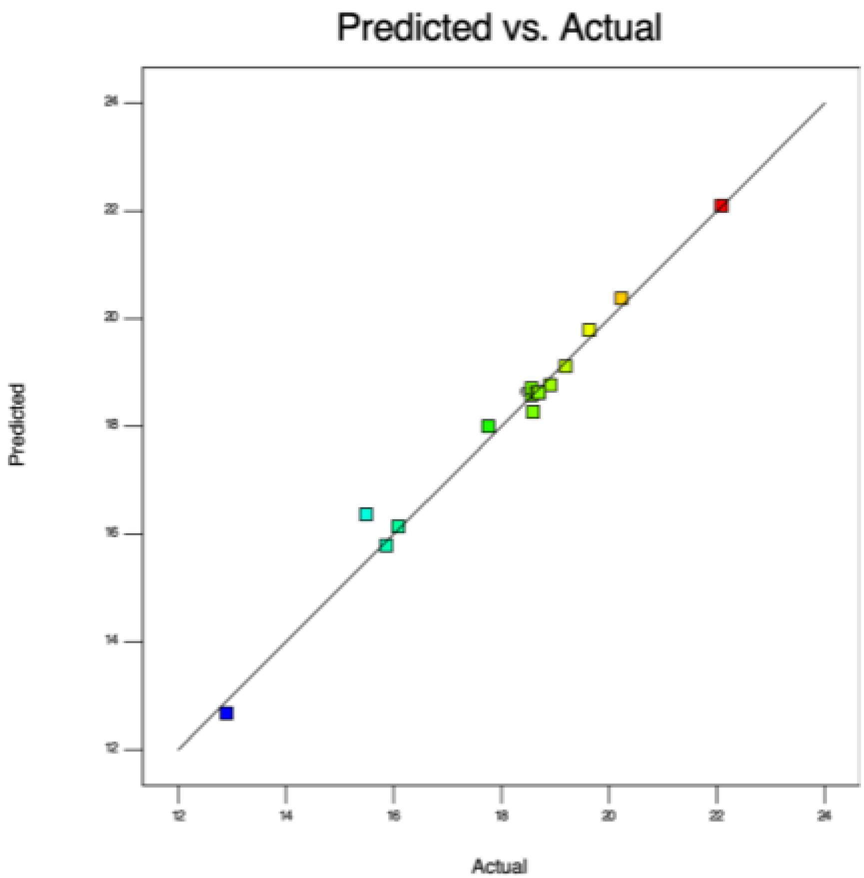

Figure 4.4: Graph showing the relationship between predicted values and actual values

The optimization process gave 17.869 MJ/kg of Calorific Value, 39.525 wt% Binding Ratio, 57.512 Seconds dwelling time and 4.316 MPa Compaction Pressure. These optimum values are shown in Table 4.5.

Table 4.5: Optimum Values of Groundnut shell Briquettes Obtained from Design Expert Software

Binding Ratio wt% A	Dwelling Time (Sec) B	Compaction Pressure (MPa) C	Calorific Value (MJ/Kg)
39.525	57.512	4.316	17.869

4.8 Rice husk Briquette Analysis

Table 4.6 shows the results of Experimental Design Matrix for the Optimization of Calorific Values obtained from the laboratory. The Calorific Values were obtained for each runs.

Table 4.6: Results of Experimental Design Matrix for Optimization of Calorific Values for Rice husk Briquettes

			Factor 1	Factor 2	Factor 3	Response 1
Std	Run	Space Type	A:Binding Ratio wt%	B:Dwelling Time seconds	C:Compaction Pressure MPa	Calorific Value MJ/kg
10	1	Axial	74	80	3.5	21.2061
19	2	Center	40	80	3.5	20.1608
3	3	Factorial	20	120	2	17.4875
7	4	Factorial	20	120	5	18.9803
8	5	Factorial	60	120	5	22.3304
15	6	Center	40	80	3.5	20.1608
14	7	Axial	40	80	6	21.6721
2	8	Factorial	60	40	2	20.1377
6	9	Factorial	60	40	5	21.1463
5	10	Factorial	20	40	5	17.2215
17	11	Center	40	80	3.5	20.1608
12	12	Axial	40	147	3.5	21.2111
9	13	Axial	20	80	3.5	17.9932
13	14	Axial	40	80	2	20.9786
16	15	Center	40	80	3.5	20.1608
20	16	Center	40	80	3.5	20.1608
11	17	Axial	40	40	3.5	19.9865
1	18	Factorial	20	40	2	16.1654
18	19	Center	40	80	3.5	20.1608
4	20	Factorial	60	120	2	21.6348

The energy value depends on the significance of the variation of the results from process parameter combinations. The quadratic regression equation developed from the software is seen in Eq 4.3. This equation gives the optimum calorific value by relating it with the variables in an actual value.

$$y = +10.40102 + 0.290659A + 0.035653B - 0.219851C - 0.000062AB - 0.003520AC + 0.000258BC - 0.002225A^2 - 0.000105B^2 + 0.089721C^2 \qquad (4.3)$$

where A = Binding Ratio; B = Dwelling Time; C = Compaction Pressure; Y = Calorific Value

The quadratic model shows how the three factors (A, B, C) affect the response (Calorific values). It comprises of one factor and multi-factor coefficients, which gives the effect of a single factor and combined effects of different factors respectively. The positive and negative terms represent synergistic and antagonistic effects respectively.

4.9 Parametric Analysis of Rice husk Briquette Produced

Fig 4.5 shows how the factors (Binding Ratio, Dwelling Time and Compaction Pressure) affect calorific value of the groundnut shell briquettes. Fig 4.5 shows that the predicted calorific value (Ypred) deviates very little from experimental calorific value (Yreal) which implies that the model is adequate. The combining factors were doubled to see their effects on the calorific value. It was observed that increase in compaction pressure had great effect on the calorific value as well as the dwelling time. The binding ratio also had effect on the calorific value but not as much as the compaction pressure and dwelling time. So in this experiment, compaction pressure and dwelling time had the greatest effect and should be put into consideration while producing Rice Husk briquettes.

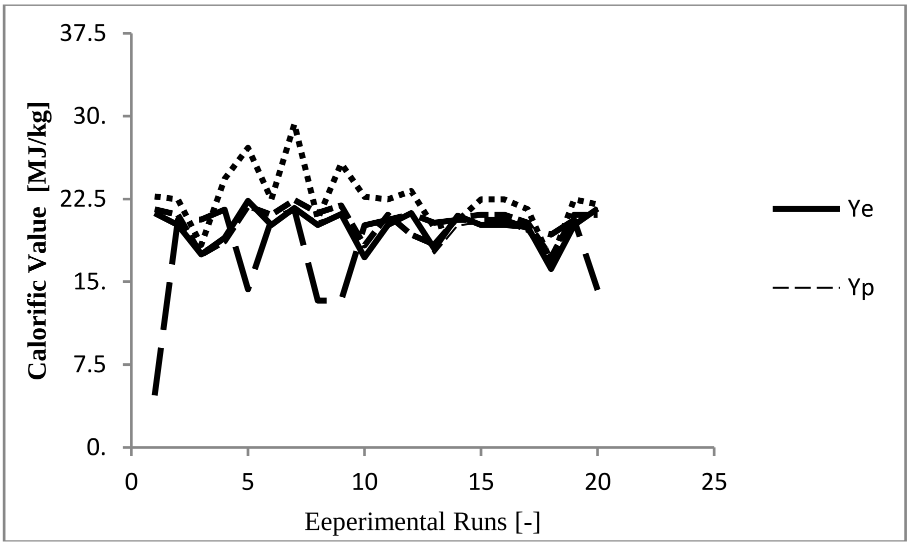

Figure 4.5: Graph of Calorific Value of Rice husk Briquettes against Experimental Runs

In Table 4.7, the sequential model sum of squares gave a model F-value of 31.50 which implies that the model is significant. This level of significance justifies the proposed quadratic model and it is adequate. The fact that the model is adequate, the statistic gave test of regression coefficient, $R^2 = 0.9659$ with adjusted R^2 value of 0.9353 which is close to the predicted R^2 value of 0.8180. The Coefficient of Variation (CV) obtained was 2.07 %. Since the Adeq Precision of 20.7739 is greater than 4, the signal is thus adequate; hence the design space can be navigated with the model. Using the 5% significance level for the analysis of variance (ANOVA), it can be seen from Table 4.7 that the terms A, B, C (Linear terms), A^2 (quadratic term).

Table 4.7: Significance of Regression Coefficients of Calorific Value for Rice husk Briquettes

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	48.33	9	5.37	31.50	< 0.0001	Significant
A-Binding Ratio	38.40	1	38.40	225.25	< 0.0001	
B-Dwelling Time	5.07	1	5.07	29.75	0.0003	
C-Compaction Pressure	1.97	1	1.97	11.57	0.0068	
AB	0.0200	1	0.0200	0.1171	0.7392	
AC	0.0892	1	0.0892	0.5232	0.4861	
BC	0.0019	1	0.0019	0.0112	0.9177	
A^2	7.08	1	7.08	41.52	< 0.0001	
B^2	0.2425	1	0.2425	1.42	0.2606	
C^2	0.3491	1	0.3491	2.05	0.1829	
Residual	1.70	10	0.1705			
Lack of Fit	1.70	5	0.3410			
Pure Error	0.0000	5	0.0000			
Cor Total	50.03	19				

From Table 4.7, the model equation is reduced to the following:

$$y = +10.40102 + 0.290659A + 0.035653B - 0.219851C - 0.002225A^2 \quad (4.3)$$

4.10 Diagram of 3D Surface Plots for Rice husk Briquettes

Fig 4.6 shows the combined effect of two independent variables on the Caloric value as shown in the 3D surface plots. The strong convergence of the dwelling time and binding ratio shows the interactive effect on the calorific value but as the convergence reduces, the interactive effect on the calorific value reduces until an optimum point was reached. This could be attributed to the particle size of the briquettes and the compaction pressure. Smaller particle size and higher compaction pressure gives higher calorific value and larger particle size and lesser compaction pressure gives smaller calorific value. Therefore, binding ratio and dwelling time have great effect on the calorific value. This conforms to the findings of (Chukwuneke *et al.*2020).

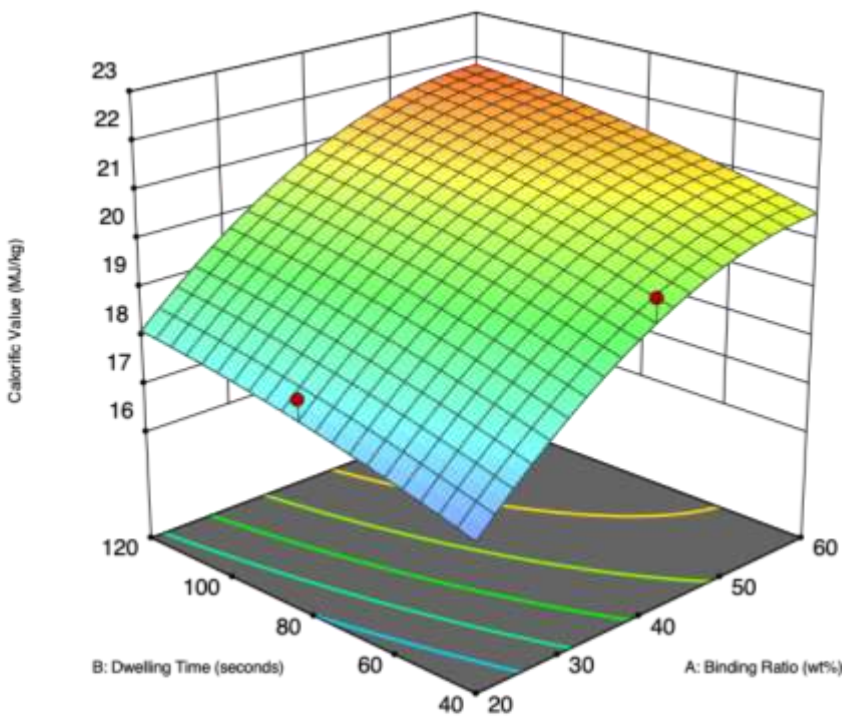

Figure 4.6: Interaction effects of factors dwelling time and binding ratio

4.11 Diagram of Perturbation Plot for Rice husk Briquette

Fig 4.7 shows the perturbation plot where the dwelling time, binding ratio and compaction pressure influences the calorific value. It was observed that the binding ratio curve increased until an optimum point is reached before it started decreasing, this may be due to non-uniform particle size of the rice husk and uneven distribution of the binder into the pore spaces. The dwelling time and compaction pressure curve was observed to be increasing andgiving rise to higher calorific value. This could be attributed to pressure exerted by the hydraulic press and the time the hydraulic press spends on the mixed sample. This implies that dwelling time and compaction pressure will bring about rice husk briquette with higher calorific value (Ameh *et al.,* 2019; Wilson *et al.*, 2017).

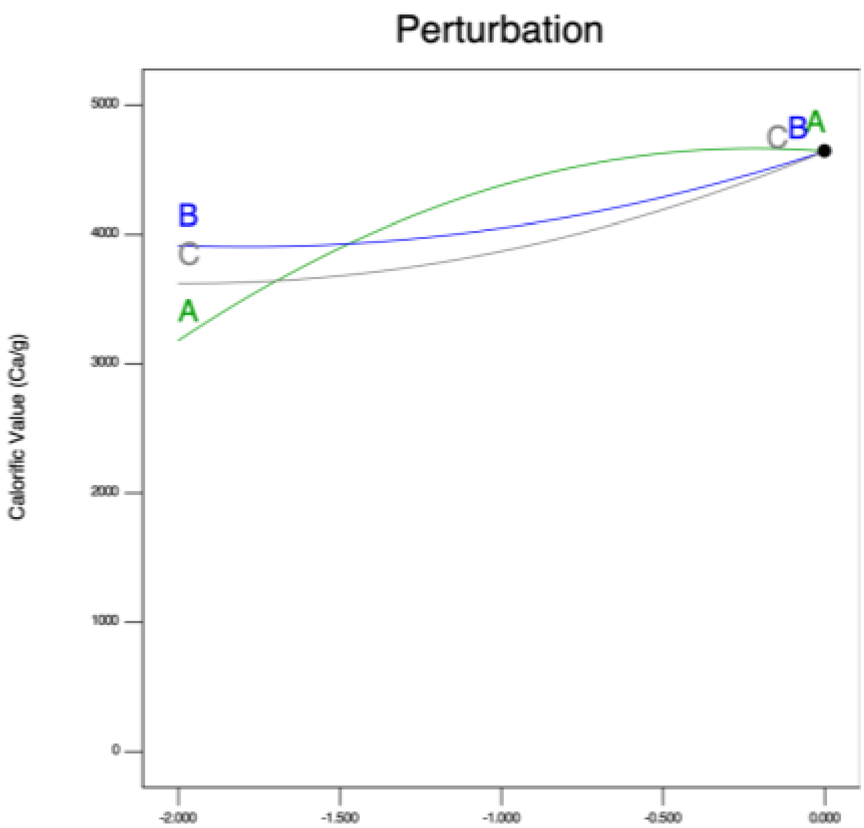

Figure 4.7: perturbation graphs showing the effects of the 3-factors on Calorific Value

4.12 Relationship between Predicted Energy Value and Actual Energy Value for Rice husk Briquette

Fig 4.8 shows the relationship between predicted energy value and actual energy value as given by the Design Expert software. Fig. 4.8 gives a close distribution of the point along the straight line which implies agreement between the experimental and predicted energy values hence the developed quadratic model is justified.

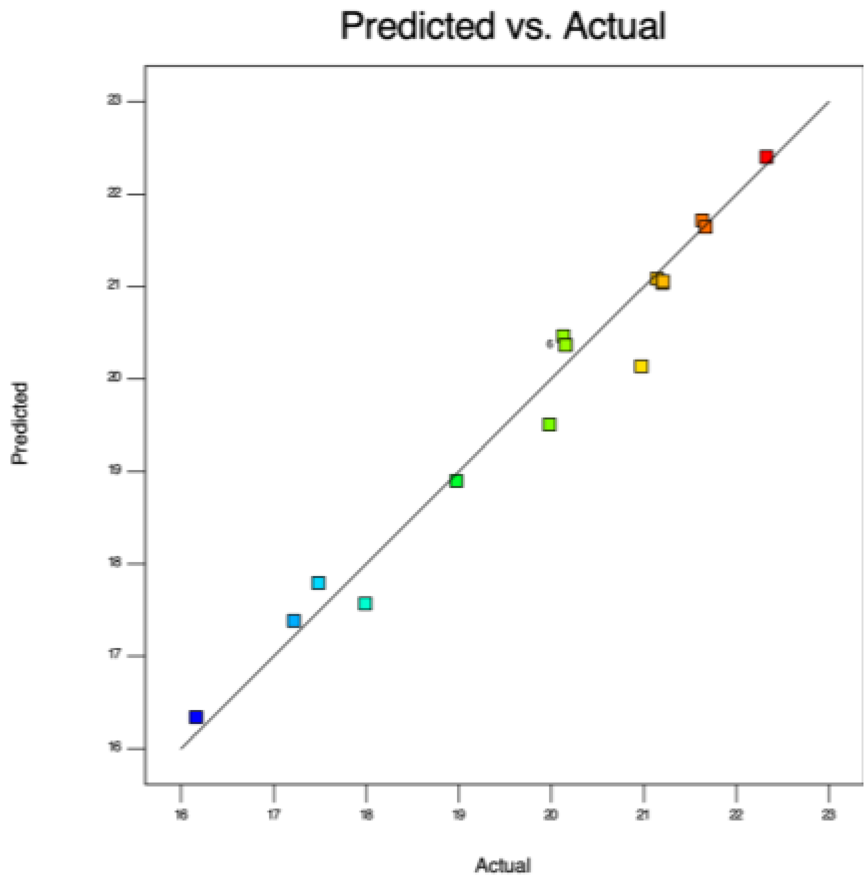

Figure 4.8: Graph showing the relationship between predicted values and actual values

The optimization process gave 19.754 MJ/kg of Calorific Value, 33.706 wt% Binding Ratio, 61.678 Seconds dwelling time and 4.595 MPa Compaction Pressure. Table 4.8. Shows the optimum values.

Table 4.8: Optimum Values of Rice husk Briquettes obtained from Design Expert Software

Binding Ratio wt% A	Dwelling Time (Sec) B	Compaction Pressure (MPa) C	Calorific Value (MJ/kg)
33.706	61.678	4.595	19.754

4.13 Performance Evaluation of Groundnut shell and Rice husk Briquettes

Table 4.9 shows the ignition time, water boiling test and the burning rate respectively. The groundnut shell and rice husk briquettes gave ignition time of 17min and 15min respectively. The ignition time is dependent on the volatile matter and the particle size. Increase in volatile matter and particle size leads to the increase in ignition time which agrees with (Onukak *et al.*, 2017).

Table 4.9 shows water boiling Test which 15.82 min for groundnut shell briquettes and 19.64 min for Rice husk briquettes. The Water Boiling Test is dependent on volatile matter and Calorific Value.

Table 4.9 shows burning rate of the groundnut shell briquette and rice husk briquette determined to be 0.16 g/min and 0.22 g/min respectively. The burning rate of briquettes is very important on briquettes application since high burning rate will require high amount of Briquettes to be used. Also, binding ratio has great significant on burning rate because little or no binder burns very fast unlike when the amount of binder is high (Onukak *et al.*, 2017).

Table 4.9: Energy Evaluation Analyses of Groundnut shell and Rice husk Briquettes

Sample	Weight of Briquettes (g)	Volume of water used (cm^3)	Ignition Time (min)	Water Boiling Time (min)	Burning Rate (g/min)
Groundnut Shell Briquette	100	750	17	15.82	0.16
Rice Husk Briquettes	100	750	15	19.64	0.22

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The groundnut shell and Rice husk briquettes have shown to be good sources of alternative energy after undergoing torrefaction a pre-treatment process at a temperature range of 200 to 300 ºC.

This research work was carried out to analyze the energy content of the briquettes produced from locally sourced groundnut shell and Rice husk. The optimization of the calorific value of the groundnut shell and Rice husk briquettes using cassava starch as binder was performed using response surface methodology (RSM). The groundnut shell and Rice Husk briquettes were produced using optimized condition of values of 39.525 wt% binding ratio, 57.512 seconds dwelling time, 4.316 MPa compaction pressure and 33.706 wt% binding ratio, 61.678 seconds dwelling time, 4.595 MPa compaction pressure respectively. This gave the calorific value of Groundnut shell and Rice husk briquettes to be 19.754 MJ/kg and 17.869 MJ/kg respectively.

The ignition time, water boiling test, burning rate for Groundnut shell Briquette obtained were 15 min, 15.82 min and 0.22g/min respectively while Rice husk Briquette gave the ignition time of 17 min, water boiling test of 19.64 min and burning rate of 0.16 g/min. Since Groundnut shell Briquette has higher calorific value, the thermal energy is high and can be recommended to industries for large scale production thereby creating employment and preserving the environment.

5.2 Recommendations

1. The combination of the groundnut shell and rice husk should be used to produce a composite briquette to obtain high quality briquette and higher calorific value

2. This work was done within a pressure range of 2 – 5 MPa, higher pressures should be considered in subsequent work.

3. The groundnut shell and rice husk used in this work was not finely grinded, so finely grinded particle size groundnut shell and rice husk samples should be used.

5.3 Contribution to Knowledge

This study was done to carry out an optimization on the calorific values of groundnut shell and rice husk briquettes produced. 20 briquettes made of groundnut shell were produced by varying the following parameters: binding ratio, dwelling time and compaction pressure. Calorific values were determined for each of the produced briquettes and design expert software was used to optimize them. The same was done for rice husk briquettes.

The design of experiments gave optimized parameters of calorific values of 19.754 MJ/kg for groundnut shell briquette and17.869 MJ/kg for rice husk briquette.

Groundnut shell briquette has more calorific value which implies that it can produce more energy and more efficiency. This can be recommended for large scale production to industries thereby creating employment and preserve the environment.

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APPENDIX

Produced Briquettes of Groundnut shells and Rice husk

Plate II: Groundnut hell and Rice husk Briquettes