DETERMINATION OF PHYSICAL AND COMBUSTION PROPERTIES OF BLENDED BRIQUETTES OF CARBONIZED SAWDUST AND BANANA LEAVES AND PSEUDO STEM WASTE

BY

OGADIS JEPKEMEI

A Thesis Submitted to the School of Engineering, Department of Manufacturing, Industrial and Textile Engineering in Partial Fulfillment of the Requirements for the Award of the Degree of Master of Science in Industrial Engineering

Moi University

2021

DECLARATION

This thesis is my original work and has not been presented in any other University for the award of master's degree or any other degree. No part of this thesis may be reproduced without prior written permission of the author and/or Moi University.

Sign:____________________ Date:________________

OGADIS JEPKEMEI

TEC/PGMT/05/15

DECLARATION BY SUPERVISORS

This thesis has been submitted with our approval

Sign:____________________ Date:________________

Dr. David Njuguna Githinji

Department of Manufacturing, Industrial and Textile Engineering,

Moi University,

P.O. Box 3900-30100, Eldoret, Kenya.

Sign:____________________ Date:________________

Dr. Charles Nzila

Department of Manufacturing, Industrial and Textile Engineering,

Moi University,

P.O. Box 3900-30100, Eldoret, Kenya.

Sign:__________ __________ Date:________________

Prof. Saul Namango

Department of Chemical and Processing Engineering,

Moi University,

P.O Box 3900-30100, Eldoret, Kenya.

DEDICATION

To my family for continuous financial and moral support in my education; to my parents, brothers and sisters for their continuous encouragement.

ACKNOWLEDGEMENT

I thank God for this far He has brought us. Special acknowledgement goes to Dr. David Njuguna, my first supervisor, for his guidance in literature review, clarity on objectives, data analysis, thesis editing, testing methodology and general thesis writing; Dr. Charles Nzila, my second supervisor, for his guidance in testing methodology, experimental design, thesis editing, and also data analysis as well as Prof. Saul Namango for his comments, encouragement and recommendations all throughout the research period. I thank the management and staff of Kenya Bureau of Standards both in the chemical and material testing laboratories for allowing me to use their facilities to carry out my experiments and tests. Finally, my sincere gratitude goes to all staff of the Manufacturing, Industrial and Textile Engineering Department and my classmates, friends, and the school administration at large.

ABSTRACT

Instability in the world's petroleum is occasioned by perpetual escalation in petroleum prices, increasing environmental effect from exhaust emissions has prompted the search for renewable sources of fuel. Currently in Kenya, biomass such as sawdust from sawmill industries and agro wastes, like banana leaves and pseudo stem, are potential sources of renewable energy. However, in most cases biomass is normally discarded in the fields with no value addition and also little information exists on their use as fuel in blended briquettes. Consequently, this study investigated the use of carbonized sawdust and banana waste as raw materials for briquettes production as an alternative energy source. Specifically, the study aimed at characterizing physical properties of the raw materials, fabricating blended briquettes at varying mix ratios/particle sizes and characterizing physical and combustion properties of the blended briquettes. In the study, pseudo stem and banana leaves from *Musa acuminata AAA* species and sawdust from *Eucalyptus tree* species were collected, dried to 8 % moisture content, hammer milled, sieved and carbonized in muffle furnace at 400 ℃ for 5 minutes. Blended briquettes were produced at constant compaction pressure of 5 MPa at varying blend ratios(1:0,4:1,3:2,1:1,2:3,1:4, 0:1)and particle sizes(2.5 mm, 5 mm, 7 mm, 9 mm,11 mm)using molasses as a binder. The briquettes were then characterized in terms of mass density, durability index, ash content, moisture content, volatile matter and calorific value. Raw materials: sawdust, banana waste and molasses had moisture contents of 12.52 %, 14.63 % and 22.23 %; volatile matter of 25.32 %, 31.45 % and 43.25 %; calorific value of 15.92 MJ/kg, 12.35 MJ/kg and 11.24 MJ/kg; ash content of 5.79 %, 6.89 % and 8.00 %, respectively. The density ranged from 392.54 kg/m^3 to 681.21 kg/m^3, calorific value,23.40 MJ/kg to 25.92 MJ/, ash content, 6.89 % to 5.79 %, moisture content, 11.10 % to 7.45 %, durability index,95.35 % to 99.70 % and CO emission, 5.64 ppm to 1.74 ppm. In addition, as the particle sizes were increased from 2.5 mm to 11 mm, the briquettes' moisture content ranged from 7.22 % to 6.98 %, ash content,5.82 % to 5.83 %, CO emission,5.87 ppm to 5.20 ppm, calorific value,26.49 MJ/kg to 25.84 MJ/kg, density,763.33 kg/m^3 to 557.68 kg/m^3 and durability index,97.77 % to 93.43 %. In conclusion, sawdust had better calorific value, lower ash and moisture contents, lower volatile matter and higher mass density than banana waste. Mix ratio of 1:1 provided optimal durability and moisture content in briquettes while that of 3:1 gave optimal CO emission. An increase in sawdust content increased both calorific values and ash content of the briquettes. Lastly, blended briquettes with fine particles have higher mass density, calorific value, durability index, and CO emission than those with coarser particles. From the study, it is recommended that briquettes with high and fine sawdust content (50% above) should be used owing to their good durability, low moisture content, low CO emission and higher calorific value. Future studies should determine effects of interaction between variables such as compaction pressure, blend ratio and particle sizes on combustion properties.

Key words : Briquette , Calorific value, particle size and Mix Ratio

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

ASTM	American Society for Testing and Materials
BW: SD	Banana Waste: Saw Dust
FAO	Food and Agriculture Organization
GOK	Government of Kenya
KEBS	Kenya Bureau of Standards
KPLC	Kenya Power and Lighting Company
MOA	Ministry Of Agriculture
MOE	Ministry Of Energy

CHAPTER 1: INTRODUCTION

1.0 Background

Biomass is being highly promoted as an alternative energy resource for the fossil fuel, especially during the past three decades, the effect of escalating prices is attributed to factors such as world economic growth, declining value of the dollar and unrest in Middle East coupled with declining domestic oil supply (Banpast*et al*., 1997). A study by Kituyi *et al*. (2001) showed that about 15.4 million tons of fuel wood was consumed in 1997 and this was supplied by farm land trees, indigenous forests, woodlands and timber off-cuts from plants. Fuel wood supply has been declining in rural Africa (Jami*e al*., 2008). Various researchers have reported this shortage in Kenya (Marfa, Huber, *et al.*, 2001; Maher, 2003; Ngetich*et al*., 2009). As a result, there is an increase in the utilization of crop residues by farmers to fulfill their energy requirements. Replacing traditional forms of biomass energy use with modern ones is expected to have a number of benefits such as a decrease in the emission of greenhouse gases and forest destruction; reduced health hazards; and an increase in energy availability (Janssen &Rutz, 2012).

The uncertainty of prices and supply of crude oil has prompted the search for alternative sources of energy to meet the ever growing energy demand. By compacting these biomass, high density and energy concentrated solid material called briquettes are produced which can supplement existing energy sources. Biomass from forestry has been the main source of fuel wood in Kenya.. Furthermore, this study revealed very minimal utilization of crop residues as domestic fuel (about 1.4 million tons). However, fuel wood supply has been declining in rural Africa (Jama*et al*., 2008). For example, Mugo (1999) reported that a shortage of fuel wood supplies resulted in approximately, 40% of the farmers in western Kenya utilizing crop residues and cow dung as domestic energy sources. In other parts of western Kenya, rural households have resorted to buying crop residues in order to cater for their fuel needs (Maher, 2003).

Close to 70 % electricity supply in Kenya is hydro based. By December, 2012 approximately 1.8 million customers had been connected to electricity supply (Stima News, Jan., 2012) benefiting about 20 % of 38.6 million Kenyan (KNBS, 2009), leaving the rest of the population to seek alternative sources of energy. Similarly, wood accounts to about 70 % of total energy consumption in Kenya, benefitting 80 % of Kenyan population. It serves 90 % of rural households and 85 % of urban households (Mugo and Kituyi, 2002). About 47 % of Kenyan households use charcoal of which 82% and 34 % are urban households and rural households respectively (UNEP, 2006). The total annual charcoal production is 2.4 million tons, produced from the forests, but with the current forest cover of 1.7 % which is below the target of 10 %, there is need to search for sustainable energy sources.

Replacing traditional forms of biomass energy use with modern ones would have a number of benefits such as a decrease in the emission of greenhouse gases and forest destruction; reduced health hazards; and an increase in available energy (Janssen &Rutz, 2012). In addition, the utilization of biomass for energy production can contribute considerably to job creation, hence improving the rural economies and reducing rural urban migration (Openshaw, 2010; Thornley*et al.*, 2008). Elsewhere in the USA, America and Duncan (2001) study reported that over 66,000 rural jobs have also been created in biomass power generation and an additional 40,000 in biofuels.

This study aimed at producing blended briquettes at varying mixture ratios of sawdust and banana waste and determined their physical and combustion properties. It was anticipated that produced briquettes would supplement traditional fuels and save environmental degradation both by deforestation and pollutants emission from combusting fossil fuels.

1.1 Statement of the Problem

Most of the Kenyan population depend on wood biomass as their source of energy, but with the increasing energy demand, the 1.7 % forest cover which is below the 10 % target is not be able to sustain the demand. There is need, to search for alternative sources of energy which would be sustainable**.** Kenya produces thousands of tonnes of agricultural wastes every year. These wastes often are burned in open field or disposed off in land (MOA, 2013). The energy potential of most of these agricultural residues has been determined while others are yet to. Residues, such as banana waste and sawdust, are a promising source of energy which can be used to cater for increasing energy demand in Kenya. By compacting these biomass, high density and energy concentrated solid material called briquettes are produced which can supplement existing energy sources. However, very little information exists on physical and combustion properties of sawdust and banana waste blended briquettes produced using molasses as a binder. Though ,much studies has been done in briquetting of different blends of agricultural residues, physical, mechanical and combustion characteristics varies depending on briquetting parameters. Most of the research done highlight that different types of biomass have different optimum characteristics. This research is designed to fabricate and study the physical and combustion characteristics of blended briquette made from sawdust and banana and testing its suitability as an alternative domestic energy source so as to determine optimum physical, mechanical and combustion characteristics.

1.2 Justification of the Study

Fossil fuel is associated with increase in global warming thus there is need for alternative fuel which is environmentally friendly. The availability of agricultural residues such as sawdust and banana leaves and pseudo stem wastes present a feasible fuel option that can be fabricated through the process of briquetting. The briquettes produced from sawdust and banana waste would supplement the traditional sources of energy hence reduce pressure on already diminished forest cover. In this way, use is made of waste products thus reducing pressure on forestry resources and also the reduction in air pollution by eliminating burning of agro-waste in fields. Briquettes produced from sawdust and banana waste would create of jobs by setting up of briquettes manufacturing firms and therefore increasing the farmers' income by providing additional source of income through sale of agro-waste.

1.3 Significance of the Study

Implementation of this research would give insight on the alternative and sustainable source of fuel from agricultural residue, and alleviates the ever increasing energy demand on depleted forest cover in the country. It also provides a database for future researchers and helps the energy entrepreneurs. This helps in the attainment of the millennium development goals i.e. availability of cheap energy sources to reduce use of wood charcoal. The sustainable development goals would reduce on poverty, as well as, development of briquette manufacturing industry, innovation and infrastructure and reduced inequality since the alternative source of fuel would be affordable.

1.4. Objectives

1.4.1 General Objective

The main objective of this study was to develop blended briquettes, for domestic applications, consisting of carbonized sawdust and banana waste and evaluation of their physical and combustion properties.

1.4.2 Specific Objectives

This objective was guided by the following specific objectives:

i) To characterise physical properties of sawdust, banana waste and molasses
ii) To fabricate carbonized sawdust-banana waste blended briquettes at varying mix ratios and particle sizes
iii) To analyze the physical and combustion properties of the blended briquettes.

1.5 Research Questions

i) How does varying mixture ratio affect physical and combustion characteristics of the blended briquettes made from sawdust and banana waste?
ii) How does varying particle size affect physical and combustion characteristics of the blended briquettes made from carbonized sawdust and banana waste?
iii) How does the physical and combustion characteristics of the blended briquettes made from carbonized sawdust and banana waste compare to other briquettes.

1.6 Scope of the Study

The briquettes studied in this work were limited to those derived from a mixture of carbonized sawdust and banana waste compacted at 5 MPa at varying ratios and particle sizes. The sawdust was derived from blue gum tree while banana waste consisted of dry leaves and pseudo stem obtained from *Musa Acuminata* banana species. In this study carbonization was carried out at 400 ° C for 5 minutes. The study of briquette’s combustion properties was limited to proximate analysis while only density and durability index was studied for physical properties. For this stydy, molasses was maintained at 20 %.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

This chapter provides a review of the current energy situation in Kenya, utilization of firewood, charcoal and briquettes as a source of energy. It also gives a review on composition of biomass, briquetting processes and summarizes the existing research gaps which the current project aims at addressing.

2.1 Current Energy Situation in Kenya

According to Mugo and Kituyi, (2002) and Matiru, (2007), Kenya mainly depends on biomass for its energy needs. Matiru (2011) reported the annual demand of fuel wood to be 70 % while petroleum and electricity constituted 21 % and 9 % of total energy consumption, respectively. About 70 % of the electricity in Kenya is produced from hydropower (KPLC, 2006). Heavy dependence on hydropower increases vulnerability due to drought resulting in low water levels in hydro stations dam causing power shortages. Even though the demand for energy in Kenya is increasing at rate of 8 % per year, slightly over 15 % of the population was connected to the national grid by 2010 (KPLC, 2010). But the industrial development in rural and urban areas is pegged on the energy supply (MoE, 2006). Wood biomass energy sources on the other hand are faced with diminishing of forest cover hence there is a need to explore other renewable sources such as agricultural residue, solar energy and biomass.

2.1.1 Utilization of firewood and charcoal as a source of energy

Wood fuel may be available as firewood, charcoal, chips, sawdust, briquettes and pellets. The particular form used depends upon factors such as availability, quantity, quality and availability of technology. Wood fuel provides an average of 75 % of developing countries' renewable energy demand (IEA, 2004). Energy from wood has traditionally been based on fuel wood and charcoal. Globally, the annual consumption of fuel wood (including wood for charcoal) was about 1.845 billion in 2009 and it contributed to an estimated 7 % of the world's total energy supply of fuel.

2.1.2 Briquettes as a source of energy

Fuel briquettes made from agricultural and commercial residues such as saw dust, weeds, leaves, rice husks, carton board and scrap paper are unique, yet well proven technology for an alternative energy source. United State Department of Agriculture (USDA, 2013) noted that briquetting helps to increase the value of charcoal and at the same assessment its price. In many parts of the world, people are making this new and modern fuel, saving time, energy, and environment and creating more income. Fuel briquettes are unique because they provide a fuel wood alternative from resources that are right under your feet or in your waste bucket. Fuel briquettes can be made relatively quickly at a low cost to the manufacturer or consumer and can be adapted and applied in a wide variety of settings, making the briquettes appropriate, sustainable and renewable. The development of renewable energy sources in the global South i.e. regions of Latin America, Asia, Africa, and Oceania has the potential to decrease the dependence on increasingly scarce energy sources and contribute to the protection of vital ecosystems. Renewable energy offers possibilities to both reduce poverty and to allow sustainable development (Goldemberg and Coelho, 2004).

According to the Survey (2006), cooking fuel generally affects the quality of air for the members of a household. Most households use solid fuels cooking such as charcoal, wood and other biomass fuels which are usually a major cause of respiratory infections given that they emit a lot of smoke. According to Chin and Siddiqui (2000), agricultural residue has varying moisture content making them technically unfeasible for direct use as fuel in combustion system. Densification of this waste to the briquettes form is an attractive option and has combustion properties comparable to wood biomass (Maiti*et al*., 2006). It was reported that by briquetting agricultural residue, the combustion characteristics, handling, volumetric calorific values, transportation, collection and storage costs improves. Briquetting agricultural residues through the extrusion process has been extensively studied (Grover and Mishra, 2006; Ndiema*et al*., 2002; Heinz et al., 2003; Husain *et al*., 2002). The finding of this study was that mechanical and physical properties of charcoal briquettes is influenced by parameters such as die pressure, dwell time, charcoal particle size, binder type and content. Similarly, different materials required different optimum conditions for the briquetting process and the combustion properties are upgraded if these agricultural residues are carbonized.

Conversion of carbonized biomass into briquette forms has been done; corn cob (Medhiyanon*et al*., 2016), saw dust (Rotich, 2013), rice husk (Jindaporn and Songchai, 2007), cotton stalk (Onaji and Siemons, 2013) and hazelnut shell charcoal (Demirbas and Sahin, 2011).

Jindaporn and Songchai (2007) reported that the combustion of the agricultural residue can be improved if blended with materials with better combustion properties. From the study of combustion characteristics of rice husk, the calorific value, ash content level, sulfur content and bulk density of rice husks charcoal were 11.7 MJ/kg, 20.6 %, 0.08 % and 825.4 kg/m^3 while those derived from bagasse were 18.8 MJ/kg, 1.3 %, 0.06 % and 935.5 kg/m^3, respectively. The ash contents of 20.6 % in rice husk are associated with fouling effect in combustion grates resulting in rupturing of boiler water tubes. This condition can be alleviated by frequent cleaning of boiler tubes.

2.1.2.1 Sawdust briquettes

Sawdust briquettes are compressed blocks of sawdust that have been soaked and pressed at high pressure as shown in Figure 2.1. These briquettes can then be used as fuel for heating or cooking. Compressed briquettes from sawdust, plant waste and waste paper are often used in undeveloped areas as a means of turning waste into cooking fuel. For the home owner, these briquettes can provide a way to dispose of wood waste and cheaply heat the house. Sawdust, the by-product of most woodworking processes, leaves manufacturers and facilities with fine particles of wood everywhere. While there are wood waste solutions like landfills, using it as animal bedding, pelletizing, or incineration, briquetting, offers so much more, including a new revenue stream (Martin, J. and Mae, R. and Manaay, A. (2008).

Figure 2.1: Uncarbonized Sawdust briquettes
Source: Martin, J. and Mae, R. and Manaay, A, (2008).

In a sawdust briquette manufacturing facilities, use of machines saves on time, resource and space. Using hydraulic cylinders to compress sawdust into consistently sized, clean briquettes, sawdust briquetting provides manufactures new options for wood waste (Darby, 2012). With the growing market for briquette-based fuel, selling energy-efficient and carbon-neutral wood briquettes as a fuel source provides numerous benefits for companies:

- Reducing need to store wood waste
- Removing airborne particles
- Eliminating costly disposal and landfill fees
- Generating a new revenue stream from briquette sales

2.1.2.2 Banana waste briquettes

In rural areas where communities cannot afford to buy propane gas or electricity, cooking often requires long hours spent collecting increasingly scarce and therefore expensive wood. More than 95 % households rely on wood and charcoal for lighting and cooking (Janssen & Rutz, 2012). Aside from the rapid rate of deforestation and desertification to which using wood for indoor cooking and heating produces one of the key environmental degradation issues affecting the continent of Africa is smoke which causes indoor air pollution which is detrimental to the environment and children’s health. Indoor air pollution is the single largest environmental risk factor for female mortality and the leading killer of children under the age of 5 worldwide (WJ Martin, 2011). As many as half a million sub-Saharan African women and children die prematurely each year due to respiratory disease cause by smoke inhalation. It is estimated that charcoal and wood burning across Africa will contribute as much as 7 billion tons of greenhouse gases into the atmosphere by 2050 cubic meters (H Ritchie, 2013).

2.1.3 Biomass energy

Biomass is the third largest energy resource in the world after coal and oil (Bapat, *et al*., 1997). Until the mid-19th century, biomass dominated global energy consumption. Even though increased fossil-fuel use has prompted a reduction in biomass consumption for energy purposes. Over the past 50 years, biomass still provides about 1.25 billion tons of oil equivalent or about 14 % of the world's annual energy consumption (Purohit, *et al*., 2006; Zeng, *et al*., 2007). Biomass is becoming increasingly important globally as a clean and reliable source of energy alternative to fossil fuel (Duku, *et al*., 2011; Li & Hu, 2003).

The simplest and least expensive biomass resources are the waste products from wood or agro-processing operations, but their supply is limited. To overcome this limitation, countries around the world are considering biomass crops for energy purposes and have begun developing technologies to use biomass more efficiently. In the United States of America and most of Europe, biomass has already penetrated the energy market. The U.S. and Sweden obtain about 4 % and 13 % of their energy, respectively, from biomass (Hall, *et al*., 1992). Sweden and Germany are implementing initiatives to phase out nuclear plants, reduce fossil fuel energy usage, and increase the use of biomass energy (Björheden, 2006).

Wood burning as a heat and light source has been popular for millennia. Biomass, if properly managed, offers many advantages such as reducing need for fossil fuels for the production of heat, steam, and electricity for residential, industrial and agricultural use and also they are always available and can be produced as a renewable energy. The most important advantage derived from the use of biomass is that it is a renewable and sustainable energy feedstock. It can significantly reduce net carbon emissions when compared to fossil fuels. For this reason, renewable and sustainable fuel is considered a clean development mechanism for reducing greenhouse gas emissions (Li & Hu, 2003).

2.1.4 Biomass densification

Densification is a process in which materials like waste sawdust, chips, shavings, agricultural waste and other biomass materials are compressed under high pressure and temperature, which causes the content of lignin in the wood or lignocelluloses material to be softened, thereby binding the material to a firm briquette. Generally, it represents all technologies used for converting plant residues into compact biomass fuel. This technology, also known as pelleting, briquetting or agglomeration, aims at improving the handling characteristics of the biomass materials (Tumuluru, *et al*., 2010).

Briquette has higher density and energy content, and is less moist compared to its raw materials. Briquetting of biomass can be done using various techniques, either with or without binder addition. In most developed countries, wood processing industries are rapidly becoming energy self-sufficient and sale excess power to local electric grids through the use of densified wood residue and other residues. However, in developing countries the development of wood energy is rare because most sawmills lack the technical know-how or are simply not ready to invest into such area (Kristofferson & Bokalders, 1986).

The idea of producing briquettes from fine timber waste and other residue dates back to the turn of 19th and 20th centuries and lately this technique has aroused the interest of most developing countries all over the world (Obernberger & Thek, 2012). Utilization of lignocellulose waste by converting them into briquettes is economically and environmentally justified in that the net calorific value per unit volume of briquettes made is increased. This is comparable to that of lower quality class of coal though higher than firewood and charcoal. Generally, two kilograms of wood briquettes holds the same energy as one litre of fuel oil (Bhattacharya, *et al*., 1989).

Briquetting of wood waste helps to resolve a key limitation to the use of biomass fuel which is its bulkiness compared to coal and other solid fuel. Briquettes made from wood are normally less than one tenth of the volume of the raw material and thus making its transportation a lot easier and far less expensive. Thus, compared to coal and other combustion fuels, biomass is expensive to handle and the cost of transportation looms large in assessments of financial viability. However, the continuously increasing price of the fossil fuel, the greater greenhouse effect caused by utilization of the fossil fuel and the increasing damage to the environment due to the use of fire wood and charcoal justifies the need to use biomass residue.

2.1.5 Briquetting technology

Briquette pressing can be categorized using several criteria i.e. based on the operating condition; hot and high pressure pressing, cold and low pressure pressing (Dutta, 2007) and based on mode of operation; batch pressing and continuous pressing. In batch pressing, briquettes are pressed in an already dimensioned presser as such they come out in their desired size. On the other hand, continuous pressing briquettes are produced in a long cylinder and later cut to dimensions (Dutta, 2007). However, pressing can be categorized into three main types depending on the type of equipment; hydraulic pressure press machine, mechanical piston press and screw compaction or extruder press (Grover & Mishra, 1996).

2.1.5.1 Mechanical piston press

Mechanical piston presses are typically used for large-scale briquettes production, ranging from 200 to 2,500 kg/hr (Tumuluru, *et al*., 2010). The mechanical press is driven by electric motors instead of a hydraulic motor. Energy loss in the machine is limited, and the output in relation to power consumption is optimal. The operating life of a mechanical press is considerably longer than hydraulic presses. Generally, a mechanical press gives a better return on investment than a hydraulic press. For the piston press briquettes machines the wear of the contact parts e.g., the ram and die is less compared to the wear of the screw and die in a screw extruder press. The power consumption for piston press briquettes machines is also less than that of screw extruder press (Grover & Mishra, 1996).

2.1.5.2 Screw compaction or extruder press

Figure 2.2 shows the screw press extruder that uses the screw press technology (P Evon, 2013). In this technology, the biomass is extruded continuously by a screw through a taper die which is heated externally to reduce the friction. With this design the sawdust from feed hopper is conveyed and compressed by the screw. During extrusion, the material moves from the feed port, with the help of a rotating screw, through the barrel and against a die, resulting in significant pressure of 50 gradient and friction due to biomass shearing (Grover & Mishra, 1996). The combined effects of wall friction at the barrel, internal friction in the material, and high rotational speed (600 rpm) of the screw, increase the temperature in the closed system and heat the biomass. This heated biomass is forced through the extrusion die to form the briquettes or pellets with the required shape. If the die is tapered, the biomass is further compacted. If the heat generated within the system is not sufficient for the material to reach a pseudo-plastic state for smooth extrusion, heat is provided to the extruders from outside either using band or tape heaters (Grover & Mishra, 1996).

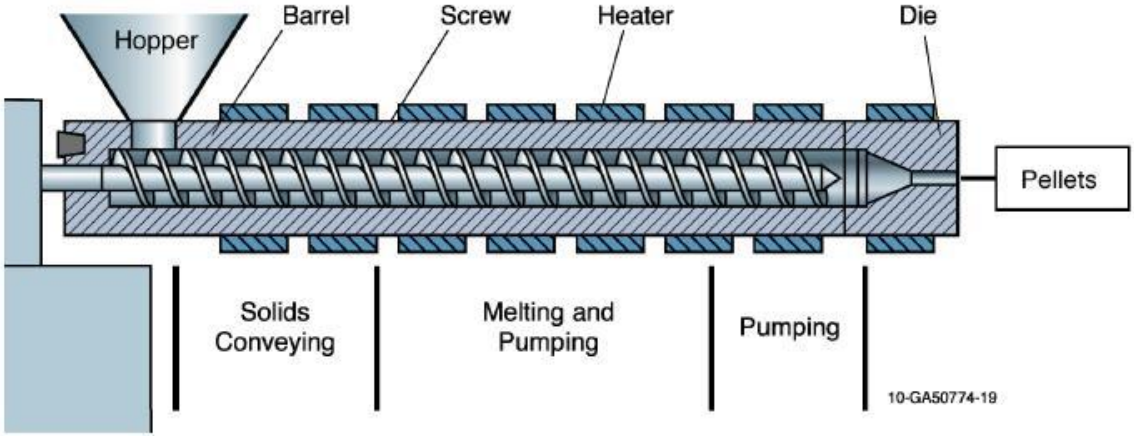

Figure 2.2: Screw press extruder

2.2 Production of Banana and Sawdust in Kenya

This section provides a review of banana and sawdust production in Kenya.

2.2.1 Banana production

Among the agricultural crops that show great potential for increased production is the banana. Indeed, the importance of bananas throughout the world, and in Kenya, cannot be over-emphasized. The crop is the world's third important starchy staple after cassava and sweet potato (FAO, 1987). Its world production estimates are placed at 49.63 million ton, of which 6.44 million is grown in Africa, 20.31 million in Asia, 13.31 million in South America, 1.5 million in Oceania, 7.66 million in Central America and 0.42 million in Europe (INIBAP, 1991; Robinson, 1996). It is mainly consumed domestically, with an annual per capita consumption of 220-460 kg, providing more than 25 % of the total calories consumed (INIBAP, 1991). In Kenya, and to a larger extent, the East African region, the crop is mainly grown and managed by smallholder farmers, predominantly peasant farmers. Table 2.1shows the average banana production statistics for the provinces of Kenya during the period 2015-2016.

Table 2.1 Average banana production statistics (2015-2016) for the provinces of Kenya

Province	Area (ha)	Production (t)	Yield (t/ha)	Production (%)
Central	16, 913	169,316	10.0	16.6
Coast	5,743	55,341	9.6	5.7
Eastern	9,669	97,144	10.0	9.5
Nairobi	48	409	8.5	0.0
North Eastern	271	1,522	5.6	0.1
Nyanza	30,234	574,740	19.0	56.1
Rift Valley	2,688	39,781	14.8	3.9
Western	7,800	86,107	11.0	8.5
Total	**73,366**	**1,024,360**	**14.0**	**100.0**

Source MALDM (2016)

2.2.1.1 Properties of banana plant waste

It is estimated that close to 220 tonnes of waste are generated per hectare of harvested banana, which are composed mainly of lingo cellulosic material (Guyle´Ne*et al*., 2009; Zhang *et al*., 2005). Such waste contains from 8 % to 18 % of total solids and 86 % to 92 % of volatile solids, approximately. The organic fraction includes around 75 % of biodegradable material (sugar and hemicellulose), 9 % of cellulose and 5 % of lignin, which are interesting sources of bioactive compounds. The rachis, pseudo stem, leaf sheath and peel are the parts of the banana plant containing the largest amount of fibrous material. Due to their potential use as reinforcing components in high-performance composite materials, these cellulose-rich sources are currently being tested as heavy metal-adsorptive material in wastewater treatment, and as feedstock for bioethanol production (Bouallagui*et al*., 2005; Velásquez-Arredondo *et al*., 2010).

Drying and storage processes need to be developed for these wastes in order to achieve important advantages, such as; easy transportation, reduced microbial load, nutrient concentration and availability for processing (Prachayawarakorn*et al*., 2008). In this regard, an important aspect at the industrial level is the knowledge of the final moisture content and the energy required for drying, which are related to the hygroscopic equilibrium of the biological materials. A study of this equilibrium during the absorption isotherms allows for an understanding of the relationship between the equilibrium moisture content and the water activity within the foods, as well as the influence of their material structure and composition on physical and combustion characteristics of sawdust and banana waste briquettes (Mulet*et al*., 2002).

> The banana waste is normally disposed in municipal landfills, which contribute to the existing environmental problems. However, the problem can be recovered by utilizing its high-added value compounds, including the dietary fibre fraction that has a great potential in the preparation of functional foods. Typical values of banana waste calorific value (12.35 MJ/kg) moisture content (14.63%), ash content (6.89%), and volatile matter (31.45%).

2.2.2 Sawdust

2.2.2.1 Generation of sawmill residues

There were about 450 sawmills in Kenya in 1994 with 15 of them categorized as large scale. They accounted for over one-half of the total annual sawn wood output. The majority of the saw mills were medium and small scale whose sawn wood recovery rates ranged from about 20 % to 30 %. The average recovery rate in the country was estimated at about 37 %. This scenario has since changed significantly due to the Government ban on logging from Government plantation forests and stringent transportation regulations even for logs harvested from private farmlands and settlements. Currently, there are few saw benches and small-scale sawmills operated using logs from privately owned farmlands. However, this situation is expected to change so that there would be sufficient logs from various types of land use following the passing of the forest policy and act (GoK, 1999).

Once the sawmilling industry in Kenya is revitalized, an estimated processing capacity of about 400,000 m^3 of sawn wood would be attained. At an average recovery rate of 40 %, it implies that the sawmilling industry would consume about 1 million m^3 of round wood annually and consequently generate about 600,000 m^3 of sawmilling wastes annually.

The large-scale sawmills, with better conversion machineries and skilled manpower, had the highest sawn wood recovery rate (41.8 %) followed by medium scale (30.1 %) which were closely followed by small scale sawmills (24.2 %). This was an average sawmilling residue of 67.9 %. Medium-and small-scale sawmills had poorly equipped and unskilled logging crews using poorly serviced and maintained equipment and machines. The quantity of the sawmilling residues followed the same pattern; large-scale sawmills generated the minimum quantity of residues while the small-scale sawmills produced the highest quantity of sawmill residues.

About 5 % of the sawmilling residues produced by the sawmilling industry were economically utilized as animal bedding and in poultry rearing. This quantity was obtained mostly from sawmills that were located near commercial towns where demand was relatively high. Most sawmills situated in rural areas simply disposed and burnt almost 100 % of their sawmilling residues in dumpsites within the saw mills. This posed serious environmental problems such as fire hazards and human health and safety risks. Saw milling residues by investors to quantify raw material availability and since these residues are available in enormous quantities, they are recommended for use in various industrial applications (J.M. Onchieku1B.N. Chikamai Kenya Forestry Research Institute, M.S. Rao Moi University Kenya-2013).

2.2.2.2 Production of sawdust

Sawdust is a major waste generated in large volumes in the timber industry which constitutes a nuisance to both public health and the environment when not properly managed. It has been affirmed that the volume of sawdust generated in Kenya is quite high due to the increasing number of sawmills. This is due to the increasing number of operating sawmills. The presence of these wastes in large quantity poses disposal problems for the industry. In the past, these residues were left in the field to be wastefully burnt away. However, in recent times, burning of wood residues in the open has been discouraged because of environmental problems associated with this practice, rather there is a potential for utilizing forestry and wood wastes especially sawdust for energy. These sawdust wastes can be converted to useful form through densification process. Furthermore, saw dusts from these mills are heterogeneous in nature comprising of mixtures of the bark, wood and chemical resins. Also these wastes are products of different species of woods with different strength properties and chemical compositions. Studies on the characterization of these materials have not been extensively carried.

2.3 Molasses

This section provides a review of production of molasses, and its properties.

2.3.1 Production of molasses in Kenya

Molasses is one of the major co-products of sugar processing. It comes out of the separation of the last boiling which produces the last low grade sugar and the last molasses, normally called the final molasses. Molasses is a heavy, viscous darkbrown liquid consisting mainly of sucrose, water, reducing sugars (glucose and fructose) ashes and other organic compounds. It is normally about 3 % of the weight of cane processed. More molasses is produced when low quality cane is processed. Mukhopadhay *et al*., 2008 reported that fermented molasses produces spirits (ethanol) and yeast.

In Kenya, molasses is used by local farmers as animal feed and also sold to;

i) Industrial users about 80% of annual production, such as, Agro-Chemical & Food Co, Spectre International, and London Distillers.
ii) Bakers 5% of annual production, such as, United Millers, and Mayfair Holdings.
iii) Farmers about 15% of annual production , such as, Kipsinende Farm, Chemusian Farm, Koiyet Farm and other smallholdings farms.

2.3.2 Properties of molasses

Molasses is a dark viscous by-product of refining sugarcane into sugar. This concentrated by-product is left over after the sugar's sucrose has been crystallized. It has a robust flavor described as bittersweet. This extraction theory is based on the mutual solubility influences in the system: water sugar, salts or non-sugar components. In many studies of the influence of the non-sugar components on the solubility of sucrose, pure substances or mixtures of pure substances have been employed, but they did not always correspond to the complicated relationships prevailing in molasses. The use of ion exchangers made it possible to start these investigations directly on molasses. It has been found that nitrogenous materials have practically no effect with respect to the sucrose solubility; potassium and sodium have considerably stronger molasses-producing properties than calcium and lithium.

Because of the economic significance of the composition of final molasses there is great permanent interest in the sugar industry in being able to calculate beforehand the amount of molasses that may be expected, i.e. at the time of delivery and processing of the sugarcane.

2.4 Physical and Combustion Properties of Briquettes

2.4.1 Physical properties of briquettes

The physical properties discussed are density and durability index.

2.4.1.1 Density

The density of biomass materials vary enormously from around 100 kg/m^3 for light dry straw to over 2000 kg/m^3 for highly compressed biomass fuels (Ryu *et al.,* 2006). High density of the fuel is associated with greater energy density. The density of briquettes affects thermal properties since thermal conductivity will be reduced at the lower density (increased fuel porosity) but the lower the density, the less heat is required for a specific volume to reach the ignition temperature. As a result, the ignition time and the rate of thermal decomposition are affected (Yang *et al.,* 2001; Ryu *et al.,* 2006). Yang *et al*. (2011) observed that the burning rate decreases with increase in materials density. Density also affects, the residence time of the gases within the char matrix of compressed briquettes. At higher density, residence time of volatile gases is increased due to low porosity (Zaror and Pyle, 2012).

The mass of the briquette can be determined by weighing the sample in digital weighing scale while the volume can be evaluated through linear measurement of the diameter and height of the briquette. The volume is then calculated. The ratio of mass to volume gives the density.

2.4.1.2 Impact resistance

This test simulates the forces encountered during emptying of densified products from trucks onto ground, or from chutes into bins. Drop tests or impact tests can be used to determine the safe height of briquette production during mass production ASTM D440-86 method is used to determine impact resistance index. In the drop test, briquettes are dropped twice from a height 1.83 m onto a concrete floor. An impact resistance index (IRI) is calculated following Equation 2.1.

$$IRI = 100 * Nn \qquad 2.1$$

Where N= Number of drops, n= Total number of broken pieces

The highest IRI is 200

2.4.1.3 Durability index tests

The durability of the briquettes is determined in accordance with the chartered index described by Suparin *et al.* (2008). The briquette samples are dropped repeatedly from a height of 1.5 m onto a solid base. The fraction of the briquette retained is used as an index of briquette breakability. Upon dropping the sample from 1.5 m height part of the sample crumbles. The remaining portion is then reweighed. Durability rating of the briquette is expressed as a percentage of the material remaining on the metal plate to the initial mass.

2.4.1.4 Proximate analysis of briquette

The proximate analysis is a standardized testing procedure that quantifies physical and combustion characteristics of biomass fuels. This is done by considering biomass

$$\text{Burning rate}=\frac{\text{Mass of fuel consumed(g)}}{\text{Total time consumed(min)}} \quad 2.2$$

fuels to be made up of four main components; calorific value, moisture content, volatile matter, ash content and fixed carbon.

2.4.2 Combustion Properties of Briquettes

The subsection provides a review on combustion properties as water boiling test and burning rate

2.4.2.1 Water boiling test

This is done to determine the burning rate of a fuel and its specific fuel consumption. A standard amount of water is boiled by different fuels under the same conditions and time taken is recorded, (Onuegbu *et al.*, 2011). Combustion process takes place in four phases; ignition, full flaming, glowing and burnout phases. Ignition is from the beginning; reaction of fuel and oxygen to the temperature before intense combustion. After ignition, combustion enters into full flaming and glowing phases. In this phase, the two predominant factors are the rates of heat transfer and the kinetic rates of reaction which determines the amount of heat released. While the burning course is divided into two phases: the burning of gas phase (volatile materials which is released through pyrolysis of the fuel upon heating) and the burning of solid phase (the solid phase as char oxidation), (Qing-ling *et al*., 2013).

2.4.2.2 Burning Rate

This is determined from the amount of total burnt briquette and burning time. The average burning rate and specific fuel consumption are given by Equation 2.2 and 2.3, respectively.

$$\text{Specific fuel consumption}=\frac{\text{Mass of fuel consumed(g)}}{\text{Total mass of boiling water(litre)}} \qquad 2.3$$

2.5 Briquetting Production Parameters

The section provides a review on briquetting production parameters as compaction, retention time, Relaxation time, and die geometry and speed

2.5.1 Compaction

Briquetting pressure is expected to have effect on the physical and compaction characteristics of the blended briquettes. The density of chopped banana pellets is found to vary proportionately with natural logarithm of applied pressure and also raising the pressure significantly raised the density (Butler and McColly, 1959).

2.5.2 Retention time

The compressive strength of briquettes is influenced by the retention time in the die (Tabil and Sokhansanj, 1996). However, at consolidation pressure above 138 MPa, retention time of about 5-20s has no significant effect on the quality, durability and stability of oak saw dust briquettes (Al-Widyan*et al.,* 2002).

2.5.3 Relaxation time

Relaxation time influences the density of briquette materials. Final relaxed density of briquette and relaxation duration after removal from the die depends on several factors notably: Die geometry, mode and level of compression, type and properties of feed material and storage condition. Studies have shown that upon removal from the die, after a high pressure compaction, the density of the briquette reduces with time to a relaxed density. For most materials the expansion rate is highest just after the removal from the die and reduces with time thereafter until a constant volume is attained (Carre*et al.,* 1987). Relaxation characteristics are measured by percent increase in elongation. Increase in voidance depends on factors such as feed material and storage conditions such as relative humidity (Wamukonya and Jenkins, 1995; Shivastava*et al*., 1990). Volume expansion is calculated using Equation 2.4:

$$Y = \alpha_0 + \alpha_1 P + \alpha_2 T \qquad \text{Equation 2.4}$$

Where Y is percent volume expansion, T is die temperature (℃), P is die pressure (kg/m^2)

α_0, α_1 and α_2 are constants

2.5.4 Die geometry and speed

The die geometry refers to size and shape of die. Die geometry affects the properties of briquettes such as moisture content, density and durability. Rise in briquetting pressure increases the briquette length. Durability of briquettes was noted at smaller die (Tabil and Sokhansanj, 1996). Die barrel temperature and screw speed significantly affected briquette density and hardness (Shankar *et al.*, 2005). Ratio of length to diameter of the die and screw speed significantly affected the flow rate of mixtures during briquetting hence affect the resulting properties of briquettes (Shankar *et al.*, 2008).

2.5.5 Feedstock variables

Feed stock refers to raw materials (input) fed into a process for conversion into something different (output). The variables considered include; moisture content, particle size, shape and homogeneity

2.5.5.1 Moisture content

Moisture facilitates starch gelatinization, protein denaturation and fibre stabilization when densifying briquettes. Moisture is observed to increase the bonding via van der Waal’s forces hence raising the contact area of the particle (Mani *et al.,* 2006). Moisture content of about 5-10% resulted in denser, more stable and durable briquette as opposed to those with higher moisture contents about 15% and above. An optimum moisture content of about 8% is recommended for high density briquettes and a moisture content of under 4% to avoid fragility of the pellets or briquettes within a few days due to absorption of moisture from the atmosphere (Li and Liu, 2000). A moisture content of 5-12% is recommended for production of good quality logs in terms of density and long-time storage properties from hardwood, softwood and bark. Li and Liu, 2000,concluded that briquetting cellulosic material needs 8-12% as optimum moisture content while those with starch and protein (mostly animal feed) need up to 20% moisture content (Sokhansanj *et al*.,2005).

2.5.5.2 Particle size, shape and distribution

Kaliyan and Morey (2006) emphasized that decrease in the particle sizes, significantly increases the tensile and compressive strength of briquettes. This was attributed to high packing density at lower loads. But Mani *et al*. (2003) suggested that diametric expansion of the biomass briquettes decreased with reduction in the particle sizes. However, the particle sizes did not have significant effect on the longitudinal expansion of the briquettes.

According to Mani *et al*. (2003), the smaller the particle sizes the higher the density of the briquettes. Generally, the density of the briquette is inversely proportional to the particle sizes. It is generally agreed that particle size distributions has effects on briquette characteristics. Most densification equipment requires that the feedstock particle length should not be more than one quarter of the diameter of the resulting briquette. In some cases, size reduction using hammer mills is necessary.

2.6 Existing Knowledge Gap

Most of researches focused on briquette derived from one biomass alone, but information on the effect of mix ratio and particle sizes on physical and combustion characteristics of blended briquettes are limited. This study hypothesizes that, if sawdust is blended with banana waste their physical and combustion characteristics would improve.

CHAPTER 3: EXPERIMENTAL METHODS

3.1 Material

The material used in this study consisted of sun dried sawdust and banana waste which were ground, sieved, carbonized and compacted to produce briquettes. Materials were carbonized to increase the carbon content hence the heating value. Table 3.1 show sample preparation

Table 3.1: Sample preparation

Sample No.	Weight of components (gm)			Weight of briquettes (gm)
	Saw dust	Banana waste	molasses	
1	50	0	20	50
2	40	10	20	50
3	30	20	20	50
4	25	25	20	50
5	20	30	20	50
6	10	40	20	50
7	0	50	20	50

3.1.1 Sawdust

Sawdust collected had a moisture content of about 28 %. It was sun dried to approximately 5 % moisture content and hammer milled before carbonizing at 400^{o}C for 5 minutes in the muffle furnace according to Gimba and Turoti (2008). The carbonized sawdust was then cooled to room temperature in the desiccator. After cooling, the materials were sieved to different particle sizes of 2.5 mm, 5 mm, 7 mm 9 mm and 11 mm following Zhang *et al.* (2012)(see Appendix EFig.E1 for sieves used in the study). The sieved materials were packed and sealed in separate labeled plastic bags to avoid absorption of moisture from the atmosphere.

3.1.2 Banana waste

Samples of dried banana leaves were obtained directly from harvested banana trees and only the leaves that were already dry were collected. The pseudo stem was obtained from harvested banana plants. By having high humidity, pseudo stem was pressed in a hydraulic press to remove the largest liquid fraction, and after that process, it was dried in a forced ventilation muffle at 60 ºC to a moisture content of 8%. The dried pseudo stem and banana leaves were hammer milled and sieved using a 2.5 mm sieve, to obtain fines with an average particle size of 2.5 mm. The milled pseudo stem and leaves were blended at the same ratios before mixing with carbonized sawdust as indicated in section 3.3.2.

3.1.3 Molasses

A commercial molasses was used in this study. 10 litres were bought from a hardware supplier and stored in a cold and dry place in the work shop. It was black in colour with a viscosity of 0.076 poise. In the current study, it was used as a binder during briquette manufacturing and its proportion was maintained at 20 % by mass in all briquettes made.

3.2 Determination of Physical and Combustion Properties of Sawdust and Banana Waste

3.2.1 Density

Density of sawdust and banana waste was determined according to ASAE S269.4 standards. Since density is property of mass against volume, the process of determining density was accomplished as follows. Both the mass and volume were measured and the measurements were computed and treated as the mass (m) and volume (v) in each case. Mass was measured using electronic balance and volume

$$\rho = \frac{m}{v} \quad \text{Equation 3.1}$$

was determined after 5 MPa compaction in a mould measuring 50mm and 100 mm. The density was determined using the Equation 3.1:

Where ρ is density (g/cm^3)
m - is the mass (g)
v - is the volume of the briquette (cm^3)

3.2.2. Calorific value

Calorific (heating) value of biomass is indicative of the energy content of the fuel. A Parr 6200 oxygen bomb calorimeter (Parr Instrument Company, Moline, IL) was used to determine the calorific value of sawdust (see Appendix D Fig. D.9). One gram was placed in a stainless steel crucible, and the material in the vessel (bomb) ignited by a 2223 cotton fuse. The vessel was filled with oxygen and surrounded by a water jacket. Upon ignition, the released heat was transferred to the water jacket. The temperature rise in the water jacket was used by the calorimeter to calculate the heating value of the sample.

3.2.3 Ash content

The amount of ash-forming material present in fuel is an indication of suitability of sawdust as fuel. ASTM 03174-97 (39) was used as by Nopporn (2013). In this case an empty crucible was heated to a temperature 500^{o}C for 30 minutes in muffle furnace before the cover was placed over it and cooled over desiccant for one hour. Thereafter, one gram of the sample was put on the weighed crucible, covered and heated gradually to temperature of 725^{o}C within 2 hours. The crucible was then cooled in desiccators before weighing. Difference in mass gives the ash content.

3.2.4 Volatile matter

Volatile matter was determined using the standard method, ASTM E872-82 (2006) as used by Sotanndee*et al*., (2010). This process was carried out by heating empty crucible to temperature of 500^oC for 30 minutes in muffle furnace. The cover was then placed and cooled in desiccators for one hour. Thereafter, one gram of the sample was put in the weighed crucible and closed with tightly fitting cover so that carbon deposit did not burn away. The sample was then transferred into the muffle furnace, ignited and temperature allowed to rise to 950^oC and was maintained for 7 minutes. The crucible was then removed from the furnace, cooled in desiccators, weighed and difference in mass was volatile matter.

3.2.5 Moisture content

Moisture content was determined as per ASTM E1871-82 (2006) standard. Empty crucibles were heated to 105°C for duration of 1 hr. They were then removed from the oven, covered and cooled immediately in a desiccant for 30 minutes. One gram of each of the samples was then weighed, put in the crucibles then dried in an oven at 105°C for 24 hrs. The crucibles were cooled in desiccators to room temperature then weighed again. Difference in mass is the moisture content.

3.3 Fabrication of Briquettes

3.3.1 Preparation of moulds and dies

Cylindrical moulds of 50 mm by 100 mm were produced from the mild steel. The cylindrical mould of 75 mm in diameter by 100 mm in length was clamped in lathe machine drill at the centre to produce an internal hole of 50 mm. The surface finishing of the internal hole was smoothened to reduce friction during briquetting process. The compaction arrangement was as shown in the drawing in Appendix E (Plate E.2).

3.3.2 Briquetting Procedure

Briquettes were produced by mixing carbonized sawdust, milled banana waste and binder. The weight of binder was kept at 20 % of sample mix weight. This was in accordance with findings of Davies and Davies (2013) for best binder ratio. 50 g of the materials-binder mixtures were hand-fed into the mould and compacted at 5 MPa using a hydraulic press shown in Figure 3.1.The compaction time was 5 minutes as recommended by Onaji and Siemons (2003) while compaction pressure was in accordance with (Oladeji and Lucas (2011).The pressure gauge was calibrated before the experiment was conducted. Once the mixture ratio was loaded into the mould, a flat cover was inserted into the base of the mould. The mould with the content was then loaded on the table of the press. Using flexible arm, the die was mounted manually on the mould till the required pressure was attained. The mould was then unloaded from the hydraulic pressure before the briquetted was removed from the mould for drying.

Figure 3.1: Hydraulic press used for production of briquettes.

To study the effect of mix ratios on the physical and combustion properties, the briquettes were fabricated at constant compaction pressure of 5 MPa using milled particle sizes of 2.5 mm. The pressure and particle size used in the study were based on the work of (Oladeji and Lucas(2011). Table 3.2 show the experimental design adopted for this study.

Table 3.2: Mix ratio of blended briquettes made at constant pressure of 5 MPa and 2.5 mm particle sizes

S/No.	Sample ID	Mix Ratio
1	SD:BW	1:0
2	SD:BW	4:1
3	SD:BW	3:2
4	SD:BW	1:1
5	SD:BW	2:3
6	SD:BW	1:4
7	SD:BW	0:1

Sawdust (SD), banana waste (BW)

To study the effect of particle size on the physical and combustion properties, the briquettes were fabricated at constant compaction pressure of 5 MPa and using a mix ratio of 1:0. The particle sizes were varied from 2.5 mm, 5 mm, 7 mm, 9 mm and 11 mm. For each particle size five replications were carried out and average values recorded.

3.4 Characterization of Blended Briquettes

3.4.1 Determination of density

This is one of the most important mechanical and combustion characteristics which determine handling, storage, and transportation characteristics of solid fuel. Density of briquette was determined according to ASAE S269.4 standards. Since density is property of mass against volume, the process of determining density of briquette was accomplished as follows. Both the height and diameter of a briquette were measured at six positions at 90^0 to each other using Vanier calipers. The average of the measurements were computed and treated as the height (h) and diameter (d) in each case. Density of briquettes was then determined using Equation 3.1.

3.4.2 Determination of durability index

The durability of the briquettes was determined in accordance with the chartered index described by Suparin*et al.* (2008). The briquette samples were dropped repeatedly from a height of 1.5 m onto a solid base. The fraction of the briquette retained was used as an index of briquette breakability. Upon dropping the sample from 1.5 m height part of the sample crumbled. The remaining portion was then reweighed. Durability rating of the briquette was expressed as a percentage of the material remaining on the metal plate to the initial mass as shown in Equation 3.2;

$$\textbf{Durability index}\ (\%) = \frac{\mathbf{A-B}}{\mathbf{A}} * 100 \qquad \text{Equation 3.2}$$

Where $\mathbf{A}$ is the mass of briquette before fall (g) and $\mathbf{B}$ is the mass after drop (g)

3.4.3 Determination of moisture content

Moisture content was determined as per ASTM D3173-11 standard. Empty crucibles were heated to 105℃ for duration of 1 hr. They were then removed from the oven, covered and cooled immediately in a desiccant for 30 minutes. One gram of each of the samples was weighed, put in the crucibles then dried in an oven at 105 ℃ for 24 hrs.The crucibles were cooled in desiccators to room temperature then weighed again. Difference in mass is the moisture content. This was expressed in wet basis as shown in Equation 3.3;

$$\text{Moisture content} = \left(\frac{\text{Wet weight-Dry weight}}{\text{Wet weight}}\right) * 100 \qquad \text{Equation 3.3}$$

3.4.4 Determination of calorific value

A Parr 6200 oxygen bomb calorimeter (Parr Instrument Company, Moline, IL) was used to determine the gross calorific value of the briquettes. One gram was placed in a stainless steel crucible, and the material in the vessel (bomb) ignited by a cotton fuse. The vessel was filled with oxygen and surrounded by a water jacket. Upon ignition, the released heat transferred to the water jacket. The temperature rise in the water jacket was used by the calorimeter to calculate the heating value of the samples. Tests on each sample were replicated five times. ASTM Standard D5865-03 (ASTM 2003b) test method for gross calorific value was referred to in this experiment. The bomb calorimeter is as shown in Appendix D (Fig. D.9).

3.4.5 Determination of ash content

Ash refers to the residue after burning of biomass. The determination of ash content was done in accordance with the standard (ASTM E 830-87) where one gram of the sample was placed into a weighed crucible. The crucible with sample in it was placed into the muffle furnace and gradually heated to 725°C and kept inside the furnace for a period of 1 hour. The crucible was removed and put in desiccator to cool to room temperature. It was then weighed and difference in weight is the ash content, determined using Equation 3.3

$$\text{Ash content (\%)} = \left(\frac{A-B}{C}\right)\times 100 \qquad \text{Equation 3.4}$$

Where, A is the mass of the crucible ash and residues (g), B is the mass of empty crucible (g), and C is the mass of the sample used (g)

3.4.6 Determination of flue gases

This was performed by loading and burning 1 kg of the briquettes in charcoal stoves which was positioned in a combustion chamber. Probe was then inserted in flue gas duct and measurement of flue gasses captured in a digital screen.

3.5 Statistical Analysis

The study involved seven mixture ratios and five particle sizes of blended briquettes. Five samples were analyzed for each condition and mean value reported. Graphical representation of the data was based on mean values and error bars on standard deviation. The data was analyzed using the T test to obtain the P values by comparing consecutive two mix ratios at a time. The P values output shows the significance difference of the different mix ratios. Sample T-test input and output files are given in Appendix C.In addition, data analysis was carried out using SAS statistical software. Significance studies were based on Least Significant Difference method LSD atα = 0.05.Sample SAS input and output files are given in Appendix (A to C).

CHAPTER 4: RESULTS AND DISCUSSION

4.1. Physical and Combustion Properties of Sawdust and Banana Waste

Table 4.1 gives the physical (density) and combustion (calorific value, moisture content, ash content and volatile matter) properties of sawdust and banana waste determined from this study.

Molasses had the highest density, ash content, moisture content and volatile matter. Comparing banana waste and sawdust, the former had higher ash content, moisture content and volatile matter while the latter had higher density and calorific value.

Table 4.1: Physical and Combustion Properties of Sawdust, Banana waste and Molasses.

Materials	Density (Kg/m^3)	Calorific Value (MJ/kg)	Ash content (%)	Volatile Matter (%)	Moisture Content (%)
Sawdust	681.21	15.92	5.79	25.32%	12.51
Banana waste	392.54	12.35	6.89	31.45%	14.63
Molasses	1330	11.24	8.00	43.25%	22.23

4.2 Effects of Mix Ratio on Physical and Combustion Properties of Blended Briquette

4.2.1 Effects of mix ratios on the density of blended briquettes

The density of blended briquette manufactured at different mix ratios of saw dust to banana waste (SD: BW) is summarized in Figures 4.1. It is clear from the results that the density increases as the proportion of sawdust was increased. This may be attributed to the fact that the determined density of sawdust was higher than that of banana waste. Varying ratios of briquetting materials have direct impact on densities as found by Chirchir *et al* (2013). This is in agreement with the current findings.

Increasing sawdust proportion in the mix seems to have significant effect for all ratios (see Appendix C Table C.1).The determined densities of briquettes ranged from 392.54 kg/m^3 to 681.21 kg/m^{3}which fits well with typical values of 100 to 2000 kg/m^3(Martin, J. and Mae, R. and Manaay, A. (2008).Notably, density is important property of fuel since it affect the rate of burning. Ideally, highly dense fuel burns longer than less dense one.

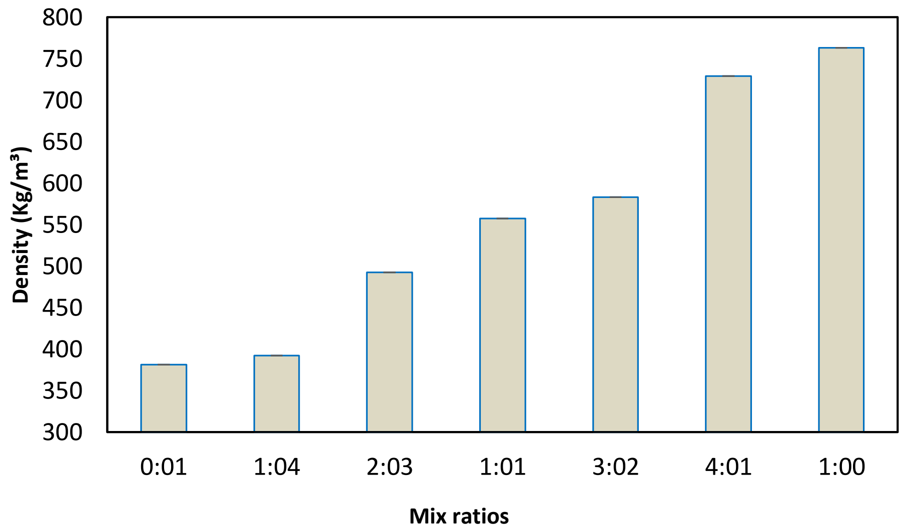

Figure 4.1: Variations of blended briquettes densities as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means.

Comparing the P values of the blended briquettes density at all mix ratios shows significant difference at 95% confident level ($p < 0.05$ see Appendix C Table 4.7). This is also confirmed by the non-overlapping error bars between the means. Therefore the density of the blended briquettes is significantly different at different mix ratios.

4.2.2 Effects of mixture ratios on the durability of blended briquettes

Durability of briquettes signifies the hardness. Hard fuel burn slowly as compared to a soft fuel. Figure 4.2 shows durability index at different mix ratios of sawdust and banana waste in the blended briquettes. Generally, the durability index reduces as the amount of banana waste in the blended briquettes decreases. The difference in durability indexes between the mean values of 0:1, 1:4 and 2:3 blended briquettes were significant at 95% confident level ($p < 0.05$ see Appendix C Table C.2 and Table 4.8).However, durability index was not significantly different between 1:1, 3:2 and 4:1 mix ratios. Apparently, any mix ratio between 1:1 and 1:0 produces blended briquettes with similar durability indexes. The 1:1 mix ratio is the optimal blend above which no significant difference is noted in the durability indexes. This is also confirmed by the overlapping error bars between the means in this range. Fuel with higher durability is preferred since it hardly breaks during handing and also burning duration is longer. Briquette strength has impact on the briquette durability, because when the strength increases the absorption of atmospheric humidity decreases.

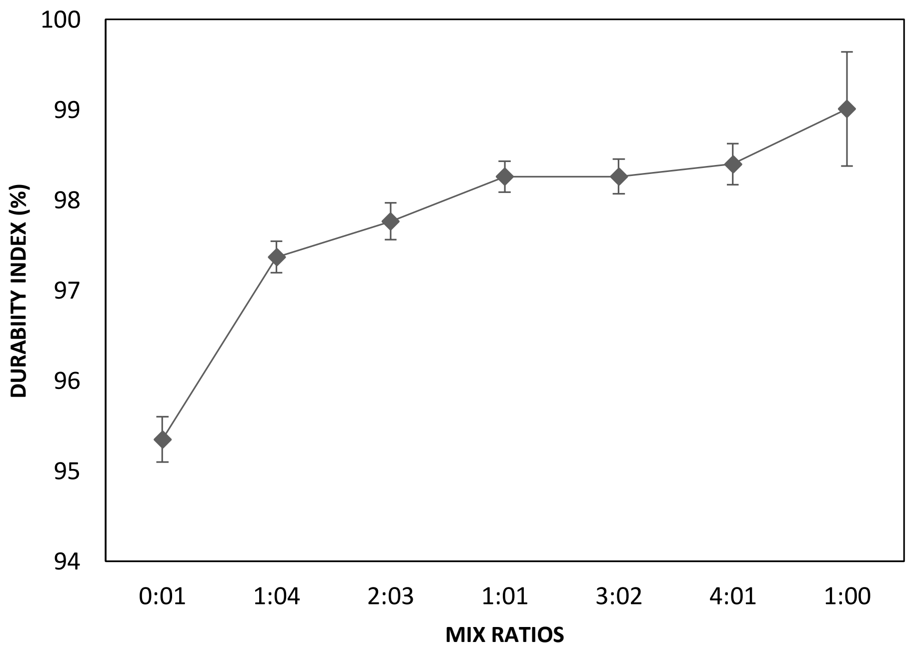

Figure 4.2 Variations of blended briquettes durability as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means

4.2.3 Effects of mixture ratios on the moisture content of blended briquettes

Figure 4.3 shows the results of the mean moisture content of blended briquettes produced at different mix ratios. Generally, moisture content decreased with decreasing content of the banana waste in the briquettes. This could be attributed to hygroscopic nature of the banana waste content which was not carbonized in this study. However, the decrease was not significant between 4:1 and 1:0 mix ratios ($p > 0.05$ see Appendix C Table C.3 and Table 4.9. Apparently, no gain is achieved in moisture content reduction by increasing sawdust content in the blended briquette above 50%. Consequently, 1:1 mix ratio may be considered the optimal blend ratio. Moisture of briquettes depends mainly on the initial moisture of raw material and it changes during the briquetting process, when the temperature increases by compression, some amount of moisture evaporates. High moisture content of briquettes leads to their bed consistency, increased number of crumbles, low energy value and consequently low price (Li and Liu, 2000).

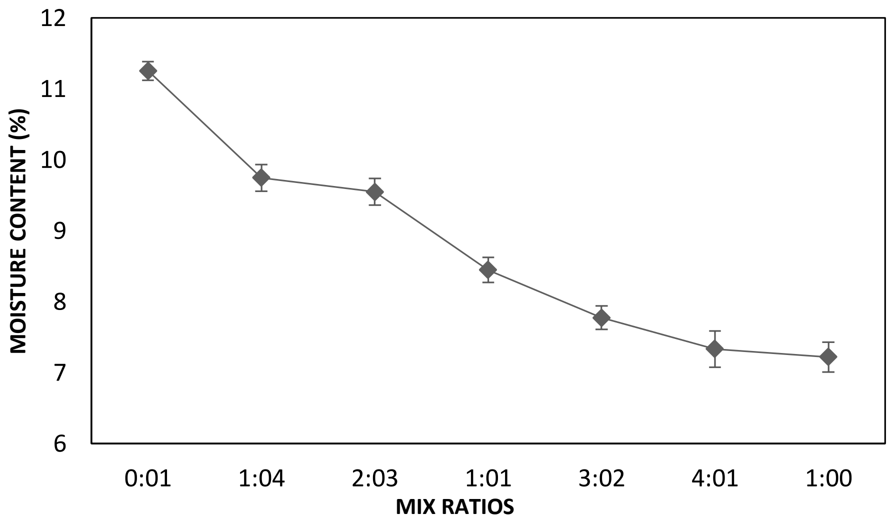

Figure 4.3: Variations of blended briquettes moisture content as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means.

4.2.4 Effects of mixture ratios on the calorific value of blended briquettes

Caloric value of the fuel is the heat produced when 1 kg of fuel is burnt. It varies based on other combustion of the fuel. Figure 4.4 shows the calorific values obtained from different mix ratio of sawdust and banana waste in the blended briquettes. In general, the caloric value of blended briquettes decreased as the banana waste content was increased. At the ratio of 1:0, the calorific value was 25.92 MJ/kg but reduced significantly to 23.40 MJ/ kg at ratio of 0:1. This reduction was significant at 95% confident level for all mix ratio ($p < 0.05$ see Appendix C Table C.4 and Table 4.10). This could be attributed to lower calorific values of non-carbonized banana waste, its increased moisture content and volatile matter as shown in Table 4.1.

Based on the previous studies on the calorific value, the results obtained for the rice husk was 13,389 kJ/kg while that of corncob briquette was 20,890 kJ/kg. These energy values are sufficient enough to produce heat required for household cooking and small scale industrial cottage applications. They also compare well with the value obtained in this research, for examples, groundnut shell briquette gives 12,600 kJ/kg (Musa, 2007), cowpea 14,372.93 kJ/kg, and soybeans gives 12,953 kJ/kg (Enweremadu, *et al.,* 2004).

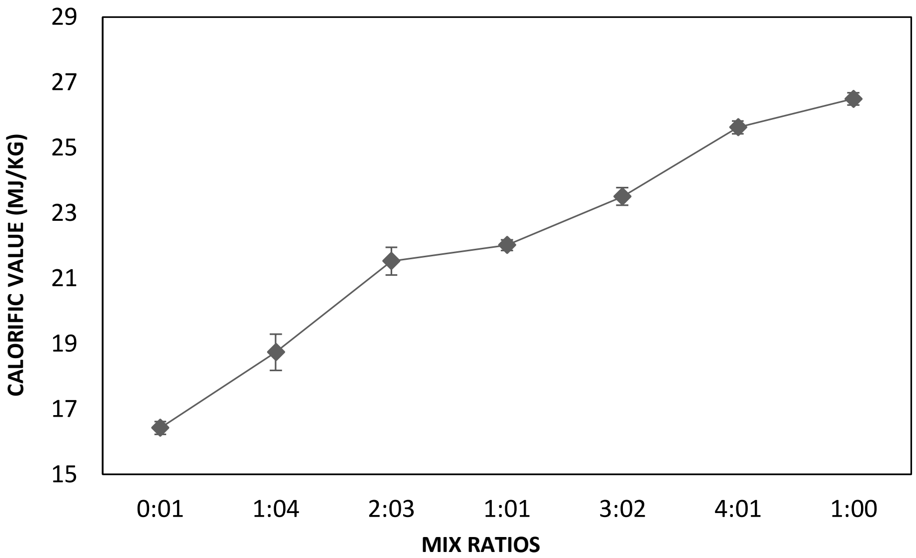

Figure 4.4: Variations of blended briquettes calorific values as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means.

4.2.5 Effects of mixture ratios on the ash content of blended briquettes

Results obtained for ash content of blended briquettes are as shown in Figure 4.5. At mixture ratios of 1:0, the ash content was 5.79 % but increased significantly to 10 % at ratio of 0:1. In general, the decrease was almost linear but there was no significant different between 1:4 and 2:3 and also between 1:1 and 3:2 mix ratios ($p < 0.05$ see Appendix C Table C.5 and Table 4.11). This suggests that, the amount of ash content in fuel is contributed significantly by the characteristics of the original materials, such as, banana waste in this case (see Table 4.1). Higher ash content is not desirable in the fuel because it lowers calorific value of the fuel.

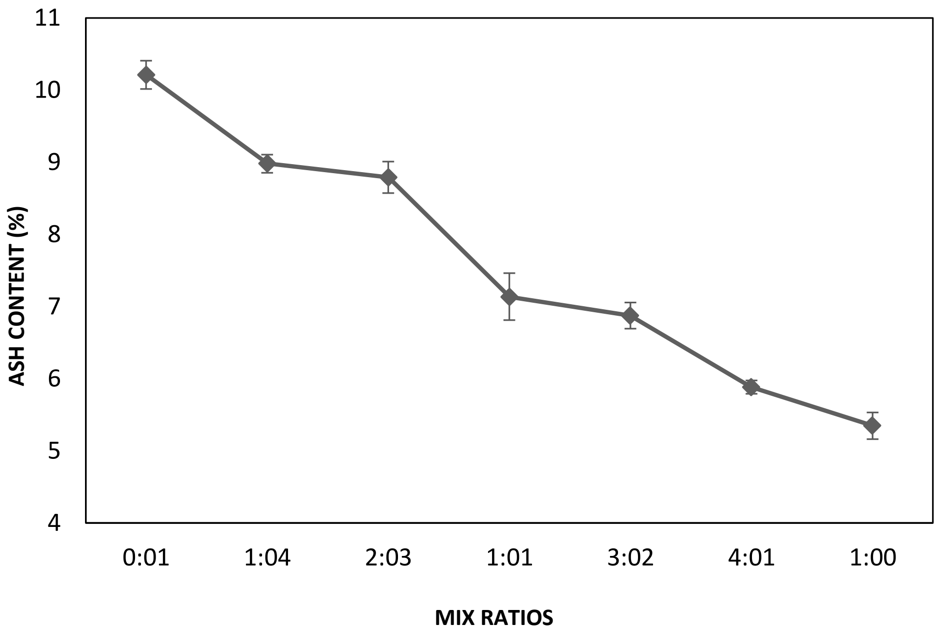

Figure 4.5: Variations of blended briquettes ash content as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means.

4.2.6 Effects of mixture ratios on the carbon monoxide of blended briquettes

Carbon monoxide emission is mainly due to incomplete combustion in fuel. It is a healthy hazard and brings suffocation if proper ventilation is not provided. From the results obtained in Figure 4.6, the production of carbon monoxide (CO) did not vary significantly from 5 % for mix ratio between 0:1 and 3:2. However, there was a significant reduction in CO production between 3:2, 4:1 and 1:0 mix ratios at 95% confident level ($p < 0.05$ see Appendix C Table C.6 and Table 4.12).Banana had higher amount of moisture content which could have induced incomplete combustion (Table 4.1 and Figure 4.3).This means as BW content reduces then the effect of moisture on combustion reduces. This conforms to emission levels recorded by Banzaert (2013) of 5-7 ppm comparable to other wood biomass levels. Notably, to achieve significant reduction in CO emission from the blended briquettes, the banana waste content has to be less than 40%.

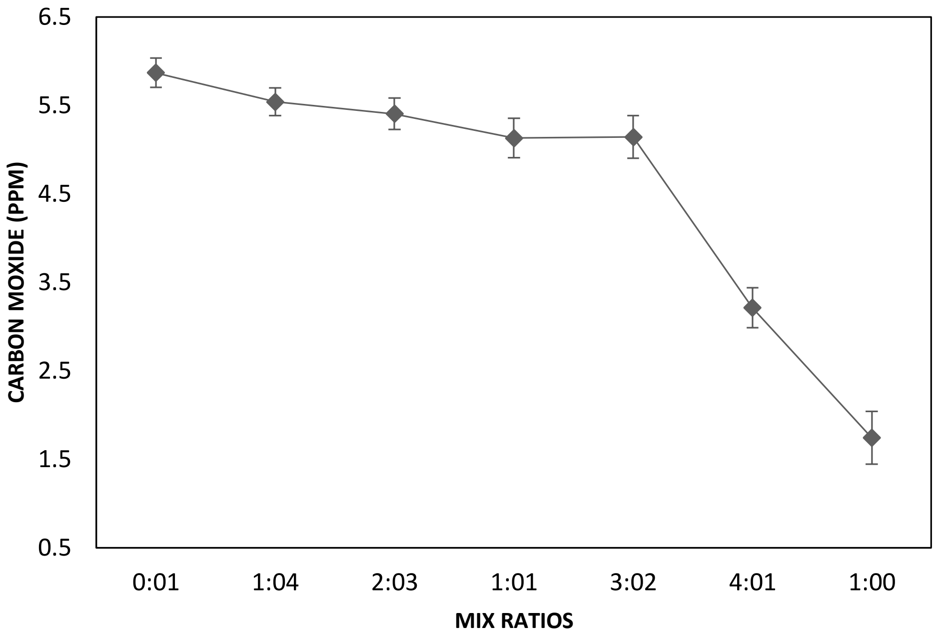

Figure 4.6: Variations of blended briquettes CO emission as a function of sawdust to banana waste mix ratio. The error bars are based on standard deviation of the means.

4.3 Effects of Particle Sizes on Physical and Combustion Properties of Briquettes

To study the effect of Particle size on physical and combustion properties, briquettes were fabricated at constant pressure of 5 MPa and at a blend ratio of 1:1. This ratio provided relatively good properties of the blended briquettes in terms of density durability index, calorific value, ash content and carbon monoxide as seen in Section 4.2.

4.3.1 Effects of particle sizes on the density of briquettes

Figure 4.7 show the density of briquettes produced using different particle sizes. Generally, the density increases increased almost linearly as the particle size was reduced. There was significant difference in density between all briquettes with different particle sizes as analyzed in Appendix B Table B.1 and Table 4.1. This could be attributed to increased compaction of smaller particle due to better bonding. The smaller the particle size, the higher the surface area which could have led to better binding. This compares well with findings of Mitchual *et al.* (2012) that coarser particles produce weaker bonds than finer ones hence less dense.

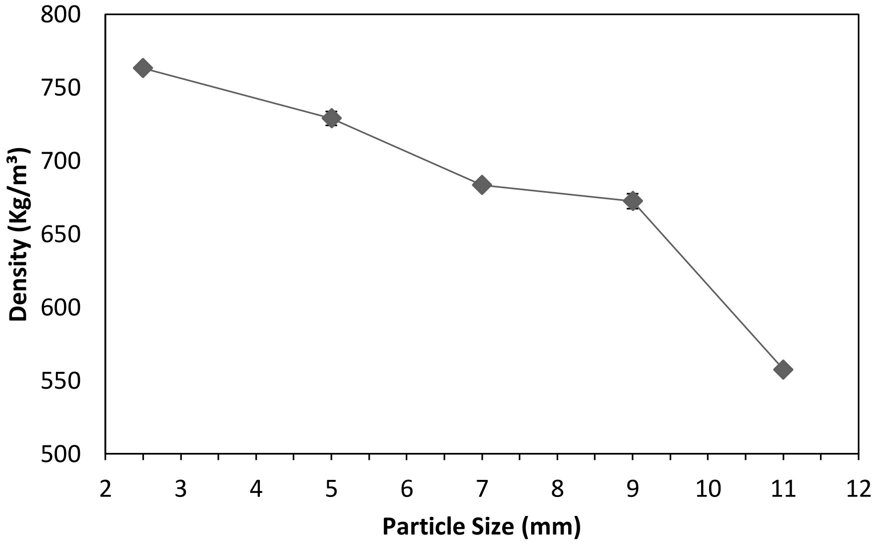

Figure 4.7: Variations of densities as a function of particle sizes in the briquette.

4.3.2 Effects of particle sizes on the durability index of briquettes

Results of effect of particle sizes on the durability are captured in Figure 4.8. In general, the durability index reduces as the particle size increases. The reduction in durability index is significant between 2.5 mm and 11 mm particle size briquettes as analyzed in Appendix B Table B.2 and Table 4.2. The result indicates that the fine particles produce durable briquettes compared to coarse particles. Notably, the effect of particle size on durability index seems less for particle sizes between 7 mm and 11 mm. The current result agrees with previous findings by Habib *et al.*, 2014 who found that coarser coal particles reduce its durability.

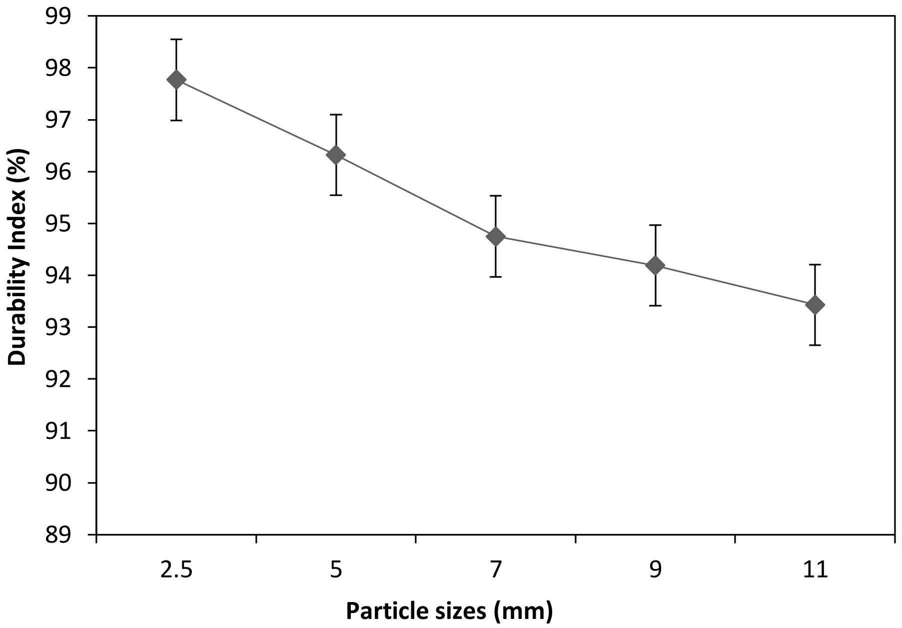

Figure 4.8: Variations of durability Index as a function of particle sizes in the briquette.

4.3.3 Effects of particle sizes on the moisture content of briquettes

Figure 4.9 shows the variation of moisture content in the briquettes as a function of the particle sizes. In general, as the particle sizes increase the moisture content of the briquettes remain almost constant (~7%) with no significant difference between them as analyzed in Appendix B Table B.3 and Table 4.3. This implies that the moisture content mainly depend on the moisture content of raw materials used which in this case were 12.5% and 14.6% for sawdust and banana waste, respectively. From studies by Li and Liu (2000) it has been found that when the feed moisture content is 8-10 %, the briquettes will have 6-8 % moisture, which agrees well with current finding..

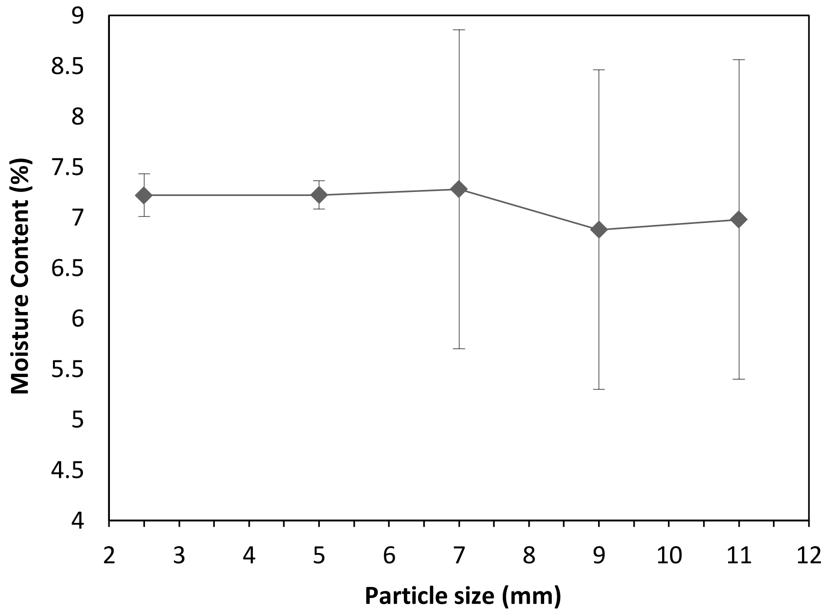

Figure 4.9: Variations of moisture content as a function of particle sizes in the briquette.

4.3.4 Effects of particle sizes on the calorific value of briquettes

Figure 4.10 shows the calorific values obtained from briquettes produced with varying particle sizes. Notably, as the particle sizes were reduced the calorific value increased from 25.84 MJ/kg at 11 mm to 26.49 MJ/kg at 2.5 mm particle sizes. This may be attributed to incomplete or difficult combustion for coarser particles owing to their small surface area to volume ratio. Importantly, no significant difference in calorific value is noted in briquettes produced with particle sizes between 5 mm and 11 mm as analyzed in Appendix B Table B.4. In terms of calorific value assessment of briquettes, 2.5 mm particle size seems to be the best. The current results are comparable to those from a study by Habib *et al*, (2014) and shows a good fit with commercial briquettes based on the DIN 51731 Standard on minimum calorific value for making commercial briquette (>17.5KJ/Kg),

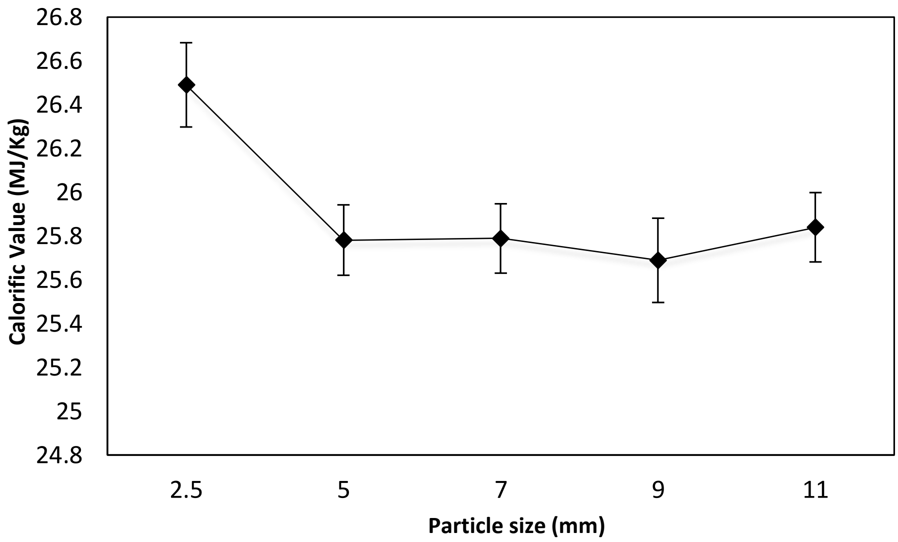

Figure 4.10: Variations of calorific value as a function of particle sizes in the briquette.

4.3.5 Effects of particle sizes on the ash content of briquettes

Figure 4.11 shows the ash content obtained in briquettes produced with different particle sizes. No significant difference was noted in ash content as the particle sizes were varied from 2.5 mm to 11 mm as analyzed in Appendix B Table B.5. The small variation in ash content amongst different particle sizes can be attributed to measurement errors. Apparently, the ash content produced by briquettes is independent of the particle sizes used in their manufacture.

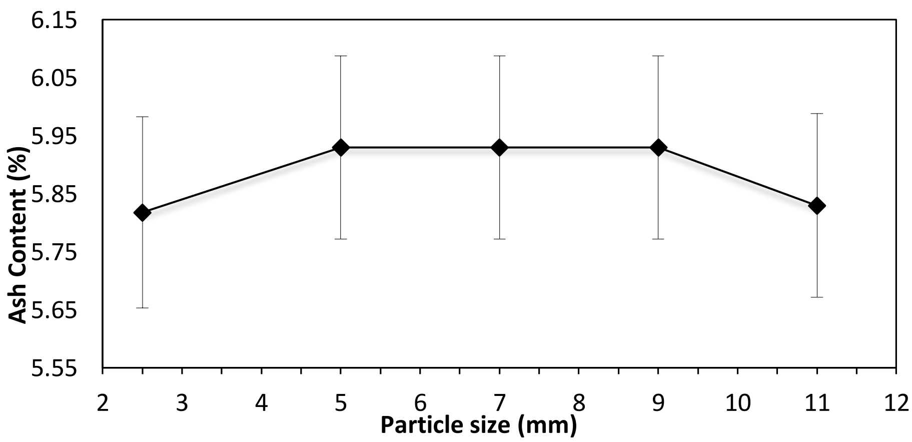

Figure 4.11: Variations of Ash Content as a function of particle sizes in the blended briquette.

4.3.6 Effects of particle sizes on the carbon monoxide of briquettes

Figure 4.12 show results of carbon monoxide emission as the particle sizes were varied in the briquettes. As the particle sizes were increased from 2.5 mm to 11 mm, the carbon monoxide emission reduced almost linearly from5.87 % to 5.20 %. This reduction was significant between briquettes made from 2.5 mm, 5 mm, 7 mm and 9 mm particle sizes as analyzed in Appendix B Table B.6. However, the emission of CO was not significant for briquettes made with 9 mm to 11 mm particle sizes. Therefore, for significant reduction in CO emissions, briquettes need to be made from particle sizes ranging from 9 mm and above. The reduction of CO emission with increase in particle sizes can be attributed to increased porosity for briquettes with coarser particles since the amount of carbon monoxide is a function of the air infiltration during combustion process. The increased porosity can be deduced from reduced density of coarser particle briquettes (see Figure 4.7). The current results are consistent with those of Banzaert, (201-3) averaging 5-7 ppm for combustion tests done on other agricultural wastes.

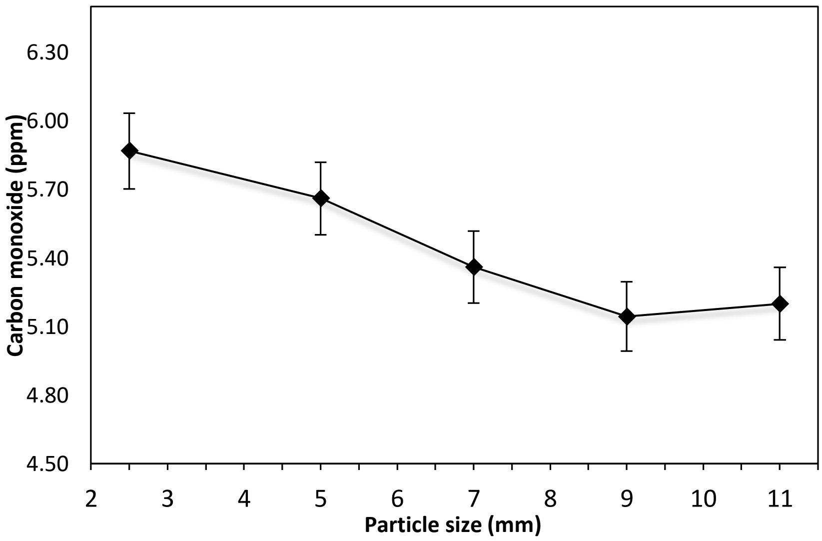

Figure 4.12: Variations of carbon monoxide production as a function of particle sizes in the blended briquette.

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

In the current study, blended briquettes produced from carbonized sawdust and banana waste were fabricated and characterized. The study investigated the effects of mix ratio and particle sizes on the physical (density and durability index) and combustion (ash content, moisture content, carbon monoxide, calorific value) properties of the blended briquettes. From the study, the following conclusions are drawn:

Sawdust has better calorific value (15.92 MJ/kg), lower ash content (5.79 %) and higher density (681.21 Kg/m^3) compared to 12.35 MJ/kg, 6.89 % and 392.54 Kg/m^3, respectively from banana waste under similar condition of measurements. On the other hand, banana waste has higher moisture content (14.63 %) and volatile matter (31.45 %) compared 12.51 % and 25.32 %, respectively from sawdust.

Different mix ratio produces blended briquettes with significantly different densities at constant compaction pressure of 5MPa. It is also evident that mix ratio between 1:1 and 1:0 has similar durability indexes while those between 0:1 and 2:3 have significantly different durability indexes. Mix ratio of 1:1 seems to be the optimal blend above which no significant difference is noted in durability index.

Moisture content of blended briquettes decreases with the increase in the sawdust content. However, there is no gain in moisture content reduction by increasing sawdust content in the blended briquette above 50%. Consequently, 1:1 mix ratio is considered the optimal blend ratio for this study.

Calorific values and ash content of blended briquettes increases significantly with the increase in the sawdust content at all mix ratios studied. However, the carbon monoxide (CO) emission of the blended briquettes decreases as the sawdust content is increased. Notably, to achieve significant reduction in CO emission, the banana waste content in the briquette has to be less than 40%. Consequently, 3:2 mix ratios is considered the optimal blend ratio for this study in terms of CO emission.

Finally blended briquettes produced from fine particles, at constant compaction pressure and mix ratio, have higher mass density, durability index, and carbon monoxide emission compared to those produced from coarser particles. The moisture and ash content of the briquettes is not influenced by the variation of the particle sizes between 2.5 mm and 11 mm. The density increases almost linearly with reduction in the particle size while durability index varies significantly for briquettes having 2.5 mm and 11 mm particles sizes but similarity in indices exist between 5 mm and 11 mm. The amount of energy produced by briquettes remains constant as the particles sizes are increased from 5 mm to 11 mm while 2.5 mm particles give the highest energy. Importantly, particle sizes greater than 9 mm produces significantly less carbon monoxide compared to other sizes studied.

5.2 Recommendations

Further research should be done to determine the effect of carbonization temperature on combustion and physical characteristics of briquettes made from sawdust and banana waste. In the current study, the carbonization temperature was kept constant at 400 °C. This need to be varied to ascertain whether it has effect on properties investigated or not.

Optimization of variables such as compaction pressure, mix ratio and particle sizes needs to be done. In the current study, interaction between the various parameter investigated were not conducted due to time constrain and the scope of the study. The current finding can therefore be used as the baseline for optimization studies in future since the effect of the variables studied is known at constant conditions.

REFERENCES

Adapa, P. (2009, 10;06 10;22). Compaction Characteristics of Barley, Canola, Oat and Wheat Straw. *Biosystems engineering; Biosystems*.

Adegbulugbe, A. (1994). Energy-Environment. *Global Energy Issues*, 7-18.

Aina O, M., & K, S. (2009). Heat Energy from Value Added Sawdust Briquettes. *Environmental Management*, 21-35.

Abakr, Y. and Abasaeed, E. (2006). Experimental Evaluation of a Conical- Screw Briquetting

Machines for the Briquetting of Carbonized Cotton Stalks in Sudan. *Journal of Engineering Science and Technology,* 1:212-230

Aga, S. (2000). A Study of Densification of Pre-heated Sawdust, Msc. Thesis No. ET-90-4, Asian Institute of Technology, Thailand

Akinbami, J. (2001). Renewable Energy Resources and Technologies in Nigeria; Present Situation, Future Prospects and Policy Framework Mitigation and Adaptation Strategies for Global Change

Altun, E. Hicyianaz, K. and Bagci, S. (2004). Influence of Coal Briquettes Size on the Combustion Kinetics. *Fuel Processing Technology Journal*, 88:1345-1357

Ardayfio, D. (2006). The Fuel/ Energy Crisis in Sub Sahara Africa. Sustaining the Future, Economic, Social and Environmental Change in Sub-Sahara Africa. The United Nations University

ASTM (American Society for Testing and Materials), (2004a). Annual Books of ASTM Standards Parts Gaseous Fuel; Coal and Coke, Atmospheric Analysis, Easton Maryland, USA

ASTM (American Society for Testing and Materials), (2004b). Standard Test Methods for Gross Calorific Value of Refuse- Derived Fuel by Bomb Calorimeter Annual Books of ASTM Standards

Announssany, M. Richard, G. Recous, S. and Guerif, J. (2000). Change in Mechanical Properties of Wheat Straw due to Decomposition and Moisture. *Journal onApplied Engineering in Agriculture,* 16: 657-664

Banzaert, A. (2013). *PhD Thesis, Massachusettes*. USA: Institute of Technology, Cambridge.

Belen B. Bisare, N. B. (2010). Utilization of Cashew Nut Shell Residue for Charcoal Briquettes and activated carbon. *Production journal of Wood Science,* 44,56-61.

Bhada, G. (2007). *Feasibility Analysis of Waste to Energy as a Key Component of Integrated Waste Management in Mumbai,*. India.

Bjorheden, R. (2006). Drivers behind the Development of Forest Energy in Sweden. *Biomass and Bioenergy 30(4):289-295.*

Bolufwi S. and Bamgboye A., (2008). . (n.d.). Physical Characteristics of Briguettes from Guinea Corn (Sorghum bi-colour) Redidue. *Agricultural Engineering International.The CIGR Ejournal. Manuscript 1364.*

Bamgboyo, I. and Bolufawi, S. (2010). Physical Characteristics of Briquettes from Guinea Corn (Sorghum Bi- color) Residues. *Agricultural Engineering Journal*, 1:1-10

Boyles, T. (2004). Combustion Properties of Biomass. *Journal on Fuel Processing Technology*. 54:17-26

Chaney, J. Clifford, M. and Wilson, R. (2009). An Experimental Study of the Combustion Characteristics of Low Density Biomass Briquettes. *Biomass and Bio energy Journal*, 12: 505-509

Chin, O. and Siddiqui, K. (2000). Characteristics of Some Biomass Briquettes Prepared under Modest Die Pressures. *Journal on Biomass and Bio Energy*, 18: 223-238

Chirchir, D. (2011). Evaluation of Physical and Combustion Characteristics of Biomass Composite Briquette,. *Unpublished MSc. Thesis*. Egerton University, Faculty of Engineering and Technology.

Chirchir,D., Nyaanga,D., and Kitheko, J.,. (2013). Effects of Binders types and amount on physical and Combustion Characteristics of Biomass Composite Briquettes. . *International Journal of Engineering Research, Science and Technology,2013/2(1).*

Dam, V. Jeg, D. and Keijsers, E. (2004). Process for Production of High Density Performance Binderless from Coconut Husk Part 1: Lignin as Intrinsic Binder Resin. *Journals on Binder Resin*, 19:207–216

Demirbas, A. and Sahin, A. (2001). Evaluation of Biomass Residue; Briquetting Waste Papers and Wheat Straw Mixtures. *Journal on Fuel Processing Technology*,55: 175-183

Demirbas,A. (2007). Biomass Resource Facilities and Biomass Conversion Processing for Fuels and Chemicals. *Journal on Energy Conversion and Management*, 42: 57–78

Dermibas, A. (2004). Physical Properties of Briquettes from Waste Paper and Wheat Straw Mixtures. *Journal on Energy Conversion and Management*, 40:437-445

DOE (Department of Energy), (2009). Official Energy Statistics for USA Government. World Nominal Oil Prices Chronology, USA

DOE (Department of Energy), (2008). USA Energy Information on Annual Coal Report, USA

Eriksson S. and Prior M,. (1990). *The Briquetting of Agriculture of Agricultural wastes For Fuel*. Food and Agricultural Organization Publication.

Etienne, P. (2007). Development of Energy Production System to Briquette Papyrus through Partial Pyrolytic Conversion, Biomass Energy Services and Technology

Enweremadu, C. Ojediran, J. Oladegi, J. and Afolabi, K. (2004). Evaluation of Energy Potential of Husks from Soyabeans and Cowpeas. *Journal on Sciences Focus,* 8:18-23

FAO. (1987). *Agriculture Production Yearbook.* Rome: Food and Agriculture Organization.

Faizal, H. Latiff, A. Mazlan, A. and Darus H. (2010). Physical and Combustion Characteristics of Biomass Residues from Palm oil Mills. *Journal on New Aspects of Fluid Mechanics and Environment*, 8:34-38

FAO (Food and Agriculture Organization), (2005). Industrial Charcoal Making. Food and Agricultural Organization of the United Nations

Geoffrey B. and Lars A. (1985). *Agricultural Residues as a source of Fuel in Developing Countries.* London: IIED.

Girald, P. Fallot, A. and Dauriac, F. (2005). Technology State of Art Review of Existing and Emerging Technologies for the Large Scale Production of Bio fuel

GOK (Government of Kenya), (2007). Kenya Vision 2030. Government of Kenya, Nairobi

Greenberg, A. Mehling, A. Lee, M. and Bock, J. (2005). Tensile Behaviour of Biomass. *Journal of Materials Science*, 24: 49-54

Halyk, R. and Hurlbut, J. (2005). Tensile and Shear Strength Characteristics of Biomass. *Journal on Mechanical Properties of Biomass,* 11:56-57

Hayashi, H. and Nakashima, S. (2002). Synthesis of Trioctahedral Smectite from Rice Husk Ash as Agro-waste

Heinz, K. Siemers, W. and Stuven, U. (2003). Technical and Economic Assessment of Charcoal and Densified Fuel from Water Hyacinths and Cotton Stalks. *Journal on Fuel Processing Technology*,7: 23-42

Himraj, D. (2003). Fuel Substitution in Sub Sahara Africa. *Journal on Environmental Management*, 17:283-288

Hollingdale, A. Krishnan, R. and Robinson, A. (1991). Charcoal Production Handbook. Natural Research Institute Technical Paper

Hulscher, S. (2002). Briquetting in South and East Asia: State of the Art Assessment. Ann. Rept.Technology & Development Group, the University of Twente, Netherlands

Husain, Z. Zainac, K. and Abdullah, Z. (2002). Briquetting of Palm Fibre and Shell from the Processing of Palm Nuts to Palm Oil. *Journal on Biomass and Bio Energy*,22:505-509.

Ivanov, J. Sudakova, G. Kuznetov, B. (2003). Manufacture of Briquetted and Granulated Fuels from Lignite with Bio binders and Heated Die. *Journal on Chemistry for Sustainable Development,* 11:847-852

Itodo, A., Elinge, C., Yusuf.H, & Birnim-Yauri, U. A. (2011). Blending Coal Char on the Combustion Profiles of Fuel Briquettes. *Combustion Of Fuel Briquettes*, 152-157.

Jenkins, P. Baxter, C. and Miles, T. (2008). Combustion Properties of Biomass Fuel Processing Technology. *Journal on Fuel Processing Technology,* 54: 17-46

Jindaporn, J. and Songchai, W. (2007). Production and Characterization of Rice Husks based Charcoal Briquettes. *KKU Engineering Journal*, 34: 391-398

Katimbo, A.,Kiggundu,N.,Kizito, S.,Kivumbi,H.B.,Tumutegyereize,P.,(Dec.,2014). Potential of Densfication of Mango Waste and Effect of Binders on Produced Briquettes. *Agricultural Engineering Int:CIGR Journal*, Vol. 14 No.4 pp.146-154.

Koutny R., Cechova B., Hutla P. and Jevic P. (n.d.). *Properties of Heat Briquettes on Basis of Cotton Processing Waste.* Praque,Czech Republic: Czech University of Life Sciences in Praque.

Khalid, N. Ahmad, H. and Toheed, A. (2000). Potential of Rice Husk for Antimony Removal. Applied Radiation and Isotopes.

Krizan, P. Soos, L. and Vukelic, D. (2009). Study of Impact Technological Parameters on the Briquetting Process.Series: Working and Living Environmental Protection

Kim, J. Lu, G. and Naruse, J. (2001). Modelling Combustion Characteristics of Bio coal Briquettes. *Journal of Energy Resources Technology*, 12:27-31

Kituyi, E. Marufu, L. Wandiga, S. and Helas, G. (2001). Bio fuel Availability and Domestic Use Patterns in Kenya. *Journal on Biomass and Bio Energy*, 20:71-82

Klose, W. and Damns, S. (2000). Pyrolysis and Activation of Different Woods Thermal Analysis. Michigan State University, USA

Koser, J. (2005). Utilization of Agricultural Residue Preliminary Analysis. *Journal Science, Ind. Res*, 39: 495- 515

KPLC (Kenya Power Lightning Company), (2006). Annual Energy Report. Nairobi, Kenya

KPLC (Kenya Power Lightning Company), (2010). Energy Report on Rural Electrification in Kenya. Nairobi, Kenya.

Li, J. and Liu, K. (2003). Fundamental of Heat and Mass Transfer, John Willy and Sons.

Liu, H. (2005). High Pressure Densification of Wood Residue to Form Upgraded Fuel. *Biomass and Bio Energy*, 19:177-186

M.I, A.-W., HF, A.-J., & Abu-Zreig MM, A.-H. N. (2002). Physical Durability and Stability of Olive Cake Briquettes. *Biosystems Engineering*, 44:3,41:3,45.

Mahri, H. Maliki, A. and Eslami, A. (2004). Potential of Rice Husk and Rice Husk Ash for Phenol Removal in Aqueous System. *AmericanJournal of Applied Science,* 1:321-326

Mani, S. Tabil, L. and Sokhansanj, S. (2003). Evaluation of Compaction Equations Applied to four Biomass Species. *CanadianJournal on Bio Systems Engineering,* 46: 55–61

Mani, S. Tabil, L. and Sokhansanj, S. (2006). Effect of Compressive, Particle Size and Moisture Content on Mechanical Properties of Biomass Pellets from Grass. *Journal on Biomass and Bioenergy,* 30: 648–654

Martin, J. and Mae, R. and Manaay, A. (2008). Design and Development of Charcoal Briquettes Machines. *Journal on Mechanical Engineering,* 16: 85-90

Matiru, V. (2007). Forest Cover and Forest Reserve Cover in Kenya Policy and Practises. Oxford Press. Nairobi, Kenya

Medhiyanon, T. Sathitruangsak, P. Sungworagan, S. and Soponronnarit, H. (2006). Solid Fuel Producing from Rubber Wood Char and Corn-Cob Char by Extrusion Technique

MOA (Ministry of Agriculture), (2006). Food Production in Kenya. Crop Development Division. Nairobi, Kenya

MOE (Ministry of Energy), (2005). Energy Policy in Kenya. GoK Printers, Nairobi, Kenya

MOE (Ministry of Energy), (2006). Study on Kenya's Energy Demand, Supply and Policy Strategy for Households, Small Scale Industries and Service Establishments, Nairobi

Moshenin, P. and Zaske, L. (2006). Stress Relaxation and Energy Requirement in Compaction of Unconsolidated Materials. *Journal of Agricultural Engineering Research*, 21:193-205

MSCL (Mumias Sugar Company Limited), (2006). 35 MW Bagasse Based Cogeneration Project. UNFCCC Clean Development Mechanism

Mugo, M. and Kituyi, J. (2002). Kenya Integrated Assessment of Energy Policy. Nairobi, Kenya.

Musa, N. (2007). Comparative Fuel Characterization of Rice Husks and Groundnut Shell Briquettes, *NJREDI,* 6:23-27

Ndiema, C. Manga, P. and Ruttoh, R. (2002). Densification and Characteristics of Rice Straw Briquettes. *Journal of the Institute of Energy,*75: 11-13

Nopporn, S. (2003). Briquette Fuel made from Coffee Residue. Msc. Thesis, Department of Appropriate Technology, Mahidol University

Nzila, C. Dewulf, J. Spanjers, H. Kiriamiti, H. and Langenhive, H. (2010). Biowaste Energy Potential in Kenya. *Journal on Renewable Energy,* 12:67- 85

Omwando, T. A. (2006). Investigating the Combustion Behaviour of Selected Agricultural Residues Available in a Fluidized Bed Combustor. *Unpublished Master's Thesis Moi University, Eldoret*.

Omwando, T. A. (2006). Investigating the Combustion Behaviour of Selected Agricultural Residues Available in Kenya in Fluidized Bed Combustor. . *Unpublished Master's ,* . Eldoret: Thesis Moi University.

Oladeji, M. (2010). Fuel Characterization of Briquettes Produced from Corncobs and Rice Husk Residues. *The Pacific Journal of Science and Technology*, 11:101-106.

Olorunnisola, A. (2004). Briquetting of Rattan Furniture Wastes. *Journal of Bamboo and Rattan,* 3:139-149

Olorunnisola, A. (2007). Production of Fuel Briquetting from Waste Paper and Coconut Admixtures. *Agricultural Engineering Journal*, 9:1-15

Onaji, P. and Siemons, R. (2003). Production of Charcoal Briquettes from Cotton Stalks in Malawi: Methodology for Feasibility Studies using Experiences in Sudan. *Journal on Biomass and Bio Energy*,4: 199-211

Owino, J. (2009). Bagasse Cogeneration Project. Climate Care, JP Morgan Environmental Market Team Global Overview.

Onuegbu T. U., Ekpunobi U E.,Ogbu I.M., Ekeoma M.O. & Obumselu F.O. (2011). *Comparative Studies of Ignition Time and Water Boiling Comparative Studies of Ignition Time and Water Boiling.* Department of Chemistry,Michael Okpala University of Agriculture,Umudike.Abia State ,Nigeria.

P., W. (2008). The effects of Briquetting Pressure on Banana Peel Briquette and the Banana Waste in Northern Thailand. *American Journal of Applied Sciences 6 (1):*, 167-171.

Paulrud, J. (2004). Upgraded Bio fuel Effect of Quality in Processing Handling Characterization, Combustion and Ash Melting

Pettersson, M. (2005). Briquetting of Biomass in Pressing Machines and their Techniques.

Panwar V., Prasad B., and Wasenar K.L.,. (2011). Biomass Residue Briquetting and characteriztion. *Journal of Energy Engineering,*, 108-137.

Qing-ling Zhao,Chen Fu-jin, Wang Yang-yang and Zhang Bai-liang. (2013). Combustion Properties of Straw Briquettes. *Research Journal of Applied Sciences, Engineering and Technology*.

R.M, D., & O.A., D. (2013). The Potential of Water Hyacynth and Hyacinth and Phytoplankton scum and organic weed as a binder for Production of Fuel Briquettes. *Combustion*.

Robinson, J. (1996). Bamnanas and Plantains. *CBA International Publication.*, pp.238.

Rotich, K. (1996). Carbonization and Briquetting of Sawdust for use in Domestic Cookers. Msc. Thesis, Department of Agricultural Engineering, University of Nairobi, Kenya

Ryu, C. Yang, A. Khor, N. Yates, V. and Swithenbank, J. (2006). Effect of Fuel Properties on Biomass Combustion: Part I. Experiments-Fuel Type. *Journal on Equivalence Ratio and Particle SizeFuel,* 85: 139-146

Samson, R. Mani, S. Boddey, R. and Sokhansanj, S. (2005). The Potential of Perennial Grasses for Developing a Global Bio-Heat Industry. *Journal on Critical Reviews in Plant Science,* 24:481–495.

Sander, B. (2002). Properties of Biomass and the Requirement for Power Production. *Journal on Biomass and Bio Energy,* 43*:* 97-103

Senelwa, K. and Sims, R. (2003). Fuel Characteristics of Short Rotation Forest Biomass. *Journal on Biomass Bio Energy,* 17: 127–140

Shafizaden, F. (2005). Pyrolysis of Biomass and Biomass Components. Overend, Elsevier Applied Science, London

Singh, R. (2004). Equilibrium Moisture Content of Biomass. *Journal of Bio Energy and Biomass,* 26:251-253

Sorum, L. Gronci, G. and Hustand, E. (2001). Pyrolysis characteristics and Kinetics of Municipal Solid Waste Fuel

Sotannde, O. Oluyege, G. and Abah, B. (2010). Physical and Combustion Properties of Briquettes from Sawdust of *Azadirachta indica*. *Journal of Forestry Research,* 21:63-67

Sokhansanj, H. Mani, G. and Zain, P. (2005). Binderless Pelletization of Biomass. Presented at ASAE Annual International Meeting July, 17-20, 2005, Niles road, USA

Thomas, M. Huijnen, T. Vliet, D. and Zuilichem, B. (2008). Effects of Process Conditions during Expander Processing and Pelleting on Starch Modification and Pellet Quality of Tapioca. *Journal of the Science of Food and Agriculture*, 79: 1481-1494

Tripathi, K. Iyer, P. and Kandpal, T. (2008). Techno-Economic Evaluation of Biomass Briquetting in India. *Journal on Biomass and Bio Energy,* 14:479–488.

Wilainpon, P. (2007). The Effect of Moderate Die Pressure on Maize Cob Briquettes: *Journal on Energy Conversion and Management*, 43:167-174

Williams, P. and Nugranad, N. (2000). Comparison of Products from the Pyrolysis and Catalytic of Rice Husks. *Journal in Biomass Energy*, 25: 493-513

Wondwondessen, B. (2009). Preparation of Charcoal using Agricultural Residues. *Journal on Education and Sciences,* 5:79-93

World Bank, (2008). Statistics on Population Growth and Level of Poverty in Kenya. Nairobi, Kenya

Yaman, H. and Sahin, M. (2000). Production of Fuel Briquettes from Olive Refuse and Paper Mill Wastes. *Fuel Processing Technology Journal,* 68:23-31

Zanzi, R. (2001). Pyrolysis of Biomass. Msc. Dissertation, Royal Institute of Technology, Department of Chemical Engineering and Technology, Stockholm

APPENDICES

Appendix A1: Effect of mixture ratios on physical and combustion characteristics

Replication	Mixture Composition ratio	Moisture content (%)	Ash content (%)	calorific value (MJ/kg)	Carbon monoxide (ppm)	Density Kg/m^3	Durability index (%)
1	0:1	11.10	9.94	16.16	5.66	380.20	95
2	0:1	11.15	10.08	16.28	5.76	381.15	95.25
3	0:1	11.26	10.28	16.45	5.86	381.24	95.36
4	0:1	11.34	10.32	16.58	6	381.29	95.45
5	0:1	11.42	10.42	16.62	6.06	382.01	95.68
1	1:4	9.51	8.75	18.08	5.34	391.00	97.16
2	1:4	9.63	9.02	18.18	5.44	392.07	97.24
3	1:4	9.75	9.03	19.12	5.54	393.17	97.37
4	1:4	9.84	9.04	19.14	5.64	393.28	97.48
5	1:4	10.00	9.05	19.16	5.74	392.38	97.59
1	2:3	9.31	8.54	21.03	5.19	491.20	97.53
2	2:3	9.43	8.64	21.23	5.29	492.05	97.64
3	2:3	9.55	8.78	21.53	5.39	492.40	97.74
4	2:3	9.67	8.89	21.73	5.49	492.90	97.85
5	2:3	9.78	9.10	22.10	5.65	493.50	98.06
1	1:1	8.20	6.59	21.76	4.83	557.17	98.05
2	1:1	8.35	7.12	21.96	5.03	557.42	98.17
3	1:1	8.48	7.21	22.06	5.13	557.53	98.28
4	1:1	8.56	7.32	22.13	5.23	557.70	98.29
5	1:1	8.64	7.43	22.16	5.43	558.08	98.51
1	3:2	7.56	6.64	23.15	4.8	583.07	98.05
2	3:2	7.67	6.76	23.34	5	583.27	98.12
3	3:2	7.78	6.87	23.54	5.2	583.32	98.24
4	3:2	7.86	6.98	23.64	5.3	583.48	98.36
5	3:2	7.99	7.10	23.84	5.4	583.78	98.53
1	4:1	6.95	5.80	25.34	2.87	729.00	98.15
2	4:1	7.23	5.82	25.54	3.13	729.02	98.23
3	4:1	7.36	5.85	25.64	3.24	729.03	98.35
4	4:1	7.49	5.90	25.74	3.35	729.04	98.57
5	4:1	7.62	6.03	25.84	3.46	729.07	98.69
1	1:0	6.90	5.12	26.21	1.35	763.09	98.05
2	1:0	7.15	5.21	26.41	1.55	763.20	98.80
3	1:0	7.25	5.37	26.51	1.75	763.31	99.10
4	1:0	7.35	5.43	26.61	2	763.46	99.40
5	1:0	7.45	5.59	26.71	2.05	763.57	99.70

Appendix A2: Effect of particle size on physical and combustion characteristics of blended briquettes

Replication	Particle size (mm)	Moisture content (%)	Ash content (%)	Calorific value (MJ/kg)	Carbon monoxide (ppm)	Density Kg/m^3	Durability index (%)
1	2.5	6.90	5.62	26.21	5.00	763.09	98.05
2	2.5	7.15	5.71	26.41	5.10	763.20	98.80
3	2.5	7.25	5.80	26.51	5.20	763.31	99.10
4	2.5	7.35	5.93	26.61	5.30	763.48	99.40
5	2.5	7.45	6.03	26.71	5.40	763.57	99.70
1	5	7.05	5.73	25.58	4.96	722.43	96.61
2	5	7.11	5.83	25.68	5.04	726.53	97.61
3	5	7.26	5.93	25.78	5.14	729.63	98.61
4	5	7.32	6.03	25.88	5.24	733.03	99.61
5	5	7.38	6.13	25.99	5.34	733.70	100.61
1	7	5.28	5.73	25.59	5.16	681.28	95.75
2	7	6.28	5.83	25.69	5.26	682.38	96.75
3	7	7.28	5.93	25.79	5.36	683.48	97.75
4	7	8.28	6.03	25.89	5.46	684.58	98.75
5	7	9.28	6.13	25.99	5.56	685.68	99.75
1	9	4.88	5.73	25.41	5.46	668.68	95.19
2	9	5.88	5.83	25.61	5.56	669.68	96.19
3	9	6.88	5.93	25.71	5.66	670.68	97.19
4	9	7.88	6.03	25.81	5.76	671.68	98.19
5	9	8.88	6.13	25.91	5.86	681.68	99.19
1	11	4.98	5.63	25.64	5.66	557.17	94.52
2	11	5.98	5.73	25.74	5.76	557.52	95.52
3	11	6.98	5.83	25.84	5.86	557.73	96.52
4	11	7.98	5.93	25.94	6.00	557.90	97.52
5	11	8.98	6.03	26.04	6.06	558.08	98.52

Appendix B

Table B.1: SAS output on effect of particle sizes on density of briquettes density
Tukey's-Studentized Range (HSD) Test for density

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	468.6011
Critical Value of Studentized Range	3.90840
Minimum Significant Difference (LCD)	14.301

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Particle sizes
A	557.070	35	2.5mm
B	529.064	35	5 mm
C	498.223	35	7mm
C	489.909	35	9 mm
D	433.249	35	11 mm

Table 4.1: T-test output on effect of particle sizes on density of briquettes density

Particle sizes (mm)	P Values	Significant difference
2.5 &5	0.00001	Yes
5 & 7	0.00001	Yes
7&9	0.001088	Yes
9 & 11	0.00001	Yes

Table B.2: SAS output on effect of particle sizes on durability index of briquettes durability index

Tukey's Studentized Range (HSD) Test for durability index

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	4643.456
Critical Value of Studentized Range	3.90840
Minimum Significant Difference (LCD)	45.018

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Particle sizes
A	96.32	35	2.5mm
A	97.77	35	5 mm
A	94.75	35	7 mm
A	94.19	35	9 mm
A	93.43	35	11 mm

Table 4.2: T-test output on effect of particle sizes on durability index of briquettes durability index

Particle sizes (mm)	P Values	Significant difference
2.5 & 5	0.306849	No
5 & 7	0.207408	No
7 & 9	0.295405	No
9 & 11	0.260862	No
2.5 & 11	0.035009	Yes

Table B.3: SAS output on effect of particle sizes on moisture content of briquettes moisture content

Tukey's Studentized Range (HSD) Test for moisture

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	1.159483
Critical Value of Studentized Range	3.90840
Minimum Significant Difference (LCD)	0.7114

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Particle sizes
A	8.7594	35	2.5mm
BB	7.3449	35	5 mm
BB	7.2840	35	9 mm
BB	7.2500	35	7 mm
D	6.6543	35	11 mm

Table 4.3: T-test output on effect of particle sizes on moisture content of briquettes moisture content

Particle sizes	P Values	Significant difference
2.5 & 5	0.486335	No
5 & 7	0.469529	No
7 & 9	0.349812	No
9 & 11	0.461402	No

Table B.4: SAS output on effect of particle sizes on calorific value of briquettes calorific value.

Tukey's Studentized Range (HSD) Test for calorific

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	0.044834
Critical Value of Studentized Range	3.90840
Minimum Significant Difference (LCD)	0.1399

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Particle sizes
AA	25.54000	35	11mm
BA	25.49000	35	7mm
BA	25.48029	35	5mm
BB	25.37286	35	9mm
C	22.03486	35	2.5mm

Table 4.4: T-test output on effect of particle sizes on calorific value of briquettes calorific value

Particle sizes	P Values	Significant difference
2.5 & 5	0.00116	Yes
5 & 7	0.469411	No
7 & 9	0.197697	No
9 & 11	0.107439	No

Table B.5: SAS output on effect of particle sizes on ash content of briquettes ash content

Tukey's Studentized Range (HSD) Test for ash

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	0.087763
Critical Value of Studentized Range	3.90840
Minimum Significant Difference (LCD)	0.1957

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Particle sizes
A	7.60057	35	2.5mm
B	6.12743	35	5 mm
CB	5.93286	35	9 mm
CB	5.93286	35	7 mm
C	5.85257	35	11 mm

Table 4.5: T-test output on effect of particle sizes on ash content of briquettes ash content

Particle sizes	P Values	Significant difference
2.5 &5	0.152393	No
5 & 7	0.5	No
7&9	0.5	No
9&11	0.173297	No

Table B.6: SAS output on effect of particle sizes on carbonmonoxide of briquettes carbon monoxide (CO)

Tukey's Studentized Range (HSD) Test for CO

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	0.089441
Critical Value of Studentized Range	3.90840
Minimum Significant Difference (LCD)	0.1976

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Particle sizes
A	5.66000	35	11mm
BA	5.66000	35	9 mm
B	5.44057	35	7mm
C	5.14486	35	5mm
D	4.57571	35	2.5 mm

Table 4.6: T-test output on effect of particle sizes on carbon monoxide of briquettes carbon monoxide (CO)

Particle sizes (mm)	P Values	Significant difference
2.5 & 5	0.038229	Yes
5 & 7	0.008536	Yes
7&9	0.029373	Yes
9 & 11	0.291816	No

Appendix C

Table C.1: SAS output on effect of mixture ratios on density of blended briquettes

Tukey's Studentized Range (HSD) Test for density

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	468.6011
Critical Value of Studentized Range	4.23087
Minimum Significant Difference (LCD)	18.317

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Mix ratios
A	681.206	35	0: 1
B	598.333	35	1:4
C	515.804	35	2:3
D	477.423	35	1:1
E	431.789	35	3:2
F	413.423	35	4:1
G	392.542	35	1:0

Table 4.7: T-test output on effect of mixture ratios on density of blended briquettes

Mix ratio	P Values	Significant difference
0:1 & 1:4	0.00001	Yes
1:4 & 2:3	0.00001	Yes
2:3 & 1:1	0.00001	Yes
1:1 & 3:2	0.00001	Yes
3:2 & 4:1	0.00001	Yes
4:1 & 1:0	0.00001	Yes

Table C.2: SAS output on effect of mixture ratios on durability index of blended briquettes

Tukey'sStudentized Range (HSD) Test for durability

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	4643.456
Critical Value of Studentized Range	4.23087
Minimum Significant Difference (LCD)	57.661

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Mix ratios
A	95.27	35	1:1
A	97.70	35	0:1
A	96.89	35	1:4
A	96.07	35	2:3
A	94.37	35	3:2
A	93.49	35	4:1
A	92.28	35	1:0

Table 4.8: T-test output on effect of mixture ratios on durability index of blended briquettes

Mix ratio	P Values	Significant difference
0:1 & 1:4	0.00001	Yes
1:4 & 2.:3	0.005392	Yes
2:3 & 1:1	0.001542	Yes
1:1 & 3:2	0.05	No
3:2 & 4:1	0.164933	No
4:1 & 1:0	0.038132	Yes

Table C.3: SAS output on effect of mixture ratios on moisture content of blended briquettes

Tukey's Studentized Range (HSD) Test for moisture

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	1.159483
Critical Value of Studentized Range	4.23087
Minimum Significant Difference (LCD)	0.9112

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Mix ratios
A	7.9576	35	1:0
A	7.6776	35	4:1
A	7.6552	35	3:2
A	7.4552	35	1:1
A	7.1928	35	2:3
A	7.1888	35	1:4
A	7.1168	35	0:1

Table 4.9: T-test output on effect of mixture ratios on moisture content of blended briquettes

Mix ratio	P Values	Significant difference
0:1 & 1:4	0.00001	Yes
1:4 & 2.:3	0.06693	No
2:3 & 1:1	0.00001	Yes
1:1 & 3:2	0.000122	Yes
3:2 & 4:1	0.006074	Yes
4:1 & 1:0	0.240482	No

Table C.4: SAS output on effect of mixture ratios on calorific value of blended briquettes

Tukey's Studentized Range (HSD) Test for calorific

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	0.044834
Critical Value of Studentized Range	4.23087
Minimum Significant Difference (LCD)	0.1792

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Mix ratios
A	25.91840	35	0:1
B	25.66400	35	1:4
C	25.14840	35	2:3
D	24.78280	35	1:1
D	24.60480	35	3:2
E	23.95920	35	4:1
F	23.40760	35	1:0

Table 4.10: T-test output on effect of mixture ratios on calorific value of blended briquettes

Mix ratio	P Values	Significant difference
0:1 & 1:4	0.000011	Yes
1:4 & 2.:3	0.00001	Yes
2:3 & 1:1	0.0204	Yes
1:1 & 3:2	0.00001	Yes
3:2 & 4:1	0.00001	Yes
4:1 & 1:0	0.000048	Yes

Table C.5: SAS output on effect of mixture ratios on ash content of blended briquettes

Tukey's Studentized Range (HSD) Test for ash

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	0.087763
Critical Value of Studentized Range	4.23087
Minimum Significant Difference (LCD)	0.2507

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Mix ratios
A	6.89160	35	1:0
B	6.62560	35	4:1
B	6.56040	35	3:2
C	6.21280	35	1:1
DC	6.01960	35	2:3
D	5.92200	35	1:4
D	5.79280	35	0:1

Table 4.11: T-test output on effect of mixture ratios on ash content of blended briquettes

Mix ratio	P Values	Significant difference
0:1 & 1:4	0.00001	Yes
1:4 & 2.:3	0.067799	No
2:3 & 1:1	0.00001	Yes
1:1 & 3:2	0.075694	No
3:2 & 4:1	0.00001	Yes
4:1 & 1:0	0.000201	Yes

Table C.6: SAS output on effect of mixture ratios on carbon monoxide of blended briquettes

Tukey's Studentized Range (HSD) Test for CO;

Alpha	0.05
Error Degrees of Freedom	140
Error Mean Square	0.089441
Critical Value of Studentized Range	4.23087
Minimum Significant Difference (LCD)	0.2531

Means with the same letter are not significantly different.

Tukey Grouping	Means	N	Mix ratios
A	5.45200	35	3:2
A	5.44640	35	0:1
A	5.42920	35	2:3
A	5.41800	35	1:4
A	5.41200	35	1:1
B	4.98400	35	4:1
B	4.98400	35	1:0

Table 4.12: T-test output on effect of mixture ratios on carbon monoxide of blended briquettes

Mix ratio	P Values	Significant difference
0:1 & 1:4	0.006245	Yes
1:4 & 2.:3	0.11561	No
2:3 & 1:1	0.03302	Yes
1:1 & 3:2	0.473711	No
3:2 & 4:1	0.00001	Yes
4:1 & 1:0	0.000011	Yes

Appendix D: Photos

Figure.D.1: Milled raw materials

Figure D.2: Cold carbonized samples in dessiccator

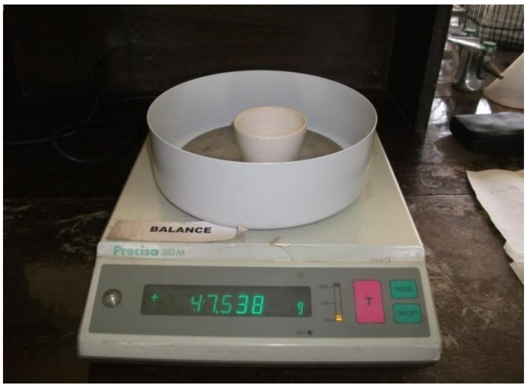

Figure.D.3: Digital electronic weighing machine

Figure. D.4: Drying of briquettes indoor

Figure D.5: Weighing of briquettes in digital scale

Figure D.6: Measuring dimension of briquette

Figure D.7: Muffle furnace

Figure D.8: Samples to be tested for calorific value

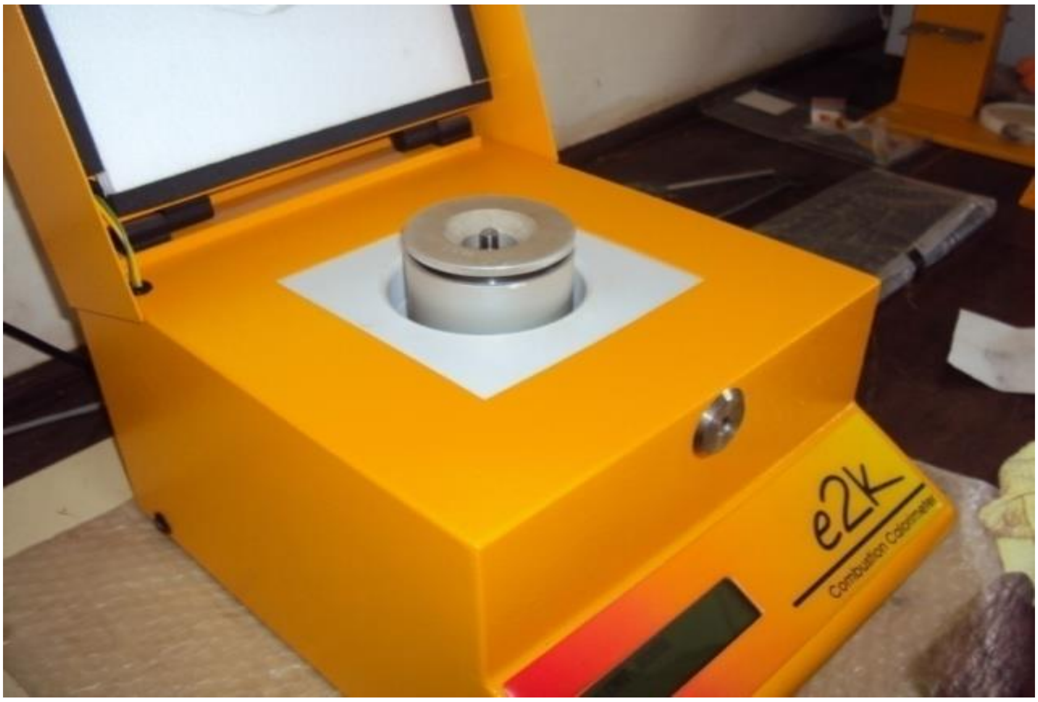

Figure: D.9: Bomb calorimeter

Appendix E: Plates of some of the tools, instruments And Equipment used for sample production of the briquettes

Figure E1: Materials sieve for particle segregation

Figure E2: Mould and die for briquette production

Figure E3: Briquette samples