OPTIMAL COMPACTION PRESSURE, PARTICLE SIZE AND BINDER RATIO FOR QUALITY BRIQUETTES MADE FROM MAIZE COBS

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DECLARATION

This research is my original work and has not been presented for a degree in any other University

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ABSTRACT

The quality of briquettes varies greatly among small scale producers in Uganda due to the different methods of production, absence of standardization, lack of technical knowledge and quality control procedures. The study aimed at investigating the effect of cassava binder ratio, compaction pressure, and particle size on thermo-physical properties of briquettes made from maize cobs and cost benefit analysis of briquette production at the optimal condition. A 3×4×5 factorial experiment with four replicates was used. Three particle size levels (small, medium and large), four compaction pressures (P1=2MPa, P2=4MPa, P3=6MPa and P4=8MPa), and five cassava binder ratios (B1=5%, B2=7.5%, B3=10%, B4=12.5%, B5=15%) were used. Briquettes were made from carbonized maize cobs using a manually operated hydraulic briquette press. Proximate analysis (moisture content, volatile matter content, fixed carbon content, ash content), calorific value and density of the briquettes were determined. Linear regression models were used to investigate the effect of compaction pressure, binder ratio and particle size on each of the dependent variables. All the independent variables had significant effect on briquette quality. Particle size and binder ratio had significant effect on heating value (p-value: 1.421×10^{-08}) at 5% level of significance. There was no significant effect on moisture content at 5% level of significance (p-value: 0.1248). Unlike compaction pressure and particle size, binder ratio had significant effect on volatile matter content (p-value: 3.54×10^{-11}) and fixed carbon content (p-value: 3.37×10^{-08}) at 5% level of significance. Much as binder ratio and compaction pressure did not have significant effect on ash content at 5% level of significance (p-values > 0.05), particle size had significant effect (p-value: 0.01107) . Compaction pressure, particle size and binder ratio had significant effect on density (p-value: $< 2.2\times10^{-16}$) at a significance level of 5%. Despite all briquettes meeting the minimum quality requirements, medium sized particles (4mm to < 6mm), 5% binder ratio and 8MPa compaction pressure produced superior quality briquettes (8.421% ash content, 12.923% volatile matter content, 65.38% fixed carbon content, 13.358% moisture content, 25247.5 J/g heating value, and 409.8824 Kg/m^3 relaxed density). In addition to the high quality briquettes, 5% binder ratio is low enough to minimize amount of cassava used for briquetting, hence helping in the fight against food insecurity. The volatile matter content of the briquettes was low (12.923%) which implies that they burn without smoke and therefore shall greatly reduce the high death toll caused by indoor air pollution. Cost benefit analysis of briquette production at optimal condition (medium sized particles, 5% binder ratio and 8MPa hydraulic cylinder pressure) had 69,809,400 Ugs

($20,532.2) net present worth, 1.15471 benefit cost ratio, 36% internal rate of return, and a discounted payback period of 3.603 years which shows economic viability. It is recommended that studies be conducted to enhance the pasting properties of cassava binder for briquette production, assess the strength of briquettes at optimal condition to ascertain whether they can withstand crumbling during handling and transportation, and investigate other raw materials since briquette quality is greatly influenced by its composition.

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CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND

Global fossil fuel deposits are declining at high rate which requires alternative renewable energy sources in order to meet the increasing energy demand for development (Singer et al., 2011). It has been estimated that 3 billion people worldwide use traditional biomass for cooking and heating, and majority of them are located in Sub Saharan Africa (Belward et al., 2011). Biomass accounts for 90% of the energy used in Uganda which can further be partitioned into 70% wood, 16% charcoal and 4% crop residue (Ferguson, 2012). 10% of the total charcoal sold in urban centres is discharged as charcoal dust. Charcoal dust and crop residue pose environmental pollution problem which has been turned into a business opportunity of briquette production for energy (Barasa et al., 2013).

Briquettes are sustainable and environmentally friendly fuel pellets that are made by waste compression. The quality of a briquette can be measured from its thermo-physical properties such as heating value, ash content, volatile matter content, moisture content, fixed carbon content and density among others (Sastry et al.,2013). Heating value of a fuel is the measure of its energy content and a high value is desirable (Sellin et al., 2013). Briquette density is influenced by material composition and the type of briquetting machine used (Križan et al., 2011). An increase in ash content increases the slagging behavior of biomass, hence the preference for low ash content (Akowuah, 2012). Much as a rise in volatile matter content increases ignition, it increases smoke during combustion (Pandey & Dhakal, 2013). Charcoal briquettes intended for barbecue use should have volatile matter content of less than 30% dry basis , fixed carbon content of greater than 60% dry basis, ash content less than 18% dry basis (Zagreb, 2008) and moisture content within a range of 10% - 18% wet basis (Kers et al., 2010) for adequate heating without emissions.

The thermo-physical properties depend on composition, geometry, particle size, material density, and compaction pressure (Mandal et al., 2014, and Caddell & Kelly, 1998). The type and amount of binder affect thermo-physical properties of briquettes (Chirchir et al. 2013).

Low compaction pressure is sufficient for briquetting using a binder (Grover & Mishra, 1996), but particles must bind properly during compression to prevent the briquettes from crumbling. Examples of binders include crude oil, starch, molasses, clay, sodium silicate and cement. Despite the great variety of binders, starch binder results into high quality briquettes (Ugwu & Agbo, 2013). Cassava is a good binder because it has high starch content and is readily available (Islam et al., 2014). However, excessive use of cassava for briquette production has a negative impact on food security and therefore its value should be optimized to minimize wastage (Katimbo et al., 2014).

1.2 PROBLEM STATEMENT

The quality of briquettes varies greatly among small scale producers in Uganda due to the different methods of production, absence of standardisation, lack of technical knowledge and quality control procedures. Sub-standard products undermine briquette potential to tap into available markets (Ferguson, 2012). There is insufficient information on optimal values of compaction pressure, particle size and binder ratio for production of quality briquettes. This therefore requires investigation of their effect on the quality of briquettes.

1.3 OBJECTIVES

1.3.1 GENERAL OBJECTIVE

To investigate the effect of cassava binder ratio, compaction pressure, and particle size on thermo-physical properties (calorific value, moisture content, volatile matter content, fixed carbon content, ash content and density) of briquettes made from maize cobs.

1.3.2 SPECIFIC OBJECTIVES

1. To determine the effect of particle size, compaction pressure and cassava binder ratio on calorific value, moisture content, volatile matter content, fixed carbon content, ash content, and density of briquettes made from maize cobs.

2. To conduct cost benefit analysis of producing briquettes at the optimal condition

1.4 RESEARCH QUESTIONS

1. What could be the optimum compaction pressure, particle size, and cassava binder ratio for quality briquettes?

2. Could production of briquettes at the optimal condition be economically viable?

1.5 RESEARCH HYPOTHESIS

1. Compaction pressure, particle size and cassava binder ratio affect calorific value, moisture content, volatile matter content, fixed carbon content, ash content, and density of briquettes from maize cobs.

2. Production of briquettes at the optimal condition is economically viable

1.6 JUSTIFICATION

Optimization of compaction pressure, particle size and cassava binder ratio will help in the production of affordable, high quality briquettes, hence promoting briquette market. Besides briquette quality enhancement, optimum cassava binder ratio will minimize on the amount of cassava used given the fact that it is one of the main crops for food security in Sub Saharan Africa. The optimum pressure will help in designing briquette making machines. Conversion of waste material in to briquettes will improve on the sanitation around waste dumping sites and increase employment opportunities at the briquette production site. The 4.3 million global deaths which are attributed to indoor air pollution from solid fuels (WHO, 2014) shall be minimized by the smokeless briquettes. It will also reduce on the rate of deforestation by substituting wood fuel with briquettes, hence promotion of environmental conservation. Therefore, this study will empower briquette producers with skills and help Uganda National Bureau of Standards in quality control of the briquettes produced. It will eventually contribute to the elimination of poor quality products, hence promoting briquette market in Uganda.

1.7 SCOPE

The study was limited to the properties of locally available raw materials (maize cobs and cassava) in Uganda. In addition, it was experimental without a survey on technology adoption.

1.8 LIMITATIONS

Maize cob char drying in exposed environmental conditions led to contamination by sand particles. This led to repetition of tests especially bomb calorimetry and proximate analysis for some samples which resulted into delays and increased costs of consumables such as oxygen gas, nitrogen gas and electricity.

CHAPTER TWO

LITERATURE REVIEW

2.1 INTRODUCTION

Fossil fuels contribute more than 80% of the global energy needs. Given its finite declining deposits and high green house gas emissions, development of renewable energy is the only viable option to meet the increasing energy demand. Renewable energy refers to energy derived from natural sources that can be replenished sustainably within a short time. These include solar energy, wind energy, hydro energy, biomass energy, geothermal energy, and bio fuels (Singer et al., 2011).

Approximately 3 billion people worldwide use traditional biomass for cooking and heating, and about 1.4 billion people do not have access to electricity. Majority of these are in Sub Saharan Africa whose wood fuel production is about 600 million m^3 per year (Belward et al., 2011). Biomass accounts for 90% of the energy used in Uganda which can further be partitioned into 70% wood, 16% charcoal and 4% crop residue (Ferguson, 2012). About 10% of the total charcoal sold in urban centres is discharged as charcoal dust. The environmental pollution problem caused by disposal of charcoal dust and crop residue has been turned into a business opportunity through briquette production for energy (Barasa et al., 2013). Briquettes are sustainable and environmentally friendly fuel pellets that are made by waste compression (Sastry et al., 2013).

Briquette producers in Uganda use different methods of production, do not have access to standards for quality control and lack technical knowledge which has led variation in the quality of briquettes in the market. Sub-standard products undermine briquette potential to tap into available markets (Ferguson, 2012). There is insufficient information on optimal values of compaction pressure, particle size and binder ratio for production of quality briquettes. This therefore requires investigation of their effect on the quality of briquettes.

2.2 RAW MATERIALS FOR MAKING BRIQUETTES

Briquettes can be made from charcoal dust, agricultural residue, wood chips and municipal solid waste. Carbonized briquettes are preferred because they burn without smoke. The type and amount of binder affect combustion properties of briquettes. Examples of binders include crude oil, starch, molasses, clay, paper, sodium silicate, and cement among others. Despite the great variety of binders, starch binder results into high quality briquettes (Ugwu & Agbo, 2013). Cassava is a good binder because it has high starch content and is readily available (Islam et al., 2014).

Pasting properties of cassava vary with variety and method of drying. Each variety of cassava has a totally distinct composition of starch which determines its effect on pasting properties. Cassava dried under sun light is preferred to that which is oven dried because pasting properties of cassava are enhanced at lower drying temperatures (Akintunde & Tunde-Akintunde, 2013). Fermentation method of cassava processing reduces cohesive and adhesive forces of the gel (Festus et al., 1996). Onset and peak gelatinisation temperatures for various cassava varieties fall within (55 ^{o}C – 62 ^{o}C) and (75 ^{o}C – 80 ^{o}C) respectively (Defloor et al., 1998).

2.3 BRIQUETTE PRODUCTION PROCESS

Large waste particles require size reduction by shredding to ease compression unlike granular waste such as saw dust which has small particles. The raw material is then dried to reduce its moisture content. The dry material can either be carbonised by pyrolysis to produce carbonised briquettes or it can be used to produce uncarbonised briquettes. Chunks of char are ground into smaller and uniform sizes in a process known as pulverisation. The processed raw material is then mixed with binder before briquetting (Barasa et al., 2013).

Uncarbonised material is compressed at low pressure when mixed with binder whereas high compaction pressure and high temperature are required in the absence of binder for adequate bonding (Grover & Mishra, 1996). The briquettes made should then be dried in order to eliminate all the free water (<18% wet basis) for better heating effect. Uncarbonised briquettes burn with smoke in ordinary stoves because of their high volatile matter content.

The process of making briquettes can be summarized graphically as shown below

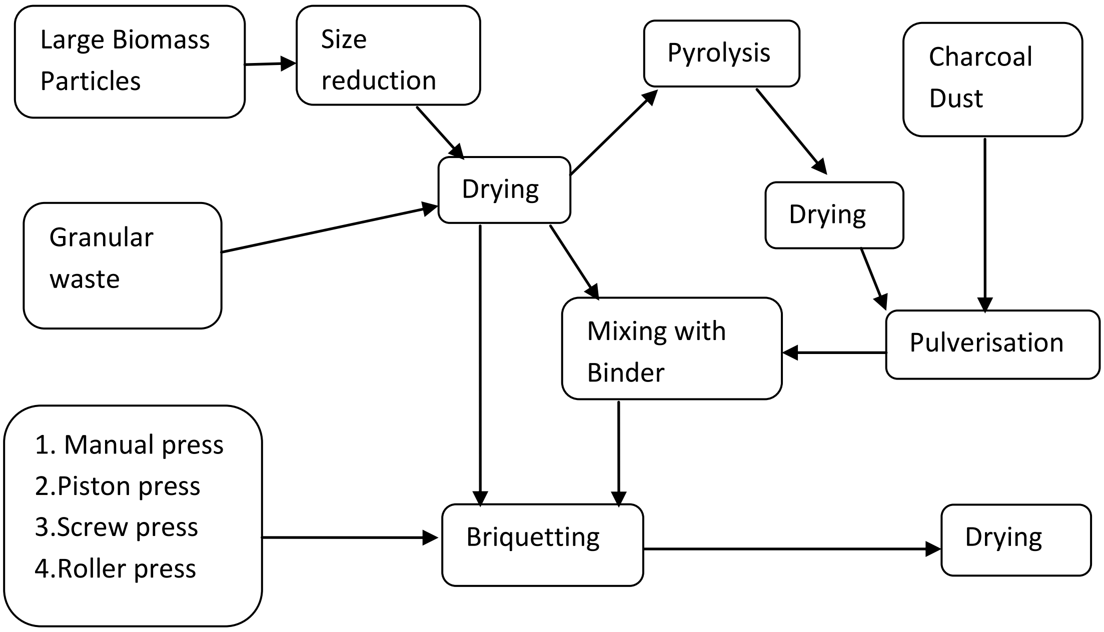

Figure 2.1: Flow diagram showing the process of briquette production

2.4 DESIRABLE BRIQUETTE QUALITY

A good quality briquette should produce sufficient amount of heat, burn without smoke to promote indoor air quality, and must be convenient for the user. The quality of a briquette can be measured from its calorific value, density, compressive strength, ash content, volatile matter content, ignition time, and burn time among others (Sastry et al.,2013). Calorific value of a fuel is the measure of its energy content (Ikelle & Joseph, 2014), and a high value is desirable (Sellin et al., 2013). Briquette density and compressive strength are influenced by material composition and the type of briquetting machine used (Križan et al., 2011).

An increase in ash content increases the slagging behavior of biomass, hence the preference of low to high ash content (Akowuah, 2012). Much as the rise in volatile matter content improves ignition ability, it increases smoke during combustion (Pandey & Dhakal, 2013). Briquettes intended for barbecue use should have volatile matter content less than 30% dry basis , fixed carbon of greater than 60% dry basis, ash content less than 18% dry basis (Zagreb, 2008), and 10% - 18% moisture content on wet basis (Kers et al., 2010).

2.5 FACTORS AFFECTING BRIQUETTE QUALITY

Briquette quality depends on geometry, composition, particle size, material density, compaction pressure, and moisture content (Kelly &Caddell, 1998; Mandal et al., 2014).

2.6.1 EFFECT OF GEOMETRY

Geometry configuration of briquettes such as provision of slots and flutes increases surface area to volume ratio, hence increasing air supply for faster ignition. Hydraulic press is recommended for producing briquettes with high shape precision of briquettes (Križan et al., 2011).

2.6.2 EFFECT OF COMPOSITION

Material composition and compression are very vital in briquette making (Sastry et al., 2013). The composition of a material is among the factors that control burning rate (Onuegbu et al., 2011), density, compression strength and calorific value of briquettes (Akowuah et al., 2012). The composition of feedstock carbonised to produce briquettes varies with species and greatly affects their briquette quality (Antal, 2003).

2.6.3 EFFECT OF MOISTURE

The percentage of moisture in the feed biomass is a very critical factor in briquette production. Much as moisture promotes bonding by van der Wall's forces to enhance compression (Grover & Mishra, 1996), it should be as low as possible because increase in moisture content reduces combustion efficiency (Pandey & Dhakal, 2013). The raw material should be dried to moisture content within a range of 10% to 15% for high quality briquettes (Grover & Mishra, 1996).

2.6.4 EFFECT OF COMPACTION PRESSURE

The compaction pressure is usually exerted using a briquetting machine which can either be a screw or a piston press (mechanical or hydraulic). Compaction pressure is required in the densification of the waste which improves volumetric calorific value, and reduces transport cost of the fuel. Briquetting using a binder is sufficient at low compaction pressure (Grover & Mishra, 1996). However, the particles must bind properly during compression to prevent the briquettes from crumbling (Ugwu & Agbo, 2013). Increase in compaction pressure results into a corresponding increase in briquette density which decreases porosity (Markson et al., 2013).

2.6.5 EFFECT OF PARTICLE SIZE

The particle size of a material is paramount in briquette making (Katimbo et al., 2014). Particle size and size distribution affect the combustion properties of charcoal briquettes (Ayhan and Ayse, 2010). Increase in particle size increases volumetric calorific value, reduces ash content and increases thermal efficiency (Davies & Abolude, 2013). Despite the poor flow characteristics of very fine particles, inclusion of 10 - 20 % fine particles increases cohesion which in turn increases the compressive strength of briquettes (Grover & Mishra, 1996).

2.6.6 EFFECT OF RAW MATERIAL DENSITY

Density is a very vital parameter because its value is directly proportional to energy to volume ratio, and ease of handling during storage and transportation (Križan et al., 2011). Briquette density is dependent on density of the raw material, compaction pressure, binder ratio and particle size (Davies & Abolude, 2013).

CHAPTER THREE

METHODOLOGY

3.1 STUDY AREA

The study was conducted at Uganda Industrial Research Institute which is located in Nakawa 6.7km along Jinja road.

3.2 STUDY DESIGN

A 3×4×5 factorial experiment was carried out in a completely randomised design with four replications to investigate main effects and interactions of the factors. The three factors were particle size, compaction pressure, and binder ratio. Particle size had three levels (Small (2 to < 4mm), Medium (4 to < 6mm) and Large (6 to < 8mm)), compaction pressure had four levels (P1=2MPa , P2=4 MPa, P3=6 MPa, P4=8 MPa), and starch binder ratio had five levels (B1=5%, B2=7.5%, B3=10%, B4=12.5%, B5=15%) of the weight of maize cob char. Four replications provided four samples per treatment which were sufficient for all the required experimental tests (Quinn & Keough, 2002]).

3.3 MATERIAL COLLECTION AND PREPARATION

Maize cobs were collected from farmers in Tiribogo village, Mpigi district and sun dried for 5 sunny days to 25% moisture content wet basis which was suitable for gasification. Dry maize cobs were carbonized using a gasifier as shown in figure 1 below to enhance complete carbonization for homogeneous char production. Operating temperatures of the gasifier reactor ranged from 850^{o}C to $1200\ ^{o}$C, maize cob consumption rate was 30 kg/hr and the char generated was 12% of the raw material by weight (Wabwire, 2014).The hot char from the gasifier was cooled using water and then sun dried to 15% moisture content wet basis.

Size reduction of the char was achieved by pounding using a mortar and pestle, and then sieved using four different mesh sizes (2mm, 4mm, 6mm, and 8mm) to obtain the required sizes. The particles of size less than 2mm were termed as fine particles, from 2mm to less than 4mm were termed as small particles, from 4mm to less than 6mm were termed as medium particles, whereas from 6mm to less than 8mm were termed as large particles.

Then the fine particles were uniformly mixed with each of the three groups of particles (Small, medium, Large) in a proportion of 15% by weight to increase strength as specified by Grover & Mishra (1996). All weights were measured using a digital weighing balance of 0.0001g precision.

Figure 3.1:Gasifier used to carbonize maize cobs

Nase14 variety of cassava was recommended by cassava researchers at Namulonge National Crops Resources Research Institute for binder due to its superior pasting properties and availability among farmers in Uganda.

Cassava tubers of *Nase14* variety were harvested from a farmer in Koboko, peeled, washed, grated, sun dried to 10% moisture content wet basis, and then ground to produce flour using a grinding machine. Starch paste was prepared using a ratio of 1kg cassava flour to 10 litres of water with continuous agitation and the temperature raised to 80 ^{o}C.

3.4 BRIQUETTE PRESS

A manually operated hydraulic briquette press was fabricated using mild steel material for the experiment with a capacity of four briquettes per turn. The cylindrical moulds in its compression chamber had external diameter of 52.5mm, internal diameter of 20mm, and height of 120mm. The press shown in figure 4 below was powered by a 20 Ton hydraulic jack that was connected to a pressure gauge of 100 bar (1500 psi) capacity using high pressure hydraulic fittings of 3500 psi capacity. The hydraulic jack piston base had a diameter of 56mm.

Figure 3.2: Hydraulic briquette press connected to pressure gauge

The pressure in hydraulic jack cylinder should be released using the release valve to lower the press component and create space for feeding material from the top of the mould. Material can be fed manually, followed by locking of the stop plate on top, then closing of the release valve before jacking to compress the material to the required compaction pressure of the hydraulic jack cylinder shown by the pressure gauge. Having attained the required pressure at a dwelling time of 25 minutes, the release valve is opened to allow unlocking of the stop plate. As soon as the stop plate is opened, the release valve should be closed to allow ejection of the compressed briquettes which can be removed by hand for drying.

Char of a given particle size was uniformly mixed with starch binder of a given ratio and then compacted using a hydraulic briquette press at a given pressure and uniform dwelling time of 25 seconds was maintained. A total of 240 experimental units were made for evaluation of calorific value, moisture content, volatile matter content, ash content, fixed carbon content, and density of briquettes. The briquettes were placed in a wooden dryer having sixty well labelled partitions that correspond to the treatment conditions to prevent them from mixing which could lead to confusion in the course of laboratory tests. Having dried for seven days in a sunny weather of 27^{o}C room temperature, they were taken for laboratory analysis.

3.5: EXPERIMENTAL TESTS

Proximate analysis was done using ELTRA Thermostep Thermogravimetric analyzer (Przyborowski et al., 2012). The material temperature increased from room temperature at a constant rate of 5^{o}C per minute to 110^{o}C at which moisture content was measured under an inert nitrogen atmosphere until attainment of constant weight. The temperature then increased at constant rate of 5^{o}C per minute to 850^{o}C and was maintained for 7 minutes under inert nitrogen gas at which volatile matter content was determined from weight loss. The temperature was then decreased to 800 ^{o}C and the inert nitrogen gas replaced by oxygen gas for complete combustion of the sample to determine ash content at constant mass. The fixed carbon content was then computed from the corresponding values of moisture content, ash content and volatile matter content.

Figure 3.3: ELTRA Thermostep Thermogravimetric analyzer (Gauteng, South Africa)

Calorific value was determined using IKA KV600 digital bomb calorimeter (Sugumaran & Seshadri , 2009) in which the briquette sample is completely burnt in excess oxygen gas as shown below.

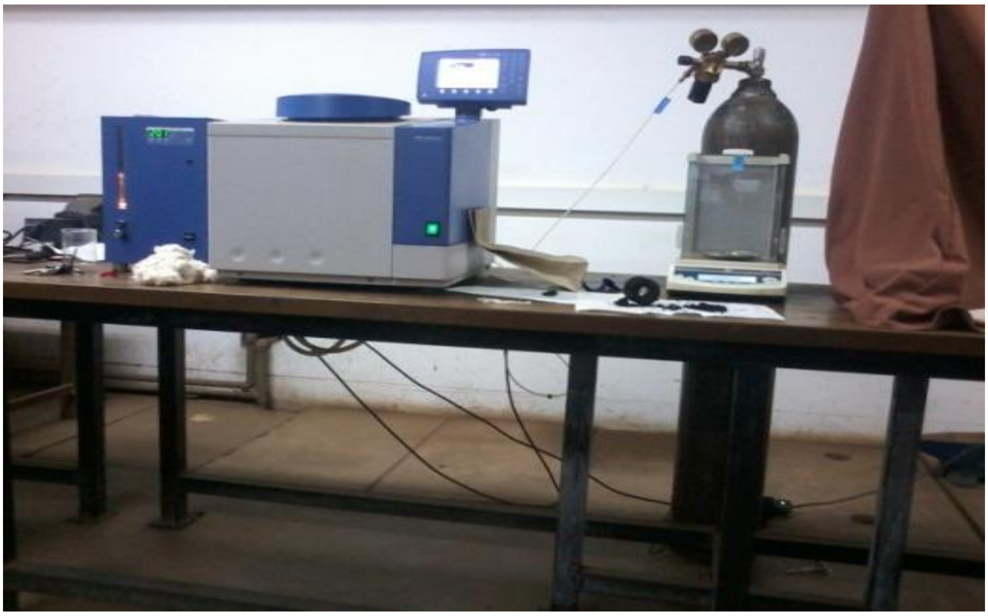

Figure 3.4: IKA KV600 digital bomb calorimeter (Staufen, Germany)

Briquette density was computed from their analytical weights, heights and cross sectional area (Demirbaş, & Şahin, 1998) using the expression below.

$$D = \frac{M}{CSA \times H} \text{ kg/m}^3 \qquad [1]$$

Where; D = Density (kg/m^3)

M = Mass (kg)

CSA = Cross sectional area (m^2)

H = Height (m)

3.6 DATA ANALYSIS

R-statistical software version 3.1.1 was used for data analysis. Since two of the independent variables (compaction pressure and binder ratio) and all dependent variables (calorific value, moisture content, volatile matter content, fixed carbon content, ash content, and density) are continuous, multiple linear regression models were chosen to investigate the impact of compaction pressure, binder ratio and particle size on each of the dependant variables. The models also allow for determination of interaction of the factors (Quinn & Keough, 2002). Having obtained the optimal conditions, cost benefit analysis was conducted.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1: DESCRIPTIVE STATISTICS

All the dependant variables (heating value, moisture content, volatile matter content, ash content, fixed carbon content, and density) were normally distributed since histograms and box plots in preliminary analysis were symmetrical. Pearson's correlation matrix shows that particle size, binder ratio and compaction pressure are not correlated ($r < 0.014$). Table 4.1 below shows summary statistics of the dependant variables.

Table 4.1: Descriptive statistics of proximate values, heating value and density of briquettes

Variable	Moisture content (%)	Volatile matter content (%)	Fixed Carbon content (%)	Ash content (%)	Heating Value (J/g)	Briquette Density (kg/m^3)
Mean	13.74	14.04	63.71	8.515	24617	381.7
Standard deviation	0.498	2.415	2.485	0.701	396.8	40

4.2 : REGRESSION ANALYSIS

Multiple linear regression models were used to investigate the impact of compaction pressure, binder ratio and particle size on each of the dependant variables. Particle size, compaction pressure and binder ratio never had significant interaction on moisture content, volatile matter content, fixed carbon content, ash content and heating value. However, there was significant interaction between compaction pressure and binder ratio on density. Residual plots for the fitted linear regression models were investigated and therefore the assumptions of independence, homoscedasticity and normality were satisfied.

The detailed results and discussion of each dependant variable are as discussed below.

4.2.1 : Ash Content

The ash content of briquettes was recorded in triplicates per treatment and used for linear regression model without aggregation. However, table 4.2 below shows results of the mean ash content per treatment.

Table 4.2 : Mean Ash Content (%) of Briquettes on Dry Basis per Treatment

Particles Size	Compaction Pressure	Binder Ratio				
		5%	7.50%	10%	12.50%	15%
Small Particles	2MPa	8.852	8.910	8.366	8.620	8.372
	4MPa	9.082	9.393	8.852	8.154	9.761
	6MPa	9.834	8.910	9.086	9.494	8.111
	8MPa	8.481	8.235	8.403	8.782	8.446
Medium Particles	2MPa	8.249	8.343	7.708	8.145	8.433
	4MPa	8.947	9.636	8.024	7.713	8.124
	6MPa	8.381	9.029	8.456	8.132	9.074
	8MPa	8.421	8.147	8.908	7.615	8.615
Large Particles	2MPa	8.216	7.731	8.201	8.799	7.844
	4MPa	8.592	8.699	7.995	7.874	8.653
	6MPa	8.644	8.419	7.909	6.863	8.229
	8MPa	8.956	8.669	7.968	8.032	10.356

Having run the multiple linear regression model on raw data, the statistical output shown in the table below was obtained.

Table 4.3: Parameter estimates and p-values for ash content model of briquettes

PARAMETER	ESTIMATE	STD Error	t-value	Pr(>|t|)
Intercept	8.432827	0.254793	33.097	$< 2\times10^{-16}$ ***
Medium Particle	-0.067109	0.169785	-0.395	0.69357
Small Particle	0.421259	0.159839	2.636	0.00986 **
Compaction Pressure	0.004941	0.003098	1.595	0.11411
Binder Ratio	-0.027380	0.018673	-1.466	0.14599

Residual standard error: 0.6674 on 173 degrees of freedom

Multiple R-squared: 0.1309, Adjusted R-squared: 0.09308

F-statistic: 3.463 on 4 and 173 df, p-value: 0.01107

Fitted model for ash content:

$$AC = 8.433 + 0.421\ SP \qquad [2]$$

Where; AC = Ash Content on dry basis (%)

SP = Small Particles

From table 4.3 above, binder ratio and compaction pressure did not have significant effect on ash content at 5% level of significance (p-values > 0.05).

Much as compaction pressure increases density which reduces porosity that could limit the amount of oxygen required for combustion (Chirchir et al., 2013) and result in increased ash content, ELTRA Thermostep Thermogravimetric proximate analyzer uses sufficient amount of oxygen that only leaves incombustible material as ash.

In addition to that, cassava binder only contains 0.2% ash content (Eze & Azubuike, 2010) which is very negligible at low binder ratios. This explains why compaction pressure and binder ratio never had significant effect on ash content.

Particle size had a significant effect on ash content at 5% level of significance (p-value: 0.00986 <0.05) and the model explains 13.09% of the total variation in ash content. Ash content of the various particles is graphically represented by the bar graph below.

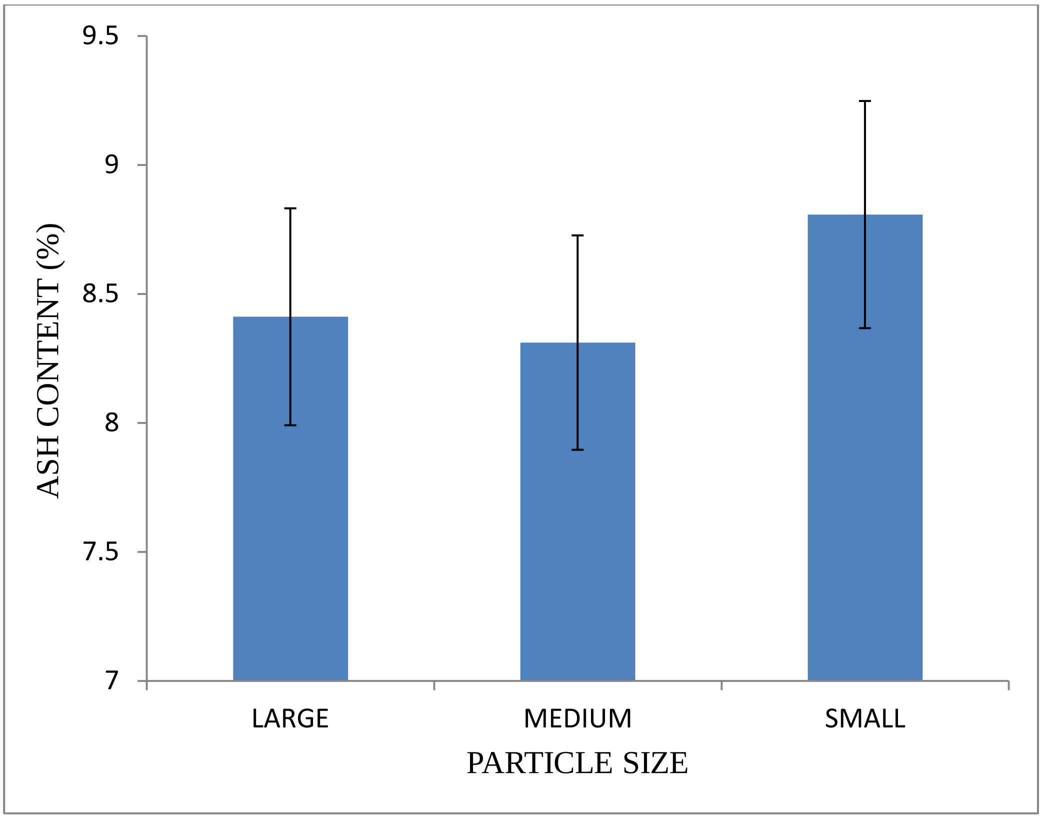

Figure 4.1 :Bar plot of ash content against particle size for briquettes from maize cobs

Large particles had 8.433% ash content which was not statistically different from that of medium particles (p-value: 0.69357>0.05) at 5% level of significance despite the slight visual difference depicted in the bar graph above. Small particles had significantly higher ash content than large particles at a significance level of 5% (p-value: 0.00986<0.05). Smaller particles had more ash content by 0.421% because of incombustibles such as sand that were retained by the 2mm sieve.

The mean ash content for all the briquettes was less than 18% dry basis (Zagreb, 2008) which implies that they burn with minimum slagging effect, hence attainment of good quality for barbeque use.

4.2.2 : Volatile matter content

Ash content of briquettes was recorded in triplicates per treatment and used for linear regression model in its raw form without aggregation. However, the table below shows results of the mean volatile matter content per treatment.

Table 4.4: Mean Volatile Matter Content (%) of Briquettes on Dry Basis per Treatment

Particles Size	Compaction Pressure	Binder Ratio				
		5%	7.50%	10%	12.50%	15%
Small Particles	2MPa	12.758	15.455	14.010	18.241	16.558
	4MPa	10.628	12.630	13.601	14.743	16.187
	6MPa	10.394	11.729	13.145	16.252	12.832
	8MPa	10.617	11.697	13.359	13.799	16.908
Medium Paricles	2MPa	10.568	12.317	16.277	14.095	16.828
	4MPa	13.474	11.078	15.536	18.114	16.081
	6MPa	12.812	12.300	14.793	15.811	14.664
	8MPa	12.923	14.482	13.174	16.067	13.442
Large Particles	2MPa	13.068	12.081	12.529	13.334	15.466
	4MPa	11.261	15.640	12.122	12.883	19.852
	6MPa	14.291	10.741	12.757	15.379	15.968
	8MPa	12.610	12.313	12.467	15.288	15.365

Having run the linear regression model on raw data, the statistical output shown in the table below was obtained.

Table 4.5: Parameter estimates and p-values for volatile matter content model of briquettes

PARAMETER	ESTIMATE	STD Error	t-value	Pr(>|t|)
Intercept	10.722451	0.738705	14.515	$< 2\times10^{-16}$ ***
Medium Particle	-0.144507	0.492247	-0.294	0.770
Small Particle	-0.577353	0.463411	-1.246	0.216
Compaction Pressure	-0.012515	0.008981	-1.394	0.167
Binder Ratio	0.407135	0.054138	7.520	3.54×10^{-11} ***

Residual standard error: 1.935 on 174 degrees of freedom

Multiple R-squared: 0.3851,   Adjusted R-squared: 0.3583

F-statistic: 14.4 on 4 and 174 df, p-value: 3.612e-09

Fitted model: VC (%) = 10.723 + 0.407 BR [3]

Where; VC = Volatile matter content on dry basis (%)

BR = Binder ratio (%)

Unlike compaction pressure and particle size, binder ratio had a significant effect on volatile matter content at 5% level of significance (p-value: 3.54×10^{-11}) and it accounts for 38.5% of the total variation in volatile matter content. Compaction pressure does not alter the composition of particles, hence its insignificant effect on volatile matter content. Maize cobs were carbonized in a gasifier where the high temperatures (850-1200^{o}C) expelled most of the volatile substances. The char particles therefore had very low volatile matter content which explains the insignificant effect of particle size on volatile matter content of the briquettes.

Since binder ratio had significant effect on volatile matter content, its paramount to visualize the relationship between the two variables as shown by the scatter plot below.

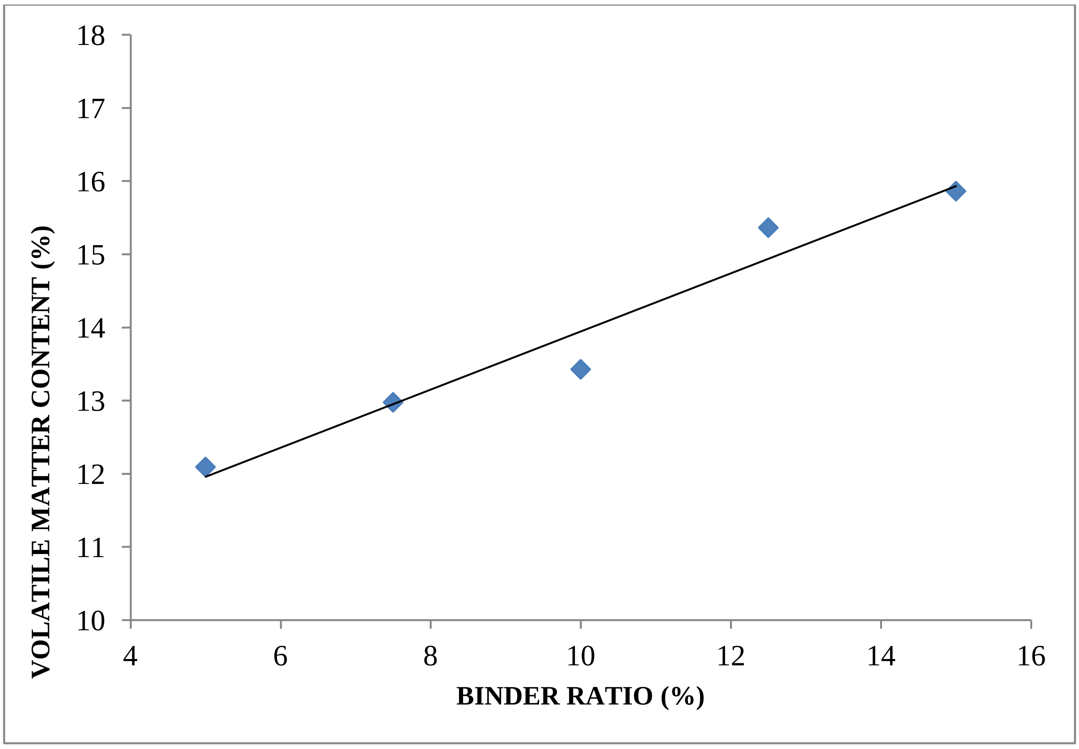

Figure 4.2: Scatter plot of volatile matter content against binder ratio for briquettes

Maize cob char without any binder had a volatile matter content of 10.723%. One percent increase in binder ratio increased volatile matter content by 0.407%. This can be attributed to the fact that cassava contains more volatile matter content than maize cob char. Given the fact that volatile matter content is directly proportional to smoke levels, the mean volatile matter content (14.04%) is less than 30% limit for barbeque use (Zagreb, 2008). This therefore implies that the briquettes are smokeless.

4.2.3 : Fixed Carbon Content

The fixed carbon content of briquettes was recorded in triplicates per treatment and used for linear regression model in its raw form without aggregation. However, the table below shows results of the mean values of fixed carbon content per treatment.

Table 4.6 :Mean Fixed carbon content (%) of briquettes from maize cobs on dry basis

Particles Size	Compaction Pressure	Binder Ratio				
		5%	7.50%	10%	12.50%	15%
Small Particles	2MPa	65.45	62.052	64.579	59.480	60.983
	4MPa	66.859	63.902	63.785	63.085	60.668
	6MPa	66.395	65.181	64.563	60.530	66.087
	8MPa	66.645	65.866	64.668	63.228	61.506
Medium Particles	2MPa	67.280	65.732	60.572	64.658	60.141
	4MPa	63.937	65.951	62.204	59.536	61.500
	6MPa	65.42	65.155	63.62	62.72	62.554
	8MPa	65.38	63.053	63.790	62.472	64.727
Large Particles	2MPa	64.950	65.931	65.303	63.899	63.370
	4MPa	66.066	62.226	66.413	64.620	58.257
	6MPa	63.799	67.184	65.923	64.626	62.336
	8MPa	64.379	64.915	66.175	62.432	60.885

Having run the linear regression model on raw data, the statistical output shown in the table below was obtained.

Table 4.7: Parameter estimates and p-values for Fixed carbon content model

PARAMETER	ESTIMATE	STD Error	t-value	Pr(>|t|)
Intercept	66.993689	0.819714	81.728	$< 2\times10^{-16}$ ***
Medium Particle	-0.054571	0.546229	-0.100	0.921
Small Particle	0.161310	0.514230	0.314	0.754
Compaction Pressure	0.007650	0.009965	0.768	0.445
Binder Ratio	-0.362290	0.060076	-6.031	3.37×10^{-08} ***

Residual standard error: 2.147 on 174 degrees of freedom

Multiple R-squared: 0.2846, Adjusted R-squared: 0.2535

F-statistic: 9.149 on 4 and 174 df, p-value: 2.877e-06

Fitted model: $FC = 66.99 – 0.36\ BR$ [4]

Where; FC = Fixed Carbon Content on dry basis (%)

BR = Binder Ratio (%)

Unlike particle size and compaction pressure, binder ratio had significant effect on fixed carbon content at 5% significance level ($p=3.37\times10^{-08}$ ***) as shown in table 4.7 above and it explains 28.5% of the total variation in fixed carbon content. All the particles were obtained from the same char having uniform fixed carbon content which explains why variation of particle size could not cause any significant effect on fixed carbon content.

Compaction pressure does not alter the material composition of dry briquettes, hence its insignificant effect on fixed carbon content.

The relationship between binder ratio and fixed carbon content is graphically represented by the scatter plot in figure 4.3 below.

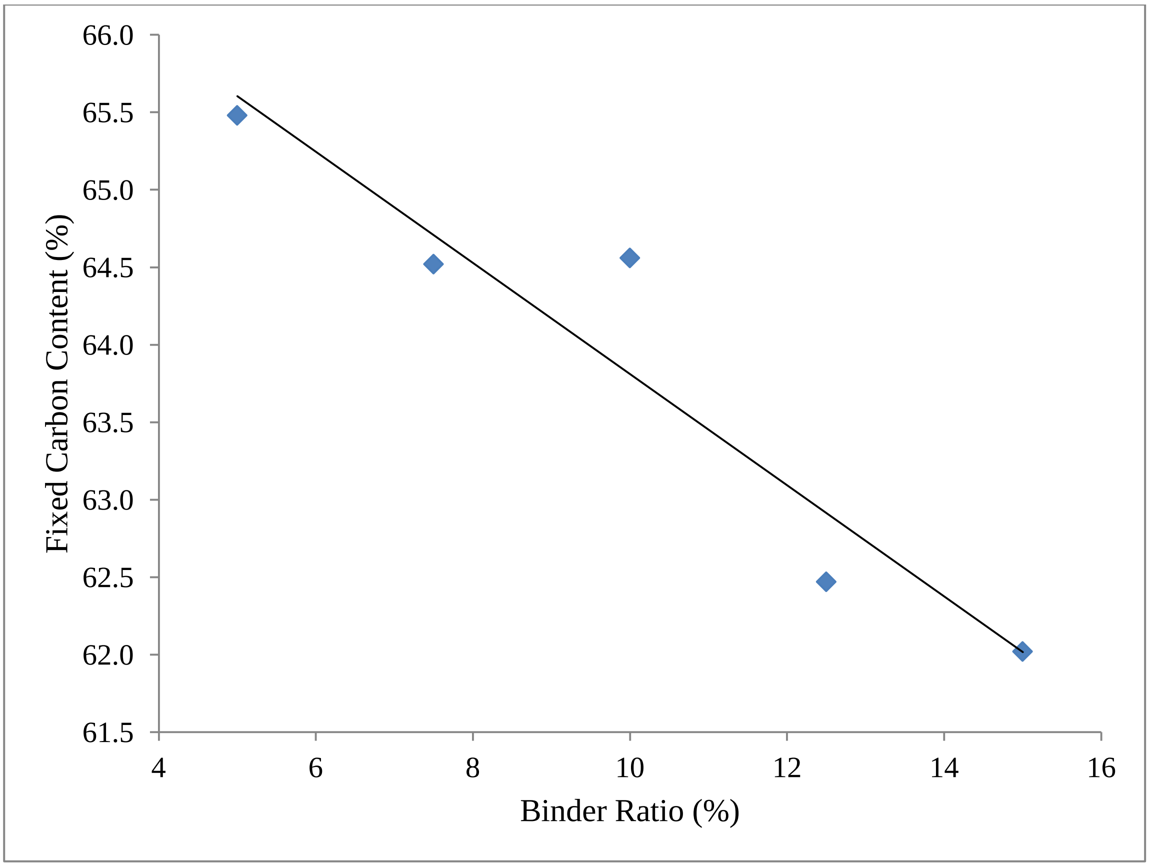

Figure 4.3: Scatter plot of fixed carbon content against binder ratio for briquettes

Maize cob char without binder contained 66.99% fixed carbon content. One percent increase in binder ratio reduced fixed carbon content by 0.36% because cassava contains less fixed carbon content than maize cob char.

4.2.4 : Moisture Content

Compaction pressure, particle size and binder ratio did not have significant effect on moisture content at 5% level of significance (p-value: 0.1248). The drying time and weather conditions were sufficient which released all the free water as evidenced by moisture content of less than 18% (Onchieku et al., 2012), hence the insignificant effect of the treatments on moisture content. The low moisture content implies that less amount of heat energy is wasted in moisture liberation which shows that the briquettes produce sufficient heating effect.

4.2.5 : Heating Value

Heating value of briquettes was recorded in duplicates per treatment and used for multiple linear regression model in their raw form without aggregation. However, the table below shows results of the mean heating value per treatment.

Table 4.8 :Mean Heating Value (J/g) of Briquettes made from maize cobs

Particles Size	Compaction Pressure	Binder Ratio				
		5%	7.50%	10%	12.50%	15%
Small Particles	2MPa	25108.0	24293.5	24670.0	24080.0	24045.0
	4MPa	25177.5	24513.0	24432.0	24050.0	24202.0
	6MPa	24997.0	24672.5	24709.5	24022.0	24084.0
	8MPa	24559.0	24390.0	24167.5	24277.0	23925.0
Medium Particles	2MPa	25276.0	24545.0	24793.0	24391.5	24417.0
	4MPa	24692.0	24715.0	24284.5	24583.0	24551.5
	6MPa	25268.0	24624.0	24628.0	24388.5	24944.0
	8MPa	25247.5	24184.0	24794.5	24131.5	24689.5
Large Particles	2MPa	25017.5	24332.5	24995.5	24365.5	24081.0
	4MPa	25287.5	24943.0	24608.0	24748.0	24589.0
	6MPa	25010.0	24742.5	24786.0	24907.5	26086.5
	8MPa	25278.0	25099.0	24484.5	24502.0	24246.5

Multiple linear regression model was run on raw data and the statistical output obtained was as shown in the table below.

Table 4.9: Parameter estimates and p-values for heating value model of briquettes

PARAMETER	ESTIMATE	STD Error	t-value	Pr(>|t|)
Intercept	25340	1.298e+02	195.187	$< 2\times 10^{-16}$ ***
Medium Particle	-81.53	7.695e+01	-1.060	0.292140
Small Particle	-288.2	8.296e+01	-3.474	0.000788 ***
Compaction Pressure	-0.07479	1.484	-0.050	0.959912
Binder Ratio	-61.99	9.536	-6.500	4.21×10^{-09} ***

Residual standard error: 322 on 114 degrees of freedom

Multiple R-squared: 0.369, Adjusted R-squared: 0.3412

F-statistic: 13.3 on 4 and 114 df, p-value: 1.421×10^{-08}

$$HV = 25340 - 288.2\,SP - 61.99\,BR \qquad [5]$$

Where; HV = Heating Value (J/g)

SP = Small Particles

BR = Binder ratio (%)

Particle size and binder ratio explain 36.9% of the total variation in heating value. Since p-value (1.421×10^{-08}) is less than 0.05, the null hypothesis that $R^2 = 0$ was rejected. The overall model is significant at 5% level of significance. Given the significant parameter estimates in table 4.9 above, the graphical representation of heating value is as shown below in figure 4.4.

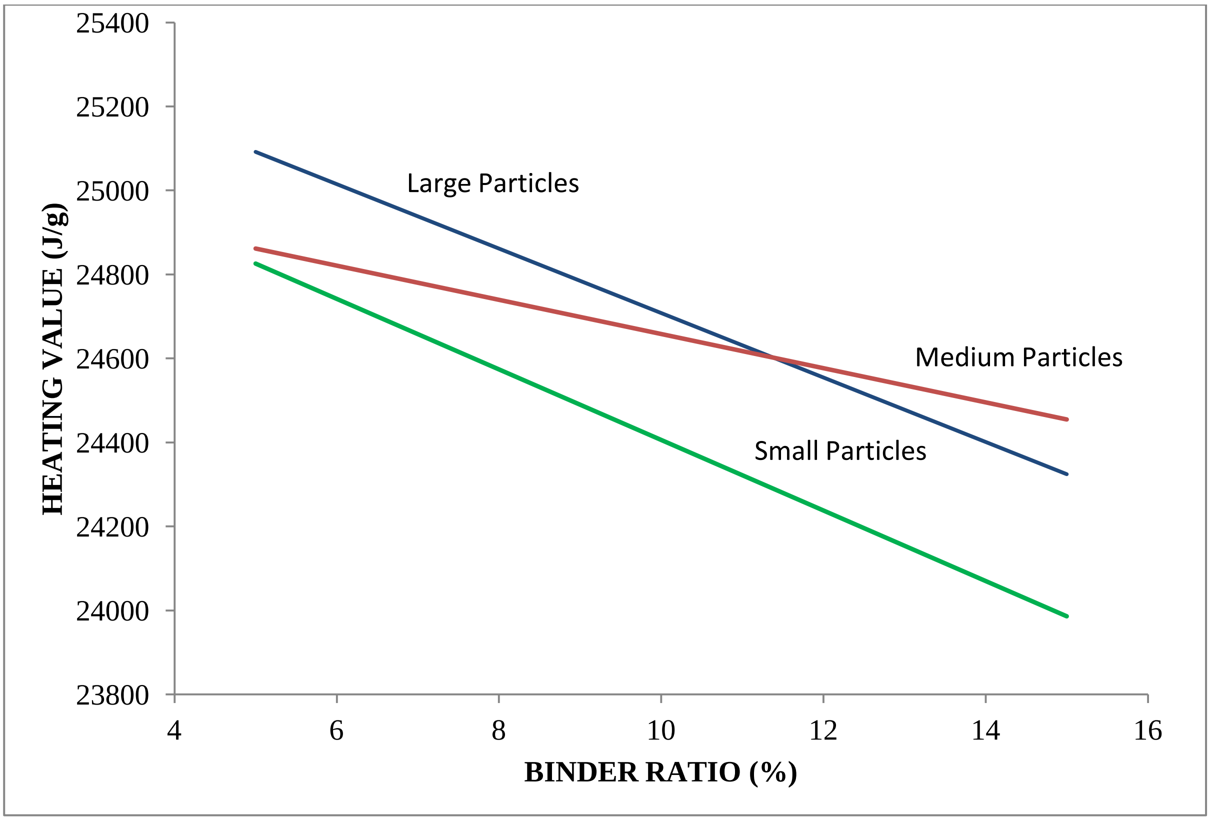

Figure 4.4: Heating value against binder ratio for different particle sizes for briquettes

Large particles of maize cob char without any binder had 25340 J/g heating value. The heating value of medium particles was not significantly different from that of large particles at 5% level of significance (p-value:0.292140). At all binder ratios, small particles had significantly less heating value than large particles at 5% level of significance (p-value:0.000788). Small particles had less heating value by 288.2J/g due to the presence of incombustibles (sand particles) which were retained by the small sieve.

One percent increase in binder ratio reduced heating value by 61.99J/g which agrees with the findings of Chirchir et al., (2013) that increase in binder ratio reduces heating value. The reduction of heating value could be attributed to the reducing fixed carbon content of the briquette as binder ratio increases.

Compaction pressure did not have statistically significant effect on heating value at 5% level of significance (p-value: 0.959912 > 0.05) because compaction pressure only enhances the volumetric calorific value of biomass, but not its heating value (Grover and Mishra, 1996). The mean heating value of carbonized briquettes produced from maize cobs is 24617 J/g which is greater than 17500 J/g requirement for sufficient heating effect (Emerhi, 2011). These briquettes can therefore reduce wood consumption, hence minimizing deforestation rate.

4.2.6 : Density

Density of briquettes was recorded in triplicates per treatment and used for multiple linear regression model in their raw form without aggregation. However, the table below shows results of the mean density per treatment.

Table 4.10 :Mean density of briquettes (kg/m^3) made from maize cobs

Particles Size	Compaction Pressure	Binder Ratio				
		5%	7.50%	10%	12.50%	15%
Small Particles	2MPa	344.2116	360.7803	373.5655	386.639	405.7784
	4MPa	338.6149	388.5321	394.8326	425.0332	421.6571
	6MPa	419.5000	407.4013	412.9971	430.2218	415.4476
	8MPa	397.5298	438.4449	432.2675	444.6716	440.2837
Medium particles	2MPa	318.6777	341.4465	354.5141	359.3961	389.7118
	4MPa	365.9773	365.7316	384.3749	367.0374	391.3157
	6MPa	379.5553	415.3582	392.5942	399.0815	405.6042
	8MPa	409.8824	396.9332	413.7293	388.3535	413.9764
Large Particles	2MPa	281.7291	331.2317	315.2131	332.5341	346.8302
	4MPa	280.6166	329.8882	349.9957	357.9035	350.3939
	6MPa	363.9602	378.0297	402.0574	379.8952	364.9489
	8MPa	379.3261	425.4382	434.6279	416.0635	405.8276

The output shown below was obtained after running multiple linear regression model for briquette density using raw data values.

Table 4.11: Parameter estimates and p-values for density model

PARAMETER	ESTIMATE	STD Error	t-value	Pr(>|t|)
Intercept	226.5827	13.3989	16.910	$< 2\times^{-16}$ ***
Medium Particle	20.6403	4.6196	4.468	2.07×10^{-05} ***
Small Particle	41.6182	4.4280	9.399	1.89×10^{-15} ***
Compaction Pressure	19.5547	2.4976	7.829	5.02×10^{-12} ***
Binder Ratio	7.7999	1.2262	6.361	5.91×10^{-9} ***
Pressure×Binder	-0.8206	0.2314	-3.547	0.000593 ***

Residual standard error: 19.01 on 172 degrees of freedom

Multiple R-squared: 0.7846, Adjusted R-squared: 0.7739

F-statistic: 73.57 on 5 and 172 df, p-value: $< 2.2\times10^{-16}$

Fitted Model:

$$D = 226.58 + 20.64\,MP + 41.62\,SP + 7.8\,BR + 19.56\,P - 0.8206 \times\ P \times BR \qquad [6]$$

Where; D = Density (kg/ m^3)

MP = Medium Particles

SP = Small Particles

BR = Binder ratio (%)

P = Compaction Pressure (MPa)

The model for briquette density is significant at 5% level of significance (p-value:$< 2.2\times10^{-16}$) and it accounts for 78.5% of the total variation. Compaction pressure, binder ratio and particle size had significant effect on briquette density at 5% significance level since their p-values are less than 0.05.

Large un compacted particles had a density of 226.58 kg/m^3. Medium and small particles had higher densities than large particles by 20.64kg/m^3 and 41.62 kg/m^3 respectively because reduction in particle size eases compaction and allows more mass of material for a given volume which increases briquette density.

The interaction between binder ratio and compaction pressure had a negative impact on briquette density. This could be attributed to the displacement of excess binder from the particles at increasing pressure which results into increase in volume, hence decreasing density. However, the resultant effect of compaction pressure and binder ratio on briquette density was positive.

One percent increase in binder ratio changes briquette density by (7.8 - 0.8206 Pressure_0) kg/m^3 if all other conditions are kept constant. Where Pressure_0 is the compaction pressure in MPa. Increase in cassava binder ratio increases briquette density (Križan et al., 2011) because it fills the pores, hence increasing the mass of material in a given volume.

Increasing compaction pressure by one mega Pascal alters the density of briquettes by (19.56 - 0.8206 Binder Ratio_0) kg/m^3 while keeping other factors constant. Binder Ratio_0 is the proportion of binder used in percentage. Compaction pressure increases briquette density (Wilaipon, 2009) because it reduces volume at constant material mass.

4.3 : OPTIMAL CONDITION DETERMINATION

Having fitted the five significant linear regression models, factor levels in each model were ranked basing on importance, followed by average ranks for all models, and then the optimal condition determined by selecting the levels with the least rank for each factor as shown below.

4.3.1 : Optimisation of Density

$$D = 226.58 + 20.64\,MP + 41.62\,SP + 7.8\,BR + 19.56\,P - 0.8206 \times\ P \times BR$$

A high density is required for briquettes because increase in density prolongs burning time, reduces space for storage and eases handling. Therefore, factor levels that increase density are given preference.

Particles Size: Small particles have the highest density, followed by medium particles, and then large particles. The ranks of Small, medium and large particles are 1, 2 and 3 respectively.

Binder Ratio: Density increases with increase in binder ratio which then implies that the highest binder ratio is given preference to low binder ratios. The ranks of 5%, 7.5%, 10%, 12.5% and 15% binder ratios are 5, 4, 3, 2, and 1 respectively.

Compaction Pressure: Density increases with increase in compaction pressure which means that the highest compaction pressures should be given preference to low compaction pressures. Ranks of 2MPa, 4 MPa, 6 MPa, and 8 MPa compaction pressures are 4, 3, 2, and 1 respectively.

4.3.2 : Optimisation of Fixed Carbon Content

$FC = 67.22 – 0.36\ BR$

Fixed carbon content of briquettes should be as high as possible because the heating value increases with increase in fixed carbon content. The fixed carbon content reduces with increase in cassava binder ratio which implies that the least binder ratio takes preference. The ranks for 5%, 7.5%, 10%, 12.5%, and 15% binder ratios are 1, 2, 3, 4, and 5 respectively.

4.3.3 : Optimisation of Ash Content

$AC = 8.433 + 0.421\ SP$

Briquettes are required to have as minimum ash content as possible to reduce slagging behaviour during combustion and for effective heating. Small particles had more ash content than the rest which implies that small particles are the least preferred in the model. The ranks of small, medium, and large particles are 3, 1.5, and 1.5 respectively.

4.3.4 : Optimisation of Volatile Matter Content

$VC = 10.723 + 0.407\ BR$

Volatile matter content corresponds to the smoke level of the briquettes which therefore makes preference of low to high volatile matter content. The volatile matter content increases with increase in binder ratio which implies that the least binder ratio is the most preferred for the model. Ranks for 5%, 7.5%, 10%, 12.5%, and 15% binder ratios are 1, 2, 3, 4, and 5 respectively.

4.3.5 : Optimisation of Heating Value

$$HV = 25340 - 288.2\, SP - 61.99\, BR$$

Heating value is the measure of the amount of heat per unit mass which is therefore required to be as high as possible for the briquettes.

Particles: Small particles have less heating value than the rest of the particles which then makes the least preference for them to medium and large particles. Ranks for small, medium, and large particles are 3, 1.5, and 1.5 respectively.

Binder Ratio: Heating value reduces with increase in cassava binder ratio, hence preference of the least binder ratio. Ranks for 5%, 7.5%, 10%, 12.5%, and 15% binder ratios are 1, 2, 3, 4, and 5 respectively.

4.3.6 : Average ranks of the factor levels

Particle size had significant effect on three of the dependent variables which therefore implies that the number of models having particle size as an explanatory variable are three. The average ranks for small, medium and large particles are 2.333, 1.667, and 2 respectively.

Medium particles have the least average rank which implies that their performance is the best among the particle sizes considered in the study

Binder ratio was significant in explaining four of the dependant variables and the average ranks for 5%, 7.5%, 10%, 12.5%, and 15% binder ratios are 2, 2.5, 3, 3.5, and 4 respectively.

The least average rank is 2 for 5% binder ratio which means that the optimal cassava binder ratio for all the dependant variables considered is 5%.

Compaction pressure only had significant effect on density and therefore, the most preferred level was 8 MPa.

Given the optimal factor levels for each factor, their combination gives the optimal condition when putting into consideration all the dependant variables. Much as all treatments satisfied the minimum briquette quality requirements, the fitted linear regression models show that medium sized particles, 5% binder ratio and 8MPa compaction pressure of the hydraulic cylinder produced briquettes with superior quality (8.421% ash content, 12.923% volatile matter content, 65.38% fixed carbon content, 13.358% moisture content, 25247.5 J/g heating value, and 409.8824 Kg/m^3 relaxed density). These make up the optimal condition of the experiment.

4.4: CONSIDERATIONS FOR COST BENEFIT ANALYSIS

Assuming the mould dimensions and research findings were used to scale up for commercial production, the briquette press capacity and raw materials can be quantified. 56mm piston base diameter of the hydraulic jack and 8MPa hydraulic cylinder pressure for production of four briquettes gives a force of 4926N per briquette. Then 100 briquettes require a force of 492600N. Assuming acceleration due to gravity of 9.81 m/s^2, the force can be provided by a hydraulic jack of 50 tons capacity to produce 100 briquettes per turn.

Given that the cylindrical moulds have 52.5mm external diameter, 20mm internal diameter and 120mm height, uncompressed medium sized particles containing 5% binder have a density of 286.22kg/m^3, and the machine can make 6.3432 kg of briquettes per turn. Assuming that the time required in minutes per turn for loading material, compression and ejection are 4, 3, and 3 respectively. It is therefore estimated that the machine can make six turns per hour. Assuming there are ten effective working hours per day, twenty two work days per month, and production throughout the year, 100.4763 tons of briquettes can be produced per year. 95.6917 tons of char and 4.7846 tons of cassava flour are required per year since 5kg of cassava is used for every 100kg of char.

Given ten litres of water per kilogram of cassava flour for binder preparation, and 50 litres for cleaning per day, 61050 litres of water is required per year. Let the useful machine life be ten years, each kilogram of briquettes costs 1000 Ugandan shillings ($ 0.294), and the average discount rate is equal to 14.15%.

Table 4.12: Capital Costs for briquette business

ITEM	QUANTITY	UNIT COST (Ugs)	AMOUNT (Ugs)
Land	2 Acres	20,000,000	40,000,000
Building	4 Rooms	5,000,000	20,000,000
Briquette Press	1	3,500,000	3,500,000
Mortar and Pestle	3	60,000	180,000
Mesh for sieving	2	120,000	240,000
Hybrid solar dryer	2	2,500,000	5,000,000
Improved stove	2	40,000	80,000
Saucepans	4	60,000	240,000
Tarpaulins	10	45,000	450,000
Weighing balance	2	120,000	240,000
Office furniture	1 set	2,500,000	2,500,000
Protective wear	10 sets	200,000	2,000,000
TOTAL			**74,430,000 ($21,891.2)**

Table 4.13: Operational Costs per Annum (Ugs) for the briquette business

ITEM	QUANTITY	UNIT COST	AMOUNT PER ANNUM
Maize cob char	95691.7 kg	100	9,569,170
Cassava binder	4784.6kg	1,200	5,741,520
Water	61050 litres	10	610,500
Repair and maintenance	Twice a year	1,000,000	2,000,000
Packaging material	111,936 pieces	150	16,790,400
Rent of sales outlet	1 Outlet	3,600,000	3,600,000
Salaries	9 Staff	3,000,000	27,000,000
Office supplies	1 office	250,000	250,000
Transport		4,000,000	4,000,000
Sales promotion		2,700,000	2,700,000
Taxes		400,000	400,000
TOTAL			**72,661,590 ($ 21,371.1)**

Table 4.14: Cash Flow (Ugs) for the briquette business

YEAR	CASH OUT FLOW	CASH IN FLOW	NET CASH FLOW
0	74,430,000	0	-74,430,000
1	72,661,590	100,476,300	27,814,710
2	72,661,590	100,476,300	27,814,710
3	72,661,590	100,476,300	27,814,710
4	72,661,590	100,476,300	27,814,710
5	72,661,590	100,476,300	27,814,710
6	72,661,590	100,476,300	27,814,710
7	72,661,590	100,476,300	27,814,710
8	72,661,590	100,476,300	27,814,710
9	72,661,590	100,476,300	27,814,710
10	72,661,590	100,476,300	27,814,710

4.5: COST BENEFIT ANALYSIS

Cost benefit analysis was conducted based on economic indicators such as net present worth, benefit cost ratio, internal rate of return and discounted payback period (Sengar et al., 2013).

4.5.1: Net present worth (NPW)

This is the difference between the present value of cash inflows and the present value of cash outflows. It is useful in capital budgeting to analyze the profitability of the project.

$$\text{Net present worth} = CF(0) + \frac{CF(1)}{1+r} + \frac{CF(2)}{(1+r)^2} + - - - + \frac{CF(n)}{(1+r)^n} \qquad [7]$$

Where; CF (n) = the net cash flow in a period (year),

n = 10 years,

r = Discount rate which is 14.15%

Net present worth = $-74{,}430{,}000 + \frac{27{,}814{,}710}{1+0.1415} + \frac{27{,}814{,}710}{(1+0.1415)^2} + - - - \; + \frac{27{,}814{,}710}{(1+0.1415)^{10}}$

Net present worth = 69,809,400 Ugs ($ 20,532.2)

Since the Net Present Worth is greater than zero, the project was accepted.

4.5.2 : Benefit Cost Ratio (BCR)

This is an economic indicator that attempts to summarize the overall value for money of a project by comparing the benefits and the costs.

$$BCR = \frac{Present\ Worth\ of\ Benefits}{Present\ worth\ of\ Costs\ (Investiment+Operation)} \qquad [8]$$

Present worth of benefits $= 0 + \frac{100{,}476{,}300}{1+0.1415} + \frac{100{,}476{,}300}{(1+0.1415)^2} + - - - + \frac{100{,}476{,}300}{(1+0.1415)^{10}}$

Present worth of benefits = 521,042,327.89 Ugs ($ 153,247.7)

Present worth of costs$= 74{,}430{,}000 + \frac{72{,}661{,}590}{1+0.1415} + \frac{72{,}661{,}590}{(1+0.1415)^2} + - - - + \frac{72{,}661{,}590}{(1+0.1415)^{10}}$

Present worth of costs = 451,232,927.68 Ugs ($132,715.6)

BCR = 1.15471

Since the Benefit Cost Ratio (1.15471) > 1, the project is acceptable for investment.

4.5.3: Discounted payback period

The discounted payback period of briquette business refers to the length of time it will take to generate discounted cash flows equivalent to the original cost of the investment. Discounted payback period was preferred to payback period because it incorporates the time value of money in the economic analysis. Discounted payback period at which the net present worth exceeds zero was calculated as shown below

$$\text{Net present worth} = \mathrm{CF}\ (0) + \frac{CF(1)}{1+r} + \frac{CF(2)}{(1+r)^2} + --- + \frac{CF(n)}{(1+r)^n} = 0 \qquad [9]$$

Where CF (n) is the net cash flow at discount rate, r =14.15%

Discounted payback period = 3.603 years

Investment in briquette business is acceptable because it takes 3.603 years to get discounted cash flows equivalent to the original cost of investment and yet the lifespan of the business considered is ten years.

4.5.4: Internal rate of return (IRR)

The is the discounted rate that makes the Net present worth of an investment zero and was calculated as shown below

$$\mathrm{NPW} = \mathrm{CF}\ (0) + \frac{CF(1)}{1+IRR} + \frac{CF(2)}{(1+IRR)^2} + --- + \frac{CF(n)}{(1+IRR)^n} = 0 \qquad [10]$$

Where CF (n) is the net cash flow in n years

$$\mathrm{IRR} = -74{,}430{,}000 + \frac{27{,}814{,}710}{1+IRR} + \frac{27{,}814{,}710}{(1+IRR)^2} + --- + \frac{27{,}814{,}710}{(1+IRR)^{10}}$$

IRR = 36%

Since the internal rate of return (36%) is greater than the required rate on investment (discount rate = 14.15%), the project was accepted.

In general, all the economic indicators considered above suggest that the briquette project is economically feasible. It is expected to add value to the firm, and improve the shareholders' wealth.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

This chapter gives the project conclusions and recommendations.

5.1: CONCLUSIONS

1. Compaction pressure, binder ratio and particle size have a significant effect on thermo-physical properties of carbonised maize cob briquettes.
2. Much as all treatments satisfied the minimum briquette quality requirements, the fitted linear models show that medium sized particles, 5% binder ratio and 8MPa hydraulic cylinder pressure produced briquettes with superior quality. This then implies that two sieves of 4mm and 6mm should be used to obtain 85% of the particles that are mixed with 15% dust particles for briquetting. For every 100kg char, 5kg of cassava starch should be added which minimises the amount of cassava used in briquette industry, hence promoting food security.
3. The briquettes with low volatile matter content are smokeless which solves the problem of indoor air pollution which has been killing 4.3 million people annually.
4. Mean heating value of briquettes produced (24617 J/g) is sufficient for heating which can replace wood, hence minimizing deforestation rate.
5. Cost benefit analysis when applying optimal conditions (medium sized particles, 5% binder ratio and 8MPa hydraulic cylinder pressure) for briquette production shows that it is economical viable. The project has a net present worth of 69,809,400 Ugs ($20,532.2), benefit cost ratio of 1.15471, internal rate of return of 36%, and a discounted payback period of 3.603 years.

5.2: RECOMMENDATIONS

1. Given that cassava is the second most important food in Africa, a study should be conducted to enhance the pasting properties of cassava binder for briquette production.
2. Another study should be done to assess the strength of briquettes at optimal condition to ascertain whether they can withstand crumbling during handling and transportation.
3. The need to standardise briquette production conditions requires investigation of other raw materials since briquette quality is greatly influenced by its composition.

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