DEVELOPMENT OF BIOMASS WASTES BRIQUETTE STOVE FOR DOMESTIC USE

By

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DECLARATION

This thesis is my own original work and has not been presented for the award of a degree in any other university

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DEDICATION

This work is dedicated to my parents, Mr. and Mrs. Saleh Mathahana Inanga who through struggles, prayers and faith have seen me through university education; my wife Brenda, son Myles, Barak and daughter Carol, who lend me their resources and time during this study.

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

ABBREVIATIONS AND ACRONYMS

Abbreviation	Description	Units
CDC	U.S. Centers for Disease Control and Prevention	
CEIHD	Centre for Entrepreneurship in International Health and Development	
CO	Carbon Monoxide	
ESDA	Energy Sustainable Development Africa	
EPA	Environmental Protection Agency	
G/CC	Grams per cubic centimetre	
Ha	Hectares	
ITDG	Intermediate Technology Development Group	
IRR	Internal Rate of Return	
KCJ	Kenya Ceramic *Jiko*	
KPCU	Kenya Planters Coffee Union	
LCC	Life Cycle Cost	
OPEC	Organization of the Petroleum Exporting Countries	
MJ	Mega Joules	
MJ/kg	Mega Joules per Kilogram	
PM	Particulate Matter	
UNDP	United Nation Development Program	
USD	United State Dollar	

NOMENCLATURE

Symbol	Description	Units
C_f	Calorific value of wood	$18MJkg^{-1}$
Cp	The specific heat capacity of water	$4200Jkg^{-1}K^{-1}$
HV_f	Average calorific value of fuel briquettes	$MJkg^{-1}$
LHvw	Latent heat of Vaporization of water	$2260Jkg^{-1}$
M_{ev}	Mass of water evaporated	Kg
M_{ib}	Mass of broken briquettes subjected to drop test	Kg
M_{ad}	Mass of air dry briquettes	Kg
M_{mod}	Mass of briquettes after subjected to oven dry process	Kg
M_{ab}	Initial mass of complete briquettes used in drop test	Kg
M_{od}	Mass of briquettes before devolatisation	Kg
M_{dev}	Mass of briquettes after devolatisation	kg
M_{ash}	Mass of ash produced after complete combustion of briquettes	kg
M_{cb}	Mass of briquettes before combustion	kg
M_f	Average amount of wood per household per meal	kg
M_{fb}	Mass of fuel used in water boiling test	Kg
M_w	Mass of water heated	kg
M_{wf}	Final mass of water	kg
M_{wi}	Initial mass of water	kg
NCV_f	Net Calorific Value of the briquettes	$MJkg^{-1}$
Ta	Initial temperature of water used in water boiling test	^oC
Tb	Boiling temperature of water during water boiling test	^oC
T_{wb}	Boiling temperature of water	^oC
T_{wi}	Ambient temperature of water	^oC
T_{wb}	Boiling temperature of water	^oC
T_{wi}	Ambient temperature of water	^oC
T	Time taken to boil the water	sec
P_1	Power of the stove for first trial	w

P_2	Power of the stove second trial	w
P_3	Power of the stove third trial	w
Q_n	Quantity of energy required to cook	kg
η_{w3}	Average efficiency of the third trial warm stove at high power testing	

SUBSCRIPTS

Symbols	Description
1	1st Trial
2	2nd Trial
3	3rd Trial
C1	Cold start high power trial high one
C2	Cold start high power trail two
C3	Cold start high power trial three
W1	Warm start high power trial one
W2	Warm start high power trail two
W3	Warm start high power trial three
S1	Low power trial one
S2	Low power trial two
S3	Low power trial three
Wa	Ambient temperature of water
Wb	Boiling temperature of water

ABSTRACT

Biomass energy in the form of woodfuel and charcoal contributes close to 68% of the total energy demand in Kenya. The continued depletion of biomass resources has led to the use of agricultural residue to supplement energy needs for domestic cooking. Biomass stoves used to burn these fuels in Kenya are characterized by high inefficiencies and high emissions that pose environmental and health risks to the users. This research aimed to reduce biomass fuels consumption, reduce fuel indoor air pollution and deforestation. The project was carried out in two phases. First, in 2010 there was a survey of the status of bio-waste fuel briquetting technology in Nairobi and peri- urban Nairobi area. Secondly, a semi-gasification stove that uses briquettes derived from solid organic waste material was developed. The survey involved an interview of 63 briquette producers identified from desktop research within Nairobi and its per-urban areas, out of which 40, 15 and 8 were community based groups, NGOs and briquette producing companies respectively. A total 175 briquette users were randomly selected and interviewed from a list of briquette consumers given by briquette producers interviewed. Based on the results of the field survey, a semi- gasifier stove was designed and constructed. The semi-gasifier stove construction took place at Kenyatta University Engineering workshops. Tests were done to determine the thermal efficiency, specific fuel consumption and power of the stove. Standard stove emission test were conducted using KANE 455. About 33% of the briquettes made were from a mixture of charcoal dust and paper. Characterization of briquettes was based on their calorific value, percentage moisture, volatile matter, ash content, fragility of briquettes and burning characteristics. The calorific value of briquettes was between 14.21kJ/g and 24.64kJ/g for water hyacinth based and carbonized baggasse briquettes respectively. Moisture content of the briquettes ranged from 5.8% to 14% for carbonized baggase briquettes and for charcoal with bean stocks plus paper respectively. Carbonized coffee husks with starch binder had the lowest volatile matter of 10.1% while coffee husks with paper had the highest volatile matter of 71.2%. Briquettes made from sawdust and paper had the lowest ash content of 8.8% whereas briquettes from charcoal dust and clay had ash content of 66.8%. The percentage fragility of the briquettes sampled ranged from 0.1% to 80.4% for charcoal with clay and sawdust with paper respectively. The semi-gasifier stove had an average thermal efficiency of 30%±3 and an average fire power of 2.5kW±1.5. The emission testing of the stove using KANE 455 gas analyzer for CO, CO_2 and CO/CO_2 ratios showed the average values of 0.2067 ± 0.0259ppm, 2.6771 ± 0.13307ppm and 2.31374 ± 0.13184 respectively. Economic analysis show that if a family were to invest in the stove, they would save about Ksh 30($ 0.35), Ksh 1000 ($11.7) and Ksh 2200 ($25.8) ,if their initial cooking stove is open fire, kerosene stove and charcoal stove respectively. If a family claimed carbon credits by using the stove, it would be entitled to up to Ksh 8,000 ($94.1) during its entire life. For mass production the stove would retail at an average of Ksh 800 ($9.4). The prototype stove developed was found to meet the intended need for being used by fuel briquettes.

CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 Biomass Energy Consumption and Demand in Kenya

Biomass in the form of woodfuel and charcoal contributes up to of 68% of the total energy demand in Kenya (Republic of Kenya, 2004). It is estimated that Kenya has a sustainable wood fuel supply of 15.5 million metric tonnes per year while the total demand is approximated to be 32 million metric tons (Republic of Kenya, 2004). The deficit which is over 16.4 million metric tonnes is met through stock depletion and use of agricultural residue. Firewood is mainly used for cooking, water heating and space heating by about 90% of the rural households and 80% of the semi-urban residence (ESDA, 2005). The average annual per capita consumption of wood fuel was approximately 741 kg and 691 kg for rural and urban households respectively (Theuri, 2004).

On the supply side close to 84% of firewood is obtained mainly from agro forestry or on-farm source, 8% from trust lands and 8% from gazetted forests (Theuri, 2004). Morover approximately 79% of households obtain firewood free of charge, 17% of the households regularly purchase it while 7% supplement their free collection of firewood by purchases (Theuri, 2004).

By 2002, charcoal consumption in Kenya was approximately 47% at the national level. This represented 82% and 34% of urban and rural households respectively. The per capita consumption was 156 kg in urban areas and 152 kg in rural areas (ESDA, 2005). Theuri (2004) found out in a survey that the amount of charcoal produced each year in Kenya was 1.6 million tones and was mostly produced using inefficient earth-mound kilns whose efficiency rarely goes above 20% hence utilizing about 8 million tonnes of wood in a year. The use of biomass energy in addition to increased demand for wood for institution and other uses has led to forest degradation and contributed to the reduction of the overall forest cover in Kenya (Duncan, 2006). It is estimated that for the period between 1963 and 2006, the average forest cover had shrunk from 10% to 1.7% (Duncan, 2006).

1.1.2 Biomass Use and Indoor air quality and Climate Change

About 84% of Kenyans have no access to grid electricity and relies on biomass fuels to provide over 75 per cent of their thermal energy requirements (Practical Action, 2008). According to the World Health Organization, indoor air pollution causes 1.5 million deaths every year (WHO, 2006), and is a major cause of respiratory infections, lung disease, ear and eye problems, breathlessness, chest pains, headaches and giddiness (ITDG, 2004).

According to the proceedings of the conference on "Scaling up Modern Energy Services" held in East Africa in 2005, it is estimated that 92% of households in East Africa, use biomass fuel for cooking, whereby more than 40% of the population is exposed to indoor air pollution. It is further estimated that over half a million people die each year because of exposure to indoor air pollution in sub-Saharan Africa (UNDP and GTZ, 2005). Biomass fuel combustion produces particulate matter and is believed to be the major cause of respiratory problems particularly to the young children. Poly aromatic hydrocarbons found in wood smoke are known to cause bladder and lung problems (Smith, 1987). Further, lung cancer can occur many years after exposure as a result of the volatile poly hydrocarbon carcinogens (Smith, 1987). The quantity of one of these carcinogens, benzo(a) pyrene, that a rural woman is exposed to in a day would be equivalent to that from smoking 450 non-filter cigarettes (Smith,1987).

Other finer particles emitted during combustion include microscopic solid particles suspended in the air and are 2.5 micrometers in diameter (Seaton *et al.* 1995; Ezzati and Kammen 2002).

Exposure to particulate matter of 2.5 has been linked to several adverse cardiovascular and respiratory health effects including tuberculosis, acute respiratory infections, low birth weight and cataracts (Seaton *et al*, 1995; Ezzati and Kammen, 2002). Carbon monoxide (CO) is also another toxic gas that is released from inefficient combustion processes that occur in open fires and inefficient cook stoves. Exposure to CO has many acute and long term health effects. The World Health Organization recommends a PM 2.5 limit of 25 micrograms per cubic meter over a 24 hour period and a carbon monoxide limit of 9 ppm over an 8 hour period (WHO, 2005)

Theuri documented that the 24-hour average of respirable particulates of 5526µg/m^3 were emitted in Kajiado and 1713µg/m^3 in Western Kenya as a result of indoor cooking with biomass fuels (ITDG, 2004). These figures are way too high compared to the EPA standards respirable particulates of 50µg/m^3 (ITDG, 2004). Therefore there is need to develop 'clean' cooking stoves which can reduce the health problems associated with biomass fuel combustion (Reed and Larson, 2001)

The continued warming up of the earth has been linked to the release of greenhouse gases into the atmosphere. These greenhouse gases originate mostly from energy generation. Among the greenhouse gases is the CO_2 released from burning of biomass fuels. Since biomass is the principal fuel for cookstoves in the developing world, these stoves produce up to 800,000 tonnes of soot every year (Robert *et al*, 2005). These particles have been found to absorb solar energy and contribute to global warming. It is projected that by 2050 cooking in Africa will contribute to approximately 6.7 billion tonnes of emissions in total, which is about 5.6% of all emissions from the continent (Robert *et al*, 2005).

1.2 Problem Statement

Biomass energy is the most utilized source of energy in Kenya, accounting for about 68% of the total energy consumption (Republic of Kenya, 2004). The continuous use of biomass fuels is posing an environmental and health threat to the country and health problems to domestic users. There is a continuous environmental degradation due to the cutting of trees for use as fuel, and increase in health problems resulting from exposure to emissions resulting from the burning of biomass fuels. Briquette technology offers an alternative source of biomass energy in forms of briquettes which can remedy the problem of continuous destruction of forest cover in the country. However, biomass briquettes require an appropriate combustion stove. Some of the available stoves emit over 25 micrograms per cubic meter of levels of Particulate Matter (PM2.5) and Carbon Monoxide (CO) gas posing serious health risks to the stove users. Semi-Gasification technology has been known to offer solution to indoor air pollution associated with 'unclean' cooking (Reed and Ralson, 2001). Therefore this research focused on designing and fabrication of a briquette semi-gas stove for domestic cooking.

1.3 Justification of the Study

Biomass fuel is one of the cheapest and the most utilized form of energy in Kenya its utilization has led to environmental and health damages to the country and users respectively. Various Community Based Organisation, NGOs and entrepreneurs have ventured in development and promotion of briquette as an alternative source of energy especially in urban areas. As the briquette technology becomes popular in the country, it is necessary to develop an appropriate biomass stove which can effectively burn biomass briquettes so as to have a 'clean' cooking. The successful utilization of biomass waste briquettes will help reduce the rate of deforestation. Moreover, an efficeint briquette stove is necessary in order to reduce the health effects assorted with indoor air. The Chinese stoves, Juntos stoves, Holy Briquette stove and Vesto stoves have been developed operating on semi-gasifier technology. However all the four prototypes face challenges and gaps making them not suitable for proper dissemination of the briquetted technology. The Chinese stove is too expensive for an average family, retailing at usd 90. The parts of the Juntos stove are loosely stacked to each other making it too delicate to cook on it.

The Holy briquette stoves faces design challenges in that once the cooking pot is placed on top of it, it affects the flow of secondary air making it smorky. The vesto stove has been designed with high engineering technology making it a challenge to be reproduced by local artisan. It is therefore a need to develop a prototype stove that addresses these gaps and operates as a semi-gasifier

1.4 Objectives

1.4.1 General Objective

The general objective of this research was to design, develop and test the thermal performance of a prototype briquette semi-gasifier stove for domestic use.

1.4.2 Specific Objectives:

The specific objectives of the research were to:

i) Undertake a survey of biomass briquetting technology and determine their physical and chemical characteristics

ii) Design and construct a prototype domestic biomass briquette stove

iii) Test the thermal performance of the prototype briquette stove

iv) Evaluate the economic and environmental benefit of the designed prototype semi-gasification stove

1.5 Scope of the Study

The research on briquette technology survey was done within Nairobi and peri-urban area of Nairobi, its peri-urban whereas the semi gasifier stove was constructed and tested at Kenyatta University. The scope of the study included carrying out surveys to establish the current briquetting technologies being used, the composition of briquettes and their chemical characteristics. Moreover, a semi-gasifier utilizing solid wastes briquettes stove was tested and its economic and environmental benefits determined.

CHAPTER 2: LITERATURE REVIEW

2.1 Biomass Energy Potential and Use in Kenya

Biomass energy in form of woodfuel and charcoal supplies an average of 68% of the total energy used in Kenya (Republic of Kenya, 2004). The estimated sustainable woodfuel supply amounts to 15.5 million metric tones per year. This leaves a deficit of 16.4 million metric tones which is obtained through stock depletion and use of agricultural and other residues (ESDA, 2005). Currently the forest cover in Kenya stands at less than 2%, which is far below the minimum of 10% recommended internationally forest cover by the internationally (Republic of Kenya, 2004).

According to the National Charcoal Survey of 2005, 90% of the rural households and 80% of semi-urban households use firewood as the source of energy mainly for their cooking purposes. The survey also showed that the amount of charcoal produced in Kenya each year was 1.6 million tones. This amount of charcoal is mostly produced using inefficient earth-mound kilns whose efficiency is less than 20%. This indicates that close to 8 million tonnes of wood goes into making charcoal yearly. This trend has contributed to unsustainable harvesting of trees for charcoal production leading to depletion of forest, soil erosion, reduced water catchment areas, biodiversity conservation and greenhouse gas emission especially in Arid and Semi-arid lands (ESDA, 2005).

Biomass comes from various sources such as closed forests, woodlands, bushlands, wooded grasslands, farms with natural vegetation and mixtures of native and exotic trees; other sorces include industrial and fuel wood plantations; and residues from agricultural crops and wood-based industries. These sources contribute to Kenya's national biomass resource as follows:

Indigenous vegetation mainly from closed forests, woodlands, bush lands and wooded grasslands – 16 million m^3;

Farmlands consisting of exotic tree species such as grevillea, eucalyptus and remnant natural vegetation is 14 million m^3; plantations mainly of eucalyptus is 2 million m^3; and residues from agriculture and wood based industries is 3 million m^3 (GTZ, 2010). These biomass sources are described in detail in the following section.

2.1.1 Woodlands and Wooded Grasslands in Kenya

Closed forest denotes woody vegetation that forms a continuous stand of at least 10m in height with interlocking crowns. Closed forest formations cover approximately 1,247,400 ha and have an average annual productivity of 1.3m^3 /ha/yr. The total potential volume that is available is approximately 1.60 million cubic meters annually. Most closed forests are gazetted (legally recorded) and are on public lands managed by the Kenya Forest Department. Others are located in protected areas such as national parks and national reserves managed by Kenya World Life service (GTZ, 2010)

Woodlands are open stands of trees at least 8 m tall with a canopy cover of 40% or more and a ground layer dominated by grasses. They cover an area of about 2,092,600 ha which is about 4 % of the total woody vegetation cover (GTZ, 2010). Average forest productivity is 0.64 m^3/ha/yr yielding a total of 1.3 million m^3 annually (GTZ, 2010). Woodlands are the natural vegetation in areas with marginal rainfall and are the transition between semi-humid and semi-arid zones. Most of them are in the Coast and Rift Valley Provinces with an equal amount in the North Eastern and Eastern Provinces. Central, Nyanza and Western Provinces have limited woodland vegetation. Various County Councils own most of the woodland vegetation on the basis of Kenya’s Trust Lands Act

Bushland vegetation consists of short shrubs of about 3-7 m in height and climbers occurring in open stands, with a canopy cover of 40% or more. They cover about 24,629,400 ha with an average growth rate of 0.44 m^3/ha/yr and contribute 10.84 million m^3 annually. Bushlands are found in the North Eastern, Coast, Rift Valley and Eastern Provinces in order of decreasing coverage. This vegetation also occurs in openings of disturbed closed forests, woodlands and in most highland forests due to human disturbance such as tree poaching and encroachment.

Their productivity in the high potential areas is remarkably high but much less in arid and semi-arid areas. (GTZ, 2010)

Wooded Grasslands are extensive; they cover an estimated 10.6 million hectares in Kenya and are characterized by grasslands and scrub vegetation with a 10-40% woody vegetation cover (GTZ, 2010). Wooded grasslands are found in the arid and semi-arid areas of the Rift Valley, North Eastern and Eastern Provinces in the order of importance. County councils own most of the wooded grasslands under Kenya's Trust Land Act. The annual increment rate of wooded grasslands is 0.25 m^3 per hectare with a potential gross yield of 2.60 million m^3 annually (GTZ, 2010).

Grasslands have scattered, short, small-diameter tree species, comprising mainly of Acacias. They cover an area of 1,203,500 ha with an average productivity of 0.08 m^3/ha/yr for an annual total of 0.096 million cubic meters. Western and Central Provinces have no grasslands and there is only a small area in Nyanza Province (GTZ, 2010).

Wood supply from farms comes from small woodlots interspersed with crops, farm boundaries and other scattered trees within farms. Farms cover about 10 million ha and have a highly variable wood productivity. This is estimated at about 1.44 m^3/ha/yr supplying wood of approximately 14.4 million m^3 per annum (GTZ, 2010)

2.2 Domestic Wood-gas Stoves

Wood-gas stove technology offers the possibility of cleaner, better controlled gas cooking for developing countries (Anderson and Reeds, 2001). Gas can be made from wood and biomass in wood-gas also known as semi-gasifiers. Several wood semi-gas stoves have been designed for cooking. Basically, domestic wood semi-gas stoves can be broadly grouped into two categories: The forced air wood semi-gas and the natural draft wood semi-gas.

The forced air wood semi-gas operates with a fan below the fuel combustion chamber which blows air that assists in combustion during cooking with the stove. In most cases, the fan is powered by electricity or solar energy, a car battery or an inbuilt thermo-cell that gets recharged while the stove is being used. An example of the latter is the Philips stoves. One disadvantage of such stoves is that they cannot operate in places without electricity, or incase the thermal cell is damaged then its operation is affected (Anderson and Reeds, 2001)

2.2.1 Natural Draft Wood-gas Stoves

The other types of wood-gas stoves are those that operate on the natural draft. They are known to be appropriate in regions that lack electricity. Among them is the Juntos wood semi-gas stove that has been developed by Anderson and Reed as shown in Fig 2.1 below (2001).

Fig 2.1: Different stove parts of a Juntos wood stove (Anderson and Reed, 2001)

This particular stove combines various parts of the stove stacked on each other, that is, the gasifier chamber, the pot holder, and the gas wick that regulates the secondary air. The design faces the challenges of the stove toppling over during cooking. The stove also faces the challenge of being difficult to extinguish. Currently the stove costs about USD 20. However, the design is still under development (Anderson and Reed, 2001).

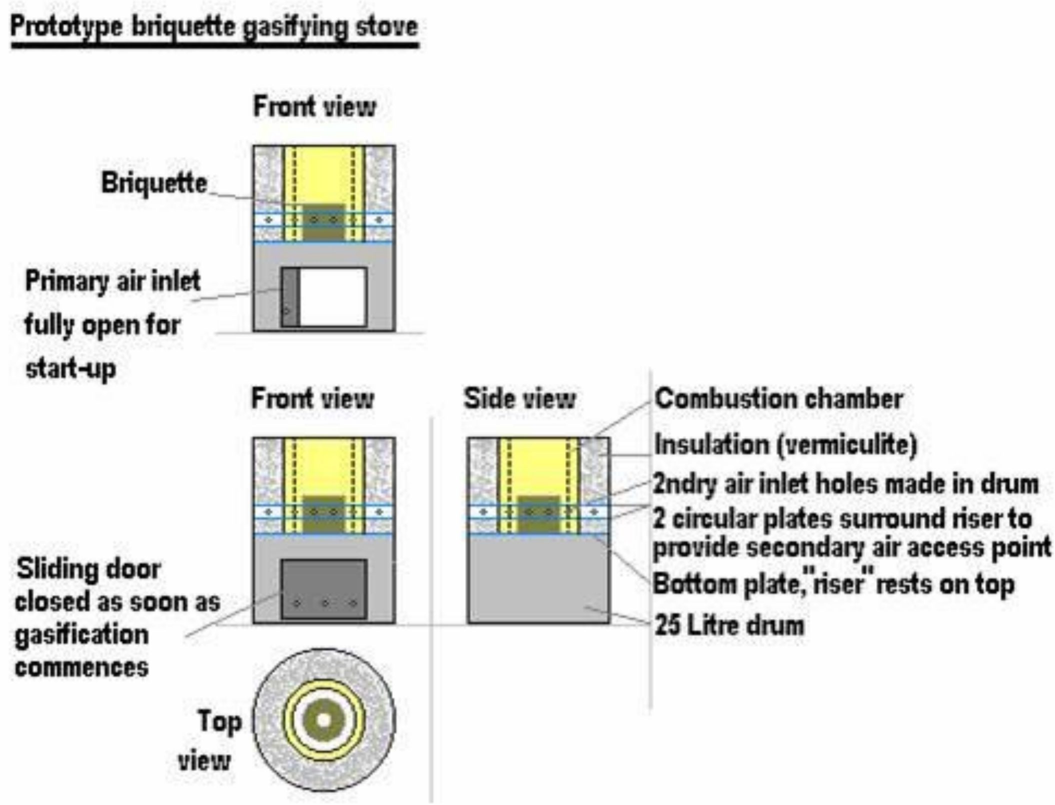

Fig 2.2: Prototype Briquette gasifying stove (Stanley and Venter, 2003)

Stanley and Venter (2003) designed a Holey briquette semi-gas stove above in Fig 2.2. The stove operates on the same principle of the Modified Inverted Downdraft gasification experiment. However the stove faces two major challenges, that is, feeding the stove with more briquettes during cooking and determination of the height at which pots needs to be placed without interfering with airflow in the reaction.

Fig.2.3: Chinese gasifier stove (Belonio, 2005)

There also exists a Chinese gasifier stove shown in Fig 2.3 above. It consists of holes on its upper and middle portions to provide the needed air for gasification. This stove is an improved version of a center-tube type stove. The Chinese gasifier stove has been reported on the internet as having an efficiency of about 60% . The cost of this stove is roughly USD 90 (Belonio, 2005).

Fig. 2.4: Vesto semi-gasifier Stove (Chrispin, 2004)

The vesto stove, shown in Fig 2.4 above, designed by Crispin in conjunction with the new dawn engineering centre. It can semi-gasify any kind of biomass material. The stove is a modification of the Tsotso, Shisa and Basintuthu stove. Its thermal efficiency is above 45%. The efficiency of such a stove could be improved further. For instance, apart from the air insulation it has, clay insulation may be added on the outside of the stove. This can help to increase the thermal efficiency and also reduce the dangers of one being scalded when accidental touching of the sides of the stove occurs. The cost of this stove is averagely USD 35 (Chrispin, 2004).

Table 2.1 Summary of Briquette Stoves Developed and their Respective Gaps

Stove Design	**Gap/Challenges Facing the Design**
Juntos Stove	Its parts loosely arranged. Faces the possibility of pot toppling over during cooking
Chinese gasifier stove	The retail price of USD 90 of the stove too high for most of the village families in Kenya.
Holey Briquette Stove	When cooking with it, the pot interferes with the flow of secondary air hence causing incomplete combustion
Vesto Stove	Made from sophisticated engineering technology make it a challenge for reproducibility with local artisan. The retail price of USD 35 still high for an average family

2.3 Critical Design Features of a Wood gas- Stove

The design of wood-gas stove begun as a trial and error exercise. However, Stanley and Kobus (2005) have established three critical design features of it as follows:

i) The secondary air should be pre-heated as much as possible before mixing with combustible gasses.

ii) The ratio of the primary air to secondary air should be about1: 9.

iii) The height of the combustion chamber should be 1.65 times its diameter.

2.4 Parameters for Improvement of a Wood Semi-gas Stove

From the above literature review, in order to increase the performance of a semi-gasification stove one has to:

i) Ensure that the secondary air is preheated as much as possible before it gets to the combustion chamber.

ii) Ensure that the secondary air joins the combustible gas in the combustion chamber at a distance of 1.65 times the diameter of the combustion chamber (Stanley and Kobus, 2005).

iii) Combine air insulation and low thermal mass ceramic material as the overall insulation of the stove.

iv) Ensure that the ceramic liner has a low a density that ranges from 0.4gcm^{-3} to 0.8gcm^{3}.

The semi-gasifier stove under research incorporated these parameters in its design.

2.5 Biomass Fuel Briquettes Production Technology

Biomass briquetting is the process of converting low bulk density biomass into high density and energy concentrated fuel briquettes. The briquetting of agro-residues is of relatively new in developing countries. The technique was adapted for organic wastes about 50 years ago in industrial countries, having been first developed to briquette low-grade coal, but interest waned in the 1960s. The interest technique was later revived in the 1980s on a significant scale in most developing countries (Legacy, 2003). This has resulted to lack of systematic information about how briquetting plants have performed in practical operation. The success or failure of briquetting is very much dependent upon the agricultural and fuel context in which it is applied. Thus, there is only a limited amount of help that can be obtained from technical appraisal or from the experience of plants in industrialized countries.

Historically, biomass briquetting technology has been developed in two distinct types, Europe and the United States has pursued and perfected the reciprocating ram/piston press while Japan has independently invented and developed the screw press technology. Although both technologies have their merits and demerits, it is universally accepted that the screw pressed briquettes are far superior to the ram pressed solid briquettes in terms of storability and combustibility (AGIGO, 2011). Japanese machines are now being manufactured in Europe under licensing agreement but no information has been reported about the manufacturing of European machines in Japan. Both technologies are being used worldwide for briquetting of sawdust and locally available agro-residues. Although the importance of biomass briquettes as a substitute fuel for wood, coal and lignite is well recognized, the numerous failures of briquetting machines in almost all developing countries have inhibited their extensive exploitation. Briquetting technology is yet to get a strong foothold in many developing countries because of the technical constraints involved and the lack of knowledge for adapting the technology to suit local conditions. Overcoming the many operational problems associated with this technology and ensuring the quality of the raw material used are crucial factors in determining its commercial success. In addition to this commercial aspect, the importance of this technology lies in conserving wood (a commodity extensively used in developing countries but leads to the widespread destruction of forests). (AGIGO, 2011)

The fact that the production of briquettes quadrupled from 1964 to 1969 in Japan speaks for the success of this technology. This technology should be differentiated from such processes as the 'Prest-o-log' technology of the United States, the 'Glomera' method in Switzerland and the 'Compress' method in West Germany (AGICO, 2011). At present, two main high pressure technologies (ram or piston press and screw extrusion machines) are used for briquetting. While the briquettes produced by a piston press are completely solid, screw press briquettes on the other hand have a concentric hole which gives better combustion characteristics due to a larger specific area. The screw press briquettes are also homogeneous and do not disintegrate easily. Having a high combustion rate, briquettes produced can substitute for coal in most applications and in boilers.

2.5.1 World Scenarios on Briquetting Technology

With an aim of improving the briquetting scene in India, the Indian Renewable Energy Development Agency (IREDA) - a finance granting agency - has financed many briquetting projects, all of which are using piston presses for briquetting purposes. But the fact remains that these are not being used efficiently because of their technical flaws and a lack of understanding of biomass characteristics (FAO-RWEDP, 1999). Initiatives such as holding meetings with entrepreneurs at different levels, providing technical back-up shells and educating entrepreneurs have to some extent helped some plants to achieve profitability and gives hope for a revival in the briquetting sector. Although briquetting has not created the necessary impact of creating confidence among entrepreneurs in other Asian countries, recent developments in technology have begun to stimulate their interest. In Indonesia, for instance, research and development works (R&D) have been undertaken by various universities, the national energy agency and various research institutes since the mid-seventies. So far, these have mainly focused on biomass conversion technologies. R&D works on biomass densification development are relatively rare. At present, densified biomass, particularly that which is not carbonized is not a popular fuel in Kenya.

The Philippine Department of Energy is currently promoting the development and widespread use of biomass resources by encouraging the pilot-testing, demonstration and commercial use of biomass combustion systems; as well as gasification and other systems for power, steam and heat generation (Hulfeng, 2010). There is a limited commercial production of biomass briquettes in Philippine. At present nine commercial firms produce amounts ranging from 1 ton/day to 50 tons/day. Briquettes are produced from sawdust, charcoal fines and/or rice husk. In the Philippines the conversion cost from biomass to briquette is very high (FAO-RWEDP, 1999).

In Sri Lanka, no briquetting projects have been implemented because of lack of exposure to the technology (FAO-RWEDP, 1999). But the prospects for substituting wood as a fuel are high because the traditional sector relies heavily on fuel wood. The tea industry is the largest firewood consumer whose supply is mainly from nearby rubber plantations or forests.

In Vietnam, people have been involved in briquetting but for limited use. The briquettes are basically used for heating/cooking purposes and this is limited to households. The present non-commercial energy, mainly from biomass fuel, shares a great part of the total energy supply. R&D efforts are being undertaken to make briquetting technology economically profitable and socially acceptable to the public so that it is eventually widely adopted (FAO-RWEDP, 1999)

India as a country has the briquetting sector which is growing gradually in spite of some failures. The most common types of machines used are the screw press and the piston type machines. As a result of a few successes and IREDA's promotional efforts, a number of entrepreneurs are confidently investing in biomass briquetting. These entrepreneurs are also making streneous efforts to improve both the production process and the technology (FAO-RWEDP, 1999).

Both national and international agencies have funded projects to improve the existing briquetting technology in India. The Indian Institute of Technology in Delhi in collaboration with the University of Twente in the Netherlands carried out researches to adapt the European screw press for use with Indian biomass (FAO-RWEDP, 1999). The two major impediments for the smooth working of the screw press is the high wear of the screw and the comparatively large specific power consumption required. This challenge has been overcome by incorporating biomass feed preheating into the production process. By this less energy is required to compress the biomass into fuel briquettes thus less wear of the screw press. The recent successes in briquetting technology and the growing number of entrepreneurs in the briquetting sector are evidence that biomass briquetting will emerge as a promising option for the new entrepreneurs and other users of biomass.

2.5.2 Briquette Technology in USA

In USA, Yard wastes were being thrown in the trash which eventually ended up in landfills. This potential source of energy almost brought to an end the larger problem of waste management in USA. The potential is also necessitated by the fact that an average American family receives 1.5 lbs of junk mail daily per year (Legacy Foundation, 2003). Tests done on the technology were carried out using a gardener chipper on trial basis. The machine built was a replica of a hand press, followed by training events in Ashland, Oregon. The quality of the briquettes produced by this process of combining junk mail and yard wastes was very promising for USA market. With its potential for use in the US now evident, two concerns with using junk mail for briquette production arose have been realized:

a) Toxicity: The burning of junk mail based briquettes posed the concern of gaseous emissions and residual ash. The question to be answered is whether the gaseous emissions and residual ash from the colored inks and dyes associated with junk mail present in sufficient quantities to pose a health or environmental hazard when the briquettes are burned In other words, do briquettes just convert a landfill ground water problem into an atmospheric one? Chromium and cadmium are used in the production of colored inks for printing and titanium is used as a whitener (Legacy Foundation, 2003).

b) Production technology: Hands-on slopping of soggy waste paper and leaves into a hand operated, seven foot- long, 200-pound wood-press, could hardly fit the lifestyles of a developed country like America. It also does make much sense to be running a 5-hp gasoline engine to grind up junk mail and yard wastes with the ostensible purpose of saving the environment. The use of junk mail with its rapid release of encapsulating fibres? makes it possible to bypass the need for large piles of decomposing yard wastes. The Legacy Foundation also found out that there was a need to develop a machine that will allow the briquette making process to be automated. For this idea to be incorporated into the American market, it must be scaled-up to a more efficient production capacity (Legacy Foundation, 2003).

2.5.3 The African Situation

The story of the adaptation of a technical innovation for the American market began in Africa in 1993. Two members of the Legacy Foundation were about to take assignment in Malawi, when a chance to review an article of by Dr. Ben Bryant caught their attention. The article described the processing of agricultural (agro-) residues into fuel briquettes for heating and cooking in the third world'. The rationale was based on presupposition that typical to many of the developing nations, 76% of the wood cut in Malawi was used for daily cooking and water heating. The maintenance of afforestation programs has a high recurrent cost leading to 'donor fatigue'. With no practical, affordable alternatives, and a population growth rate of 3.2% per year, the nation was experiencing rapidly increasing deforestation. The Foundation proceeded to adapt the fuel briquette making process to areas of stated need (FAO-RWEDEP, 2007).

In Kenya, two plants were installed; the earliest was the one of 1983, which utilized coffee husks for the production of briquettes and pellets for industrial boilers but also has a unit which produces charcoal from coffee-husks and then makes converts it into briquettes using molasses as a binder (Legacy Foundation, 2003). The industrial plants used a piston and a screw briquette and a large pelletizing plant whilst the char-briquette plant used a screw extrusion press (Legacy Foundation, 2003).

In Ghana, a plant that was installed operates successfully on wood residues based upon two Taiwanese screw-presses. The plant is fully commercial and sells its output to bakeries (FAO-RWEDP, 1999).

It is reported that at Diourbel in Senegal, there was a plant which produced pellets made from groundnut shells and are sold for fuel. However, the main use of the pelletizing plant is to manufacture cattle feed.

One of the paradoxes of the situation in Africa is that that much of the attention of reports about briquetting has been derived from plants in Africa which have largely been unsuccessful either technically or commercially (and sometimes both) whereas very little has been written about countries where the technique has had at least some limited success. This situation reflects one of the problems with briquetting plants in Africa, that is, they are conceived of as "projects undertaken by development agencies rather than businesses.

2.5.4 Challenges Facing Briquette Technology in Africa

In some situations where the plant is effectively free to the user, there has been evidence of provision of equipment whose operational power costs per unit of product are greater than the price of coal or fuel wood in local markets. It is also economically wrong to supply plant whose maintenance needs cannot be supplied locally and which require frequent visits by overseas engineers if the plant is to be kept going. Second, there is a clear "guinea-pig" character to many of the plants in Africa; that is they have been installed as pilot-plants to test new techniques or types of product (Legacy Foundation, 2003). There is nothing wrong in principle with this; new ideas, particularly those which are a break with existing practices in Europe or the U.S.A., have to try out in practical operation. However, such plants have to be installed as test-beds and given appropriate support and monitoring, neither of which has been forthcoming. It is also important for expectations not be raised too high since failure may produce demoralization. These two issues are mirrors of each other: in the first case, existing and sophisticated plant is unloaded on to users who cannot utilize it and in the second, untried "appropriate" technology is presented as a proven technique. The third problem is simply lack of good information by plant buyers about the range of alternative products. This is a common problem not confined to briquetting machinery but has also led to the installation of plant which could probably be improved on. It is difficult, for example, to believe that it was the best choice to buy a machine for use in Ethiopia which depended upon an imported binder particularly when its raw-material, that is, sawdust, can easily be briquetted by binderless techniques.

2.5.5 Briquette Technology in Kenya

Kenya has a large potential of fuel briquette production given the extent of various raw materials found in different parts of the country. These materials stem from agro industrial and timber industry wastes. The exact method of preparation depends upon the material that is being briquetted as illustrated in the following three cases of compressing bagasse, sawdust and organic urban waste into cooking briquettes.

The process of industrial briquettes production from agri-business wastes involves (Legacy Foundation, 2003):

i) Carbonization of the wastes using the fluidized bed process to produce char dust from the agro-wastes

ii) Feeding the char dust into a mixer where water and a binder mixed together before being fed into an extruder. The most common binding agents are gum Arabica, starch, clay, and animal dung.

iii) The mixture of the char dust, water and a binding agent is then fed into an extruder and compressed making fuel briquettes ready for drying.

iv) The briquettes are then aired to allow them to dry. This will take between three days to fourteen days depending on the weather. This is according to the earlier briquette survey findings.

2.5.6 Fuel Briquettes from Bagasse

Table 2.1 Yearly tonnage of bagasse at Nzoia Sugar Company

Year	Harvested Area (ha)	Fibre % Cane	Cane Milled (Tons)	Estimated Bagasse (tons)	Est. Used Bagasse (tons)	Excess Bagasse (tons)
1995	6134.7	17.6	424427.3	74571.9	51805.6	22766.3
1996	3747.2	18.3	306438.7	56078.3	39640.9	16437.4
1997	5579.6	18.3	453618.5	82966.8	58634.7	24332.1
1998	5697.7	17.7	471135.4	83249.6	57977.9	25271.7
1999	9192.4	17.2	602528.3	103755.4	71435.8	32319.6
2000	6919.1	16.6	320421.4	53157.9	35970.5	17187.4

(Kibwage, 2003)

Surplus bagasse presents a disposal problem for many sugar factories in western Kenya. For example, the average tonnage of excess bagasse produced per year in Nzoia Sugar factory is over 24000 tonnes. Using a bagasse-to-briquette conversion ratio of 5:1, Nzoia could produce 4845 tonnes of bagasse charcoal briquettes (Keya *et al*., 2000). The pilot briquetting technology remains simple, applicable and of benefit to surrounding communities due to its low cost production that competes with wood.

When making carbonized briquettes from bagasse, the bagasse is fed into a fluidized bed carbonizer where char dust is produced. The dust is mixed with an appropriate binder which can either be gum Arabica or starch. The mixture is then fed into a hopper which compresses the material to give briquettes before being aired and ready to be used once dry.

Fig 2.5: Carbonized bagasse briquettes

Fig 2.5: Carbonized bagasse briquettes

Fig 2.6: Fuel briquettes making from agro-based wastes, carbonized bagasse included

2.5.7 Fuel Briquettes from Sawdust

Sawdust is a waste material from all types of primary and secondary wood processing. Between 10 and 13% (Kibwage, 2003) of a log is reduced to sawdust in milling operations. Sawdust is bulky, and is therefore expensive to store and transport. The calorific value of sawdust is as low as 17kJ/g such that briquetting becomes an ideal for reducing the bulk, increasing the density, and increase the calorific value. The process of making fuel briquettes from sawdust involves compressing the sawdust at a high pressure and heat. This causes a self-binding effect for the sawdust.

In some cases, sawdust briquettes have been formed under sufficiently high pressure to produce cohesion between wood particles. The lignin softens and binds the briquette so that no additional binder is required. The advantages of producing sawdust fuel briquettes include:

The price of sawdust fuel briquettes is about the same as that of fuelwood but is much more convenient to use as they do not require further cutting and chopping. It has been discovered that they burn very well in any kind of solid fuel stove and boiler (Kibwage, 2003). Briquettes have also been found to ignite quickly and burn cleanly, producing only 1% to 6 % ash. In addition, briquettes don't contain sulphur and burn without producing odour. In terms of energy content, the burning of 1 kg of sawdust fuel briquettes produces 18000 kJ of energy, roughly equivalent to that of medium quality coal; a briquette plant may also be profitably integrated into larger sawmilling operations (Kibwage, 2003)

Due to present limitations of equipment currently available in Kenya, locally-produced sawdust briquettes have suboptimal densities which cause incomplete burn and excess smoke (Kibwage, 2003). In Kenya there exist an enormous potential for producing fuel briquettes from saw dust wastes. The heaps of saw dusts are huge as evidence in the photo caption in Fig 2.7


ENVIRONMENT

Sawdust new threat to Rift Valley lak

Almost eight years since sawmills in Molo and Elburgon shut down as a result of the logging ban, little hills of sawdust still stand defiantly in the area, reminding residents and visitors alike of the once thriving timber industry that is no more.

The little hills seem intact at a glance but residents say strong winds blow away the loose sawdust onto paths and roads where it is washed by floods into rivers.

The effect of the amount of sawdust being washed into the rivers for now appears insignificant but the enormity of the level of pollution will certainly be felt when the sawdust hills are gone and all the sawdust has settled in lakes.

Prior to the logging ban, Rift Valley Province had 221 sawmills, most of them using the old circular saws that generated a lot of sawdust.

By 1995, Nakuru District had 64 sawmills – the highest in the province, followed by Kericho 35, Koibatek 27, Laikipia 23, Uasin Gishu 20, Keiyo 19, Trans Nzoia 13 and Baringo 8.

Some millers initially burnt the sawdust, but the endless smoke (because sawdust burns slowly for days and even months) dis-

Mountains of sawdust are a common sight in Molo, Turi and Elburgon in Nakuru District and pose a danger to the environment
– PHOTOS / JOSEPH KIHERI.

sites including road reserves. Other sawmillers dumped it within the timber yards.

The locals collected off-cuts and shorts from the sawmills for their fuel and generally ignored sawdust.

The idea of making charcoal bra-

charcoal."

Mr Opiyo said that boarding schools and hospitals could also use sawdust to heat water if they acquired large-sized braziers designed to use sawdust.

Mr Opiyo proposed the establish-

Fig 2.7: Heaps of sawdust threatening the Rift Valley lakes (Kibwage, 2003).

2.5.8 Fuel briquettes from urban waste

Solid waste disposal is one of the most serious urban environmental problems in developing countries. In Kenya, municipal authorities collect and dispose less than 40% of these wastes. This failure is attributed to inadequate resource mobilization, over-reliance on imported equipment, use of inappropriate technology, lack of public awareness on waste management, absence of sufficient capacity for waste processing and recycling, and non-implementation of environmental laws pertaining to waste disposal (Kibwage, 2003). Open or crude dumping is the most common method used by municipal authorities. Waste poses a health hazard when it lies scattered in the streets and at the dumping sites. It is now an accepted environmental philosophy that wastes have value and should be utilized based on the four “R”s “Reduce, Reuse, Recover and Recycle”. Through recycling, urban wastes are transformed into useful products (Legacy Foundation, 2003). Waste paper and leaves, in particular, provide a potentially important, alternative source of cooking fuel.

According to the briquette technology survey, briquette technology started back in early 1980’s in the country as an alternative fuel to oil following high price hikes by OPEC. The earliest successful briquetting plant was the coffee husk, which produced carbonized briquette from coffee husks. This technology has not been able to permeate in the rural and the marginalized Peri-urban communities, and therefore it has remained at the commercial level.

Legacy foundation based in the USA developed the technology of making raw briquettes (uncarbonized) from small particle biomass as a way of utilizing abundant biomass waste among the rural and marginalized communities. Mostly the briquettes are produced by a piston-type wooden machine that produces four-inch diameter briquettes, but the size could be increased or reduced according to the desire of the producer, by changing the size of the feeding pipe (Legacy Foundation, 2003).

CHAPTER 3: METHODOLOGY

3.1 Overview

This chapter outlines the methodology used to achieve the research objectives. This included carrying out of field surveys to determine the adoption and penetration of biomass briquette technology and the laboratory characterization of fuel briquettes. Design, construction and testing procedures of a semi- gasifier briquette stove are also given. Finally the chapter gives the testing, data collection and data analysis procedures.

3.2 Study Area

The area covered by the study was Nairobi and the surrounding suburbs of Kiambu which is about coordinates 1.10°S 36. 49°E / 1.16°S 36.82°E, Machakos at coordinates 1.31°S 37.61°E / 1.51°S 37.26°E / -1.517; 37.267, Kajiado at coordinates 01.51°S 36.46°E / 1.85°S 36.78°E and Limuru at coordinates 1.06°S 36.39°E / 1.1°S 36.65°E. The study area shown in fig 3.1

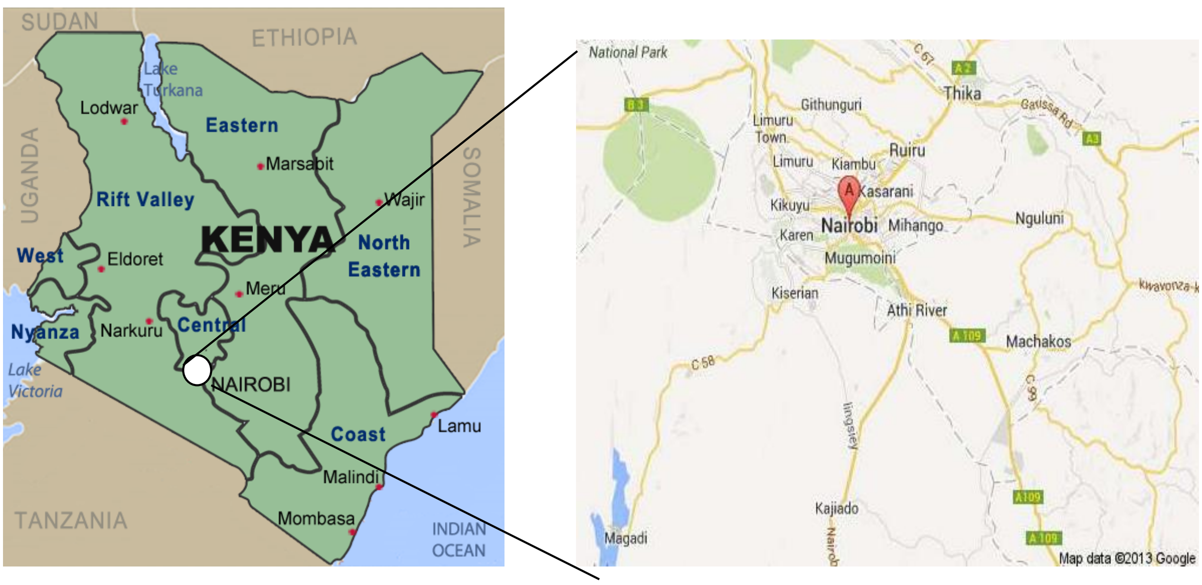

Fig 3.1: A Map of Kenya showing the study area

Briquette technology survey was conducted within Nairobi and surrounding areas. Survey information was gathered from briquette developers and vendors who consisted of self help groups & community groups, NGOs and large scale briquette producers who have automated their briquette production. As outlined in (David and Robert, 1967) methodology, a total sample of 63 producers were identified from a total of 68 number of recorded briquetted prducers and interviewed within the project study area. After every interview with the individual producers, samples of their briquettes were picked and labeled accordingly for laboratory analysis as outlined in (CDC, 2008) sampling methodology.

3.3 Study Design

A total of 63 briquettes production stakeholders were identified from documented reports and write-ups on briquette technology in Kenya. These stakeholders were categorized into three groups depending on the nature of their organizations: Self help/community groups, NGOs and large scale fuel briquettes producers. For each category, a sample size of 40, 8 and 15 were identified, that is vendors for the Self help, NGO and large scale producers with automated production line, respectively. This resulted to a total 63 interviewees in the category of self help groups, NGOs and large scale briquettes producers according to (CDC, 2008) survey producers. Each of the briquette producer interviewed was requested to name at least 5 of her customers this help in indentify frequent briquette consumers for purposes of interviewing them.

3.3.1 Research Instrument and Evaluation

The main tools and instrument for data collection were questionnaires (see Appendix A). The questionnaire was designed and administered to the briquettes manufactures to investigate the following: Type of the organization, knowledge base of the briquetting technology, source and type of the raw materials used, production process and marketing strategy of the briquettes. Other parameters investigated included: Age of consumers, gender, marital status, briquette expenditures, quality and the type of briquettes used.

3.3.2 Logistics and Field Survey

The identified briquette producers were contacted and field meetings were planned to discuss the pertinent issues concerning the survey. During this time the briquetted consumers were also interviewed. After each interview biomass briquette samples were collected and taken for laboratory analysis

3.4 Sampling Procedure

From desk research a total of 6 briquette producers and vendors had been identified to be in operation in Nairobi. All the identified 68 fuel briquette producers/ stakeholders were grouped into three based on the type of organization in briquette production. These were: Self help/community groups, NGO and large companies. The sample sizes were identified according to(CDC 2008) and recorded as shown in table 3.2:

Table 3.2: Sampled organizations

Type of Organization/Stakeholders	**Recorded number of groups in operation**	**Sample Size**
Selfhelp/ community group	45	40
NGO	8	8
Large Scale briquette producers	15	15

Once the sample sizes had been identified as shown in Table 3.2, the sample size of briquette consumers for each group was carried in such a way that 5 customers were identified from each briquette producer yielding a total of 315 consumers, which were assigned numbers 1-315. Using the Stat Trek random number generators (Stat Trek, 2010), a sample size of 175 (David and Robert, 1967) was randomly generated for interview purposes.

3.5 Personnel and Training

Three research assistants were recruited and taken through the field survey protocols and research tools. Testing of the tools was conducted, feedback gathered and final questionnaire developed within three days as recommended by (CDC, 2008).

3.6 Collection of Biomass Briquettes Samples

Out of the 63 samples of briquettes collected from the 63 briquette producers, only 10 different samples were identified, the rest looked similar. The 10 indentified samples were taken for laboratory analysis. The samples provided a representation of briquetting technology, viability and availability of materials within Nairobi and its environs. This would enhance comparison of the biomass fuel briquettes as an alternative fuel, to other common fuels, i.e. fuel wood, charcoal and kerosene.

3.7 Questionnaire Data Analysis

Once the questionnaires had fully been filled, the information was extracted and entered in an excel spreadsheet. The data collected was grouped based on Self help/community groups, NGO and large companies as proposed by data analysis methodology for (CDC, 2008). Data was analyzed using excel spread sheet to obtain the mean, maximum and minimum values. Descriptive statistics was used to present the results (CDC, 2008).

3.8 Determining of Physical and Chemical Properties of Biomass Biquettes Sample

3.8.1 Calorific Value of Biomass Briquettes

The calorific value of the briquettes was determined using the bomb calorimeter method (Electra Energy, 2011). The experiments were conducted at University of Nairobi Department of Chemistry Laboratory from the 15th of November to 30th November, 2010. The equipment shown in Fig 3.2 and 3.3 shows equipment set for the experiment.

Fig 3.2: Setup for the bomb calorimeter

Fig 3.3: Weighing of fuel briquettes

i) A 450g of sun-dried biomass fuel briquettes, (Mf_{b}) weight using a digital weighing balance of model Stanton St01 made in Great Britain with accuracy of 0.1g. The weighed sample was then loaded to a Ballistic Bomb Calorimeter, model GallenKamp made in Great Britain.

ii) 1700g of water, M_{wa}, was weighed using the digital weighing scale of accuracy 0.1g and then placed in a bomb calorimeter.

iii) The ambient temperature of the water in the bomb calorimeter was recorded, T_a.

iv) The briquette and samples then completely burnt in the bomb calorimeter and heat released to heat water in the calorimeter the final temperature of water, (M_{wb}) was then recorded .

The above procedure was repeated three times for each of the 10 samples collected. The test results are provided in Table 4.2 in chapter 4.

The average gross calorific value of the biomass briquettes samples were was obtained using equation 3.1 as follows:

$$Cf_b = \frac{\{ M_w \times 4.2(T_b - T_a) \} + M_{ev} \times LH_{vw}}{Mf_b}$$

(3.1)

(Electra Energy, 2011)

3.8.2 Percentage Moisture Content of Briquettes

The dried briquettes samples were weighed using the digital weighing balance model Stanton St01 of Great Britain with accuracy of 0.1g. The briquettes were then subjected to oven drying with the temperature set at 110^o C until no further change in weighed could be recorded. The percentage moisture content was then calculated using the equation 3.2 below.

$$\%_{mc} = \frac{M_{ad} - M_{\text{mod}}}{M_{mad}} \text{ x } 100 \quad (3.2)$$

(Leco Corporation, 2011)

Where :

M_{ad} is mass of air dried briquettes

M_{mod} is the mass of oven dried briquettes

3.8.3 Volatile Matter of Briquettes

The percentage of volatile matter was determined according to the procedure given by (Leco Corporation, 2011) whereby mass of oven dried briquettes were determined and recorded. The briquettes were then subjected to devolatization using an aluminium pan of capacity 5 litres and 2mm thickness to act as a devotalizer. Here the briquettes were put on a pan and subjected to heat provided by charcoal on a KCJ, until one could see the briquettes become fully black and no further volatile matter emitted then they were weighed. The equation below was then used to calculate the volatile matter of the briquettes.

$$\%_{vm} = \frac{M_{od} - M_{dev}}{M_{od}} \text{ x } 100 \qquad (3.3)$$

(Leco Corporation, 2011)

Where

M_{od} is the mass if oven dry briquettes

M_{dev} is the mass of briquettes after devolatizaton

3.8.4 Percentage Ash Content

Samples of various briquettes with an average weight ranging from 1700g to 7000g as recorded in Table 4.5 were loaded onto an aluminium pan of diameter 12cm and thickness of 2mm. The pan was then placed on a standard KCJ stove measuring 15cm diameter combustion chamber with power output of 1300±700W (Nordica M, Damon O, Dean S, *et al* (2007). This went on until the briquettes were fully charred into ash. The process took between 20 minutes to 3 hours depending on the type of briquettes. Once fully charring of briquettes to ash was completed, the ash left on the aluminium pan was weighed using weighing balance model Stanton St01 made in Great Britain and recorded. The tests were repeated three times for each type of briquette and the average recorded (Leco Corporation, 2011). The percentage ash content of the briquettes was then computed using equation 3.4:

$$\%_{ac} = \frac{M_{ash}}{M_{cb}} \text{ x } 100 \qquad (3.4)$$

(Sluter *et al*, 2008)

Where

M_{ash} is the mass of ash after fully charring

M_{cb} mass of oven dried briquettes before charring

3.8.5 Percentage Breakability of Briquettes

Percentage breakability test was done according to (Leco Corporation, 2011) whereby a mass of briquettes weighing between 17g and 356g was put in plastic bags. From a height of 2m, each packet of briquettes was dropped for 10 times on a concrete surface. The mass of all uncompleted briquettes were measured and % of breakage determined using the equation below

$$\%_{b} = \frac{M_{ib}}{M_{ab}} \text{ x } 100 \qquad (3.5)$$

(Sluter *et al*, 2008)

Where:

M_{ib} is the mass of incomplete briquettes after the drop test

M_{ab} of air dried briquettes

3.8.6 Ignition and Burning Characteristics of Biomass Briquettes

Each type of the sampled briquettes weighing 500g was lit in an open fire. The time taken to fully ignite and to burn completely was noted and recorded. During the process, the smokiness and colour of the flame was noted through observation (Energypedia, 2012)

3.9 Design of a Semi-gasifier

The Ministry of Energy records show that a typical family in Kenya uses 3394kg of wood for cooking in a year (Ministry of Energy Kenya, 2010). This translates to 9.3kg of wood per day and 3.1kg of wood fuel per meal. Therefore the amount of energy required for cooking a common meal can be given by equations 3.6 to 3.8 (Belonio, 2005):

1. The quantity of energy required to cook a meal will be given by:

$$Q_n = C_f \text{ x } M_f \text{ x } E_s \qquad (3.6)$$

Where

Q_n is the useful energy needed to cook a meal

C_f if the specific capacity of fuel used

M_f is the mass of fuel burnt

E_s is the thermal efficiency of the stove device

Where 3.1 kg of wood of an average 18MJ/kg is consumed per meal on open fire of 14% thermal efficiency (Grant Ballard-Tremeer *et al*, 2010). Thus 18 x 3.1 x 0.14 giving 7.81MJ of energy

2. Amount of fuel needed in cooking as expressed will be given by:

$$FC = \frac{Q_n}{HV_f \text{ x } g} \qquad (3.7)$$

Working with the heating value of briquettes at 16.8MJ/kg (Legacy Foundation, 2003) and design efficiency of the stove to be 30%.- substituting in the above equation gives

$$FC = 7.25/ (16.8x.30) = 1.55 \text{ kg of briquettes} \qquad (3.8)$$

Final design of the stove is shown in Fig 3.10 and in Appendix 2 as a technical drawing.

3.9.1 Construction Procedure for Semi-gasification Stove

The stove was fabricated at Kenyatta University science workshop from January 2009 to December 2009. The testing was done at the Department of Energy Engineering workshops and laboratories at Kenyatta University between January 2010 and December 2010.

The construction of the stove involved the construction of the mould to be used in the fabrication of the stove's insulation. The outer metallic housing of the stove was made from the mild steel sheet and joined by welding.

3.10 Thermal Performance of Semi-gasifier Stove

The stove performance was evaluated by determining the following parameters:

i) Efficiency

ii) Stove power

iii) Specific fuel Consumption

iv) Stove emission levels

Fig 3.4 shows the setup which was done when measuring stove performance

Fig 3.4: Photo showing the water boiling test

The procedure for determining the parameters are described in the section that follows:

3.10.1 Thermal Efficiency (*η*)

Thermal efficiency was determined using the standard water boiling test (Bailis *et al*, 2005), where the thermal efficiency of the stove was determined in three phases:

i) High power cold start

In the first phase of the cold-start high-power test, the stove was at room temperature. Using a digital weighing balance of model Stanton St01 made in Great Britain with accuracy of 0.1g, different bundle of briquettes were weighed so as to boil a measured quantity of water in a 5 litres cooking pan. The boiled water was then replaced with cold water to perform the second phase of the test. The different amounts of water heated, time taken, and type of briquettes used were recorded as shown in Appendix c

ii) High power cold start

The second phase, the hot-start high-power test, followed immediately after the first test while stove was still hot. Again, a different pre-weighed bundle of briquettes was used to boil a measured quantity of water in a standard pot. The weight of briquettes and water used were recorded as shown in Appendix C. Repeating the test with a hot stove helped to identify differences in performance between a when a stove is cold and when it is hot.

iii) Simmer stage

The third phase followed immediately after the second. Here, the amount of fuel briquettes required to simmer measured amount of water at just below boiling for 45 minutes was determined. The amount of briquettes used and water simmered was recorded as shown in Appendix c. This step simulated the long cooking of legumes or pulses common throughout most places in the world.

This combination of tests measured some aspects of the stove's performance at both high and low power outputs, which are associated with the stove's ability to conserve fuel (Rob and Damon et *al*, 2007). Thermal efficiency of the stove for the high power and low power were computed using equations 3.9, 3.10 and 3.11:

$$h = \frac{\left\{\left(Mw_i \times \left(Tw_b - Tw_a\right)0.0042\right) + \left(2.26 \times \left(Mw_i - Mw_f\right)\right)\right\}}{\left(Mf_i - Mf_f\right) \times NCV_{fuel}} \qquad (3.9)$$

(Rob and Damon *et al*, 2007)

The efficiency of the stove during simmering stage was given by the equation:

$$\eta_s = \frac{\left\{2.26 \times \left(\mathrm{Mw_i} - \mathrm{Mw_f}\right)\right\}}{\left\{\left(\mathrm{Mf_i} - \mathrm{Mf_f}\right) \times \mathrm{NCV_f}\right\}} \qquad (3.10)$$

(Rob and Damon *et al*, 2007)

Where:

2.26– is the latent heat of vaporization of water in MJ/kg

The overall efficiency of the stove was given by equation below:

$$\eta_o = \frac{\eta_c + \eta_w + \eta_s}{3} \qquad (3.11)$$

(Rob and Damon et *al*, 2007)

Three tests for each stage, that is, cold, warm and simmering were conducted on the stove using fuel type, wood fuel, paper, sawdust and leave-type briquettes. The results were as recorded in Appendix c

3.10.2 Stove Delivery Power (*P*)

The power of the semi- gasifier stove is given by the equation:

$$P\ (kW) = \frac{M_w \times 4.2 \times (T_{wb} - T_{wi})}{t} \quad (3.12)$$

(Rob and Damon et *al*, 2007)

3.10.3 Stove Specific Fuel Consumption (*SFC*)

This characteristic of the stove is aimed at establishing the amount of fuel needed to heat one litre of water from room temperature to boiling point. This is given by the equation 3.13:

$$Sfc = \frac{Mf}{Lw} \quad (3.13)$$

(Rob and Damon et *al*, 2007)

3.10.4 Emission Testing of Semi-gasifier Stove

The emission of the stove was determined by using KANE 445 flue gas analyser during the water boiling test. Three trials were carried out and the results averaged. The results were as presented in Appendix C. The tests were carried out by getting a sample of the emission using a probe from the hood as shown in figure 3.13 (Bond, 2004):

Figure 3.5: Photo showing emission testing of the semi-gasifier stove

3.11 Economic Analysis of the Briquette Semi-gasifier Stove

The economic analysis of the semi- gasifier stove was done by a simple cost savings analysis based on when a family moves from using open fire, charcoal and kerosene modes of cooking to using the semi-gasifier stove for the a period of 4 years (Helga, 1999).

3.11.1 A Simple payback

Simple payback period was computed by using the equation below,

$$PpR = \frac{C - CtrS}{St} \qquad (3.14)$$

(Helga, 1999)

Where P_pR is the simple payback period in years.

C is the cost of the new cooking stove in US dollars.

CtrS is the cost of the baseline stove in US dollars.

S_t saving in expenditure in fuel for moving from the baseline stove to the new stove.

3.11.2 Benefit Analysis of the New Stove

This was computed using the following equation:

$$Nt = \frac{St}{\sum Ct} \qquad (3.15)$$

(Helga, 1999)

Where N_t is the net benefit of the stove.

St is the savings in the fuel by the new stove during lifespan of the stove.

$\sum Ct$ summation of costs related with the use of the stove during its.

3.11.3 Rate of Return for the Stove

This was computed using the following equation:

$$R = \frac{Nt}{\sum Cj} \qquad (3.16)$$

(Helga, 1999)

Where R is the rate of return for acquiring a new stove.

N_t is the net benefit of the stove.

C_j is the expenditure on the stove during the stove lifespan.

3.12 Data Analysis

3.12.1Field Survey Analysis

Qualitative data obtained from the field survey was processed using excel and SPSS packages and presented in descriptive form. Quantitative data was presented using excel spreadsheet and represented in tabular, bar graphs and pie charts formats. Pictorial data was presented in the same pictorial format with descriptive presentation accompanying the data (CDC, 2008)

3.12.2 Properties Determination of Biomass Briquettes Analysis

Qualitative data was presented in descriptive, pictorial and tabular formats while quantitative data was analyzed using excel spreadsheets and presented in tabular and graphical formats in Tables 4.3, 4.4, 4.5, 4.6 and 4.7 in chapter 4 (CDC, 2008)

3.12.3 Analysis of Thermal Performance of Semi-gasifier Stove

Data gathered was analyzed using Rob and Damon et *al*, (2007) software via excel sheet. The parameters for various tests were entered into excell spreadsheet and the outcome presented in tabular and graphical formats as shown in tables 4.8 and 4.9 in chapter 4.

3.12.4 Emission Testing of Semi-gasifier Stove

The KANE 445 flue gas analyzer has inbuilt software that receives and analyzes CO, CO_2 levels and CO/CO_2 values and presents them in a tabular format. The results were extracted and presented in a tabular format as shown in Table 4.10, chapter 4

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Overview

In order to design efficient briquette stove, it is necessary to have an understanding of the briquette making process and the raw materials used and their physical and chemical characteristics of the briquettes. This chapter presents results of both the field surveys and the semi-gasifier stove test performance. The results of the field surveys covers baseline survey information majorly on penetration of the technology, organizations involved in briquette technology and the age distribution of those involved in briquette making. Moreover, information on the survey are on the raw material used and their respective ratios was also established. This chapter also presents the results of sampled briquettes characterization including calorific value, moisture content, percentage volatile matter, ash content, and breakability of briquettes characteristics.

4.1.1 Baseline Survey

Ten samples that were identified from the field included Carbonized bagasse with molasses binder from Mumias sugar, Tree leaves with waste paper binder from Miumbuni Women Group in Machakos/Makueni district, Carbonized Rice husks with paper binder from Mwea milling mills-Mwea, water hyacinth, Tree leaves with gum arabica from Terra Nouva groups-Dagoreti Nairobi, charcoal dust with clay binder from Kangema in Kiambu, charcoal dust mixed with waste paper and clay binder from NAFE, Women with a Vision in Nairobi, charcoal dust mixed with bean stalks and waste paper from Onyonii Youth group, Kabete in Kiambu, Coffee husks mixed with waste paper which is a UN Habitat in Dandora Youth Group in Nairobi and coffee husks with rice starch binder for KPCU Dandora in Muranga/Kiambu/Nairobi.

The field survey showed that 54% of the briquettes making businesses are concentrated in urban and peri-urban areas of Nairobi because such centres generate huge industrial and domestic solid waste. Lack of access to alternative cooking fuel in addition to the high cost of kerosene and LPG has encouraged penetration of biomass briquette technology. Figure 4.1 shows the distribution of briquettes vendors in Nairobi and surrounding.

Fig.4.1: Distribution of briquette vendors in Nairobi and surrounding towns

The survey also showed that majority of the briquette fabricators and sellers were the community based organizations (CBO) and self help groups accounting for 46% which were founded by briquette expert or consultants such as Stanley of Legacy Foundation (Legacy, 2003). Fig 4.2 shows the types of organizations involved in briquette production in Nairobi and surrounding suburbs.

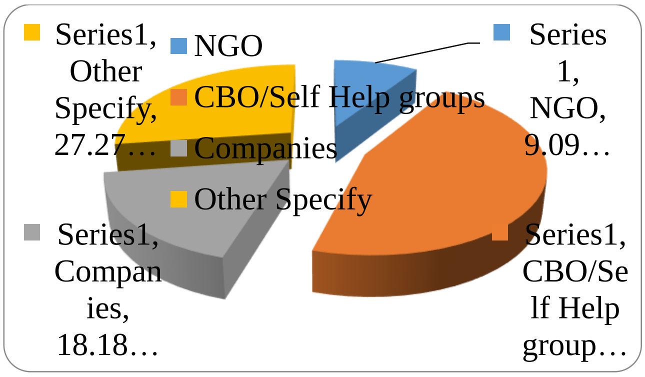

Figure 4.2: Types of organizations involved in Briquette making in Nairobi its environs

Briquette Technology was found to be more common in Nairobi and its surrounding environment. This can be attributed to high rate of biomass deficit in Nairobi which was reported to be 99.1% (Mugo and Gathui, 2010), thus the need for affordable alternative to fuel wood. The 27% represented by “others” in figure 4.2 were education institutions, fish vendors and small food vendors.

Legacy foundation have made a lot of efforts to promote briquette technology by introducing to through community based organizations and self help groups, explains why the technology is more common with CBOs and Self Help groups in Nairobi. Majority of the CBOs and self-help groups used the wooden piston press which is the design introduced and promoted by Legacy Foundation.

On the age distribution of briquettes vendors, it was found out that the majority were aged between 4 and 50 as shown in figure 4.3. Most of them were self employed and rely on briquette making for a livelihood

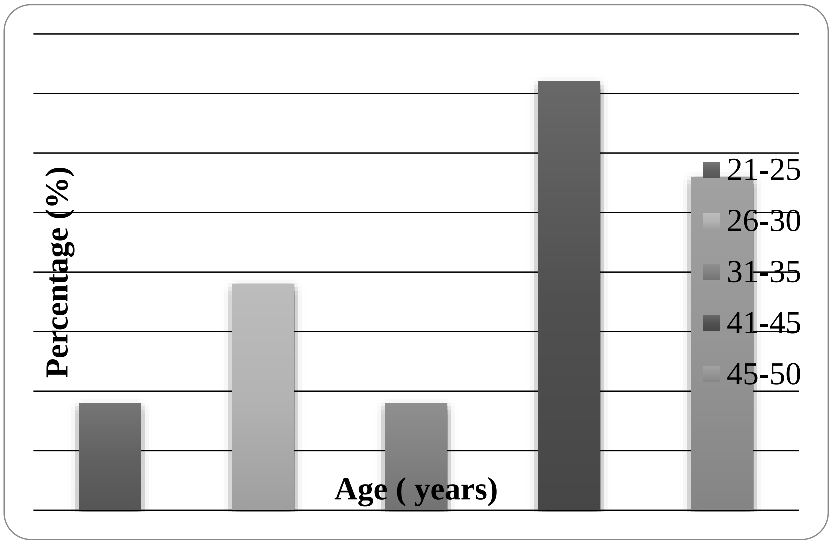

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Figure 4.3: Demographic distribution of vendors in Nairobi and surrounding towns

About 56% of the respondents interviewed indicated that they learnt briquetting technology from Legacy Foundationt. About 43% informants' briquette fabricators used piston briquette press while 30% used screw briquette press. Piston press was used because it was affordable and simple to operate. The machine also had a high production capacity of averagely 700 briquettes (140kg) per day.

Figure 4.4 show the range in number of briquettes produced per day, 44% of the respondents produced between 100-500 (20-100kg) briquettes per day, 22% produced between 600-1000 (120-200kg) briquettes, 14% produced between 1100 (220kg) and 1500 (300kg) briquettes while 17% producing more than 2000 (400kg) briquettes per day. The figure 4.4 shows the production of biomass briquettes by various groups.

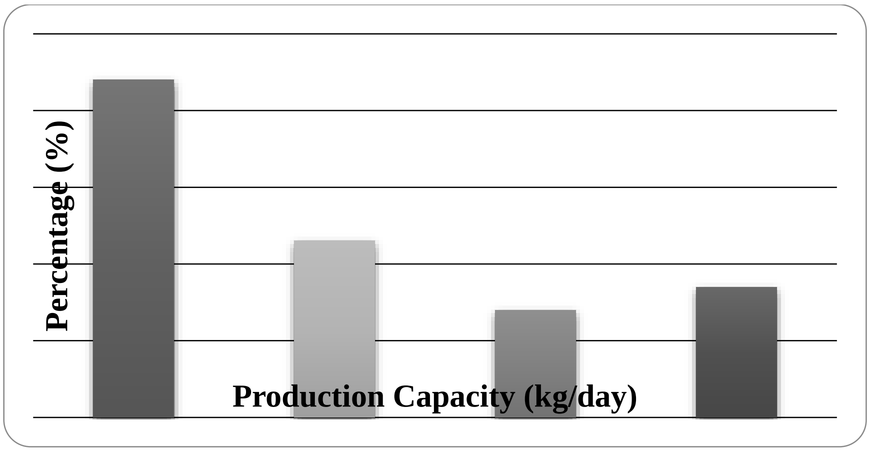

Figure 4.4: Production of briquettes per day

4.1.2 Raw Materials for Briquette Production

This research study found out that the most commonly used raw materials for biomass briquetting varied from agri-based materials such as beans stalks, potato peelings, bagasse and coffee husks; urban waste materials such as waste paper, and charcoal dust; agro-forestry and forests materials such saw dust and dead tree leaves. The respondents also provided their best preferred raw materials for making briquettes and various ratios as summarized in Table 4.1. In making these briquettes, water was added to the mixture to allow proper pounding before being pressed to form high density briquettes. On average, the amount of water added ranged between 2% and 3%, by weight, depending on the type of the material

Table 4.1: Different raw materials with various ratios for making fuel briquettes

S/N	Raw Materials	Ratio (for 100kg mixture)	Vendor	Co-ordinates	Binder
1	Charcoal dust + clay+ waste paper	69:7:24	Women with Vision group, Nairobi	1.25°S, 36.66° E	Clay and waste paper acts as a binding agent
2	Coffee husks + waste paper	59:41	Dandora Youth group, Nairobi	1.25°S, 36.90° E	Waste paper is the binding agent
3	Charcoal dust+ Bean stalks + Waste Paper	39:20:41	Onyonii Youth group, Kabete-Kiambu	1.26°S, 36.71° E	Paper is the binding agent
4	Tree leaves + Waste paper	59:41	Miumbuni Women group in Machakos	1.51°S, 37.26° E	Waste paper is the binder
5	Charcoal dust + clay	95:5	Kangema women group, Kiambu	0.41°S 36.58°E	Clay is used as a binding agent
6	Carbonised coffee husks + starch binder	95:5	CharDust Ltd, Karen-Nairobi	1.22ºN 36.43ºE	Starch as the binder
7	Carbonized Sugar baggasse + molasses	97:3	St Deborah Secondary	0.33°N, 34.48° E	Carbonized baggasse was achieved using fluidized bed carbonizer
8	Water hyacinth	100	Dagoreti youth grounp	0.10°S, 34.75° E	No binder needed
9	Carbonized rice husks + waste Paper	71:29	Mwea Mills	0.49°S 37.37°E	The rice husk carbonized using fluidized bed carbonizer
10	Tree Leaves + gum arabica	96:4	Terra Nouva groups, Dagoreti	1.30° S, 36.76° E	Gum Arabica is one of the best binders

Source: Field Survey

The choice of a particular raw material was based on several factors such as local availability, burning characteristics of the fabricated briquettes, and expertise and vendors. The raw materials for making briquettes were sourced from various places with majority of respondents sourcing their raw materials from solid waste dumping sites in the urban areas. Other biomass waste sources included offices wastes, super markets and local waste material dealers. Paper was the most utilized binder due to its availability as waste in Nairobi and its peri-urban areas.

The biomass briquette vendors faced many challenges in terms of sourcing their raw materials, include high transportation costs, uncertainty on the continued supply of wastes, lack of appropriate drying and storage facilities, and lack of protective clothing to handle waste materials exposing the briquette fabricators to health risks.

4.1.3 Briquette Making Process

Briquette making process involved grinding or pounding the materials and mixing it with binders and water. The mixture was then pressed in briquette pressing machines. One example of pressing machine is shown in Fig4.5, where Fig4.6 shows readymade briquettes being dried in sun.

The binders used in briquette making included clay soil, waste paper, molasses and gum Arabica. The gum Arabica was obtained from acacia trees, and is shown in Fig 4.7

Fig 4.5: Wooden briquette making machine

Fig 4.6: Briquettes being sun-dried

Fig 4.7: Gum Arabica used as a binder for making biomass fuel briquettes

The study found out that about 82% of the fuel briquette fabricators studied used manual briquette machine presses.. The Results by Legacy foundation showed that 84% of the women in *Ukambani* used manual press machine and 12% did the mixing using their own hands. Only

4% used electricity (Legacy Foundation, 2003). This compares well with results from the survey done in this study.

4.1.4 Quality of Briquettes Produced in Kenya

The quality of briquettes produced was determined mainly by their burning characteristics and breakability. The survey showed that briquettes it took 20min for briquettes made from waste paper to be fully burnt while up to 90min for briquettes made from tree leaves. 29% of the respondents said their briquettes produced smoke when used for cooking, while 20% of them indicated that the briquettes produced no smoke when used for cooking. The study also found out that 72% of briquettes produced were structurally strong enough to withstand impact while being transported. The burning time depended on constituents of biomass materials of the briquettes. Briquettes with highest percentage of paper lasted the least time while briquettes made of charcoal dust and clay took the longest time to fully burn down as summarized in table 4.7. This gives consumers a wide variety of the type of briquettes to select from depending on their mode of cooking. Consumers who wished to have a quick and high power cooking would then prefer paper briquettes. For those who preferred a longer time of cooking that required low power, charcoal dust with clay were the preferred briquettes. Fragility among the briquettes especially during transportation and handling was as low as 18% while smokiness of the briquettes was 29%. This implies that biomass briquette was the best alternatives for the Nairobi urban poor. The above findings compared well with laboratory tests on quality of briquettes in section 4.2.

4.2 Physical and Chemical Properties of Briquettes

The calorific value of various briquettes obtained using the methodology described in section 3.4.1 are presented in table 4.3

4.2.1 Calorific Value of the Briquettes

Table 4.3: Results of calorific values of different types of fuel briquettes

S/N	Type of briquettes	Mass of water, Mw (g)	Initial temperature of water Ti, (ºC)	Final temp of water , Tf (ºC	Mass of fuel Mf (g)	Average Calorific value (kJ/g)
1	Carbonized Baggasse	1700	23.49	24.18	200	24.64 ± 0.05
2	Tree Leaves + Gum Arabica	1700	23.87	25.34	904	15.85± 0.05
3	Carbonized Rice husks + Waste Paper	1700	23.89	24.66	250	22.01± 0.05
4	Water Hyacinth	1700	24.16	25.18	700.5	14.21± 0.05
5	Tree leaves + Waste Paper	1700	24.96	26.25	758.5	16.60± 0.05
6	Charcoal dust + Clay	1700	23.06	24.18	430	18.86± 0.05
7	Charcoal dust +Clay+ Waste Paper	1700	23.59	24.62	660.9	21.80± 0.05
8	Charcoal dust+ crushed Bean stalks + Waste Paper	1700	23.74	25.45	944.8	17.66± 0.05
9	Coffee husks + Waste Paper	1700	20.94	22.62	1124.5	14.58± 0.05
10	Coffee husks + starch binder	1700	23.30	24.72	626	22.14± 0.05
11	. Saw dust + waste paper	1700	23.16	24.46	709.6	17.88± 0.05

From the results above, the gross calorific value of biomass fuel briquettes ranged between 14.21kJ/g and 24.64kJ/g. The briquettes with the lowest calorific value were those made from water hyacinth. They were also found to have high percentage moisture content. This together with the presence of clay, which is non-combustible, contributed to the low calorific value of the briquettes. In general, the average calorific value of the briquettes compared well with the average calorific value of briquettes of 16.8j/g reported by Legacy Foundation (Legacy Foundation, 2003)

4.2.2 Percentage Moisture Content

The percentage moisture content for different briquettes are shown in Table 4.4

Table 4.4: Percentage moisture content of various types of fuel briquettes

S/N	Type of briquette	Percentage dry weight basis content (%)
1	Charcoal dust + Clay+ Waste Paper	8.7±0.2
2	Coffee husks + Waste Paper	10.3±0.1
3	Charcoal dust+ Bean stalks + Waste Paper	14.0±0.1
4	Tree Leaves + Waste Paper	9.7±0.2
5	Charcoal dust + Clay	12.4±0.1
6	Carbonised Coffee husks + starch binder	9.0±0.1
7	Carbonized Baggasse	5.8±0.2
8	Water Hyacinth	8.3±0.1
9	Carbonized Rice husks + Waste Paper	9.1±0.1
10	Tree Leaves + Gum Arabica	12.4±0.1
11	Sawdust + waste paper	9.8±0.1

The briquettes that were analyzed had a percentage moisture content ranging between 5.8% for carbonized baggasse briquettes and 12.4% for briquettes made from clay with clay as a binder and tree leaves with gam Arabica. Briquettes made of leaves had a high percentage of moisture content and this may be attributed to the leaves stocks that contain higher moisture content. Briquettes made from baggasse had the lowest moisture content and this is because the process of carbonizing briquettes drove away moisture in the biomass material.

4.2.3 Proximate Analysis of Biomass Briquettes

The percentage volatile matter, carbon content and ash content were obtained for various briquettes as explained in sections 3.42 to 3.4.4 and presented in Table 4.5

Table 4.5: Percentage of volatile matter, carbon content and ash content of different types of fuel briquettes

S/N	Type of briquette	Percentage of volatile matter	Percentage of carbon content	Ash content
1	Charcoal dust + Clay+ Waste Paper	22.06±0.01	67.33	10.61±0.01
2	Coffee husks + Waste Paper	60.62±0.01	24.47±0.01	14.91±0.01
3	Charcoal dust+ Bean stalks + Waste Paper	8.42±0.01	62.02±0.01	29.56±0.01
4	Tree Leaves + Waste Paper	59.57±0.01	31.59±0.01	8.84±0.01
5	Charcoal dust + Clay	9.00±0.01	62.39±0.01	28.60±0.01
6	Carbonised Coffee husks + starch binder	6.02±0.01	53.91±0.01	40.06±0.01
7	Carbonized Sugar Baggasse	14.04±0.01	75.54±0.01	10.43±0.01
8	Water Hyacinth	45.20±0.01	22.55±0.01	32.25±0.01
9	Carbonized Rice husks + Waste Paper	35.29±0.01	42.00±0.01	22.70±0.01
10	Tree Leaves + Gum Arabica	48.18±0.01	37.90±0.01	13.92±0.01
11	Sawdust + waste paper	16.90±0.01	74.98±0.01	8.12±0.01

Briquettes made of coffee husks and paper had a percentage volatile matter of 60.62 ±0.01% with a burning time of between 25-30 minutes whereas briquettes made from charcoal dust with clay had a very low percentage volatile matter of 9% but longest burn time of 1 hour. Thus, it was concluded that briquettes with high volatile matter have less burn time while those with low volatile matter have a longer burning time

The briquettes that were analysed showed that those made from sawdust and waster paper had the lowest percentage ash content of 8.12±0.01%, whereas those made from carbonized coffee husks and starch binder had the highest percentage of 40±0.1%. This is because paper which is used as a binder in the leave briquettes burns completely unlike those with starch binder which when burnt down produces ash (Legacy Foundation, 2003). Briquettes made from charcoal dust and clay too had high ash content because of the clay component which gives a lot of ash when burnt. It was observed that briquettes that used waste paper as a binding agent had lower ash content for the paper burns down completely leaving very little ash unlike the briquettes that used clay as a binder that tended to have a higher ash content (Legacy foundation, 2003)

4.2.4 Breakage Percentage of the Briquettes

Percentage breakage of briquettes are shown in the Table 4.6

Table 4.6: Breakage percentage of briquettes

S/N	Type of briquette	Breakage Percentage (%)
1	Charcoal dust + Clay+ Waste Paper	11.11
2	Coffee husks + Waste Paper	80.41
3	Charcoal dust+ Bean stalks + Waste Paper	74.50
4	Tree Leaves + Waste Paper	0.38
5	Charcoal dust + Clay	80.17
6	Carbonised Coffee husks + starch binder	12.47
7	Carbonized Baggasse	5.01
8	Water Hyacinth	0.30
9	Carbonized Rice husks + Waste Paper	12.26
10	Tree Leaves + Gum Arabica	46.82
11	Sawdust + waste paper	0.05

It was found out that briquettes made of coffee husks and waste paper did not bind well and had the highest breakability percentage of 80%, whereas sawdust and waste paper bonded well and had the lowest breakability percentage of 0.05%. This is attributed to the size of particles of the briquetting material. For sawdust, its finer particles allowed an almost homogenous bonding with waste paper hence able to withstand the breakage impact unlike coffee husks whose particles were huge and therefore unable to bond well. Water hyacinth had a low breakage percentage too because when pressed together its material bonds well together and do not require any external binder, hence the strong bond. Clay and charcoal dust had a high breakage percentage too, of 80%. This is because clay isn’t a strong binder compared to other binding agents like waste paper and gum Arabica (Legacy Foundation, 2003). For bean stocks, charcoal dust and paper, the size of bean stocks in the mixture affected homogenous bonding hence it was easy to break (Legacy, 2003)

4.2.5 Briquette Burning Characteristics

Burning characteristics of various briquettes when burnt in open-fire are recorded in Table 4.7

Table 4.7: Burning qualities of different types of briquettes

S/N	Type of briquette	Smokiness of the briquettes	Average Time taken for full ignition (minutes)	Average Time taken to burn completely into ashes (minutes)
1	Charcoal dust + Clay+ Waste Paper	No smoke	10	60
2	Coffee husks + Waste Paper	White smoke	2.5	27.5
3	Charcoal dust+ Bean stalks + Waste Paper	No smoke	2.5	60
4	Tree Leaves + Waste Paper	White smoke	2.5	30 minutes
5	Charcoal dust + Clay	No smoke	2.5	60
6	Carbonised Coffee husks + starch binder	No smoke	10	180
7	Carbonized Baggasse	White smoke	2.5	20
8	Water Hyacinth	Little smoke	2.5	25
9	Carbonized Rice husks + Waste Paper	White smoke	2.5	45
10	Tree Leaves + Gum Arabica	White smoke	1.5	20
11	11. Sawdust + waste paper	Little white smoke	3.5	32.5

The burning characteristics results showed that briquettes made from carbonized coffee husks with starch binder would be the most preferred. This is because there is no emission of smoke when burnt in an open fire and had the longest burning time of 3 hours. This was attributed to low percentage volatile matter of 6% as recorded in Table 4.5

4.3 Testing of the Semi-gasifier Stove

The stove was successfully constructed as shown in figures below

Fig 4.8: Stove base

Fig 4.9: Stove liner

Fig 4.10: Stove inside compartment

Fig 4.11: Stove outer compartment

Fig 4.12: Stove liner fixed to the stove base

Fig 4.13: Inner compartment fixed

Fig 4.14: Assembled stove

Fig 4.15: Stove fed with fuel

The stove was later tested by establishing:

i) The burning characteristics of the stove

ii) The Stove efficiency

iii) The stove power

iv) The emission level of the stove

4.3.1 Burning Characteristics of the Stove

The stove achieved semi-gasification burning characteristics. The flame produced was in between blue and yellow colour. Compared to an open fire flame, the flame from this natural draft gasification stove was more blue. This means that it is cleaner compared to the open fire flame.

Fig 4.16: Burning characteristics of stove

4.3.2 Combustion efficiency of the stove

The average thermal performance of the stove using various biomass fuel types were extracted and recorded in the table below. See Appendix A-3 for raw data and performance data.

Table 4.8: Average thermal performance of stove using various fuel types

Fuel Type	Average thermal efficiency (ɳ)	Average Specific fuel consumption (g/l)	Average power (w)	Observation and Comparison with Literature
Wood fuel	26.3±2	89±3	3750±559	Wood fuel has the highest power out put
Paper briquettes	33.0±2.0	145.6±2.0	3455±175.0	Has the highest thermal efficiency because paper briquettes have a low moisture content
Sawdust briquettes	30.3±2.0	126.7±3.0	3137±212.0	Sawdust have very high power deviation and this is attributed to huge variation on particle size of sawdust used
Leave biomass briquettes	30.0±2.0	138.0±5.0	2930.0±134.0	Leaves have lowest power output.

When the stove was tested with fire wood , its average thermal efficiency was found to be (26 ±2)W for high power cold start, 26 ± 1 for high power warm start and 27 ±1 for simmering stage. The average stove power at the cold start was (3750 ± 559) W, (4867± 1165) W for high power warm start and (2858±115) W for simmering stage. When tested with various biomass fuel briquettes, the paper briquettes had thermal efficiency of averagely (33±2) W while the leaves briquettes had thermal efficiency of (30±2) W. In terms of specific fuel consumption, generally, use of fuel briquettes had a higher specific fuel consumption compared to fired wood. The average specific fuel consumption for wood was 89±3 g/litre while the paper briquettes had specific fuel consumption of 145.6±2.0 g/litre of water boiled. This was attributed to the density of the fuel; fire wood had a higher density compared to the biomass fuel briquettes recorded at averagely 500kg/m^3 (Legacy Foundation, 2003). The thermal efficiency of a stove by various fuels is related to the moisture content of the fuel. From Table 4.4, paper briquettes have been recorded to have the lowest moisture content. This explains why they recorded the highest average thermal efficiency in Table 4.8.

4.4 Comparison of the Stove with Other Common Cooking Methods

Below is a table showing most common cooking methods, their characteristics and performance compared to the project gasification stove.

Table 4.9: Table showing comparison of the stove with other briquette stove

	Type of Briquette Stove			
Parameters	Project Briquette stove	Vestos Stove	KV Holey-briquette stove	References
Average thermal efficiency (%)	30±3	45±5	35±2	Nordica *et al* (2007)
Thermal power (w)	4067±100	4000±200	1100±700	Nordica *et al* (2007)
Specific fuel consumption (g/litre of water boiled)	120±70	143±20	500±30	Energypedia, 2012
Initial cost of the stove ($)	10.5	35	6	Briquette survey, (2010)

The stove was compared with other modes of cooking as shown in the table above. The thermal efficiency of the stove was less than that of a paraffin stove. The stove consumes between 84g to 242g of fuel to boil one litre of water, when using fuel wood and briquettes respectively, compared to an open fire which consumes 143g (Energypedia, 2012) of fuel to boil one litre of water. Charcoal stove specific fuel consumption was reported to be 260g to boil one litre of water (Energypedia, 2012).

4.5 Emission Testing of Semi-gasifier Stove

The emission testing results were as recorded in Table 4.10. For raw data, see appendix 3.

Table 4.10: CO, CO_2 emissions and CO/CO_2 ratio for Semi-gasifier stove

	CO emissions (ppm)			CO_2 emissions%			CO/CO_2 ratio		
	Cold Start	Hot Start	Simmering	Cold start	Hot start	Simmering	Cold start	Hot start	Simmering
MEAN	0.0669	0.0369	0.0278	3.2556	2.814	1.9615	2.3473	1.6643	1.6771
±SD	±0.0433	±0.0162	±0.0180	±0.15730	±0.13369	±0.10822	±0.115274	±0.14452	±0.09827

The stove had an average emission of (0.0669 ±0.0433) ppm carbon monoxide in cold start, an average of (0.0369±0.0433) ppm in hot start and a decrease of emission of (0.0278±0.0180) ppm in simmering stage. The World Health Organization recommends a PM 2.5 limit of 25 micrograms per cubic meter over a 24 hour period and a carbon monoxide limit of 9 ppm over an 8 hour period (WHO, 2005). Therefore, cooking with the stove on average 3 times a day would yield an exposure of less than 1 ppm Carbon monoxide and this is far less than the upper limit exposure set out by the WHO. In terms of CO to CO_2 ratio, the highest percentage is 2.3% for cold start and averagely 1.6% for both hot and simmering stages. This indicates that the stove burns relatively clean compared to gas cooking appliances whose $CO/_{CO_2}$ ratio has been established to be 2% (Bryan *et al*, 2002).

4.6 Cost of Semi-gasifier stove and Implications on Wood Fuel Savings

In Kenya, a typical family uses 3.1kg of wood fuel per day (Ministry of Energy, 2010). The average price of wood fuel by 2010 was found to be Kshs 2.5 per kg (Briquette field survey, 2010). This translates to an expenditure of Ksh 232.50 (USD 3) per month. For a typical family that used charcoal for cooking, the survey found that it used one 4-kg tin of charcoal per day, retailing at Ksh 40 per 4 litre-tin in 2010 (Briquette survey, 2010). This translates to Ksh 1200 (USD 15) per month. A family that used kerosene for cooking needed 30 litres of kerosene per months (Theuri, 2004). Retailing at a pump price of Ksh 70 per litre (ERC, 2015), such a family would require 30 litres of kerosene costing Ksh 2400 (USD 30) per month.

The field survey showed that a typical family would require 4.5kg of briquettes per day retailing at an average price of Ksh 1.5 per kg, a family would require Ksh 200 per month (USD 2.5) for its cooking.

Therefore a family that moved from using wood fuel to briquettes woul save at least Ksh 30 (USD 0.5) per month in Nairobi and peri urban Nairobi. A family that moved from using charcoal to using biomass briquettes would save up to Ksh 1000 (USD 12.5) per month, whereas a family that moved from using kerosene to fuel briquettes would save Ksh 2200 (USD 27.5) per month.

4.6.1 Simple payback period of the stove

Using equation (3.14) with project retail price of Ksh 800 (USD 10) and with a lifespan of 50 months, then simple payback period($P_{P}N$) when a family moves from using fuel wood on an a three stone fire to the project stove is 27 months. Thus the simple payback period ($P_{P}N$) when a family moves from using a charcoal stove retailing at Ksh 200 (USD 2.5) (ESDA, 2005) to the project stove is less than a month, while the simple payback period (P_PN) for moving from using kerosene stove retailing at Kshs 300 (USD3.75) (briquette survey, 2010) to using the briquettes stove will be less than 2weeks.

4.6.2 Net benefit of the Semi-gasifier stove

Using equation (3.14) and working with 50 months as the stove lifespan, the net benefit accrued by a family in four years when they move from using fuel wood on three stone fire to semi-gasifier is Ksh 700, whereas for a family which move from using a charcoal stove to the project stove will realize a net benefit value of Ksh 49,200 in four years. Moving from using Kerosene stove to the semi-gasifier stove, in four years, has the highest net benefit of Ksh 109, 200.

4.6.3 Rate of Return

When a family moves from using fuel wood to semi-gasifier stove for four years, using equation (3.15), the rate of return for the semi-gasifier stove was found to be 87%. When a family moves from using charcoal to semi-gasifier stove in four years, the rate of return was found to be 6, 100%. While the rate of return in four years for a family moving from using kerosene to semi-gasifier stove was 13, 650% .

4.7 Environmental Benefits and Carbon Credits

From the figures by Kenya Ministry of Energy, a typical family used 3.4tonnes of wood biomass in a year. In case a family shifted from using wood for cooking to using the briquette stove, up to 3.4 tonnes of greenhouse gas savings into the environment would be realised (Gold Standard, 2012). This can be traded under the carbon credit trading scheme at an average price of $5 (Latin carbon, 2013). With a four years lifespan of the stove, at least 10 tonnes of carbon credits would be realized when a family uses the briquettes semi-gasification stove. This gives a gross value of $50 realized by the stove in its lifespan.

4.8 Summary of the Findings

From the briquette survey done, it was observed that more than 50% of the artisans interviewed were found in Nairobi urban and peri- urban areas. The technology was found to be practised more by community based organisations and self help groups. There were also some companies that dealt in the technology. Over 30% of the interviewed artisans were aged between 41-45 years.

In terms of the number of briquettes produced per day, 45% of the respondents produced between (20-50) kg of briquettes. About 33% of the briquettes made were from a mixture of charcoal dust and paper. There were two major types of briquettes, that is, those carbonized mostly produced by companies in motorized system and raw or uncarbonized briquettes which were manually produced by small groups of artisans. The ratio of mixing the carbonized material and a binding agent, mostly gum Arabica and starch was found to be 19:1 for carbonized briquettes while for raw briquettes the material to binding agent (which mostly was found to be paper) was in the ratio of 9:1.

The capital investment of the business was found to be $267 and $533 for a wooden and metallic briquette machines respectfully. The survey found out that about 82% of the fuel briquette fabricators in Nairobi use manual machine presses to make briquettes, 10% use bare hands to mould fuel briquettes while 8% use electricity. The survey found the average price of 1 kg of briquettes to be Ksh 1.5.

The sampled briquettes from the artisans were characterized based on calorific value of the briquettes, percentage moisture of the briquettes, percentage volatile matter, and percentage ash content; percentage breakability of the briquettes, briquette burning characteristics and finally the density of the briquettes. The calorific value of briquettes was found to be between 14.21kJ/g and 24.64kJ/g for charcoal with clay and coffee husk with starch respectively.

Moisture content of the briquettes was found to range between 5.8% and 14% for carbonized baggase briquettes and charcoal with bean stocks with paper, respectively. Carbonized coffee husks with starch binder had the lowest volatile matter of 6.02% while coffee husks with paper had the highest volatile matter of 60.62%. Briquettes made from sawdust and paper had the lowest ash content of 8.12% whereas briquette from briquettes from carbonized coffee husks and waste paper had an ash content of 40.06%.

The percentage breakability of the briquettes sampled ranged between 0.05% and 80.41% for charcoal with clay and sawdust with paper respectively. The density of the briquettes sampled ranged between 195kg/m^3 and 1040kg/m^3 for saw dust with paper and carbonized coffee husks with starch binder respectively. Most of the briquettes sampled took between 2-3 minutes to fully ignite. Carbonized coffee husk with starch took the longest time to ignite, that is, up to 10 minutes. This can be attributed The time taken for the sampled briquettes to burn fully into ash was between 20 minutes and 60 minutes. The thermal efficiency of the stove was found to be 30.0%±3, and average specific fuel consumption of briquettes being 180±40g/litre of water boiled. The stove's average power was found to be 2.5±1.5kW.

A family that moved from using fuel wood, charcoal and kerosene would realze a rate of return of 87%, 6100 % and 13650 respectively during the lifespan of the semi-gasifier stove of four years. This means tha in all the three cases, it is really profitable and cost saving for a family to shift to using a semi-gasifier stove. If a family claimed carbon credits by using the stove, they would be entitled to up to Ksh (3200) $40 during its entire life. When mass produced, the stove would retail at averagely Ksh 800 ($10).

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

The research covered three main parts of the research: field survey on the briquette technology in Nairobi and its surrounding, proximate analysis of briquettes in the market and design & construction of a semi-gasifier stove to utilize briquettes. The findings and conclusions of the research can be outlined as follows:

a) The briquettes survey was conducted and the following was found:

i) The briquette technology was gaining momentum in Kenya due to the constant increase in wood fuel process.

ii) The briquette technology was practiced mostly in Nairobi and its peri-urban environment by community based organization and self help groups.

iii) Out of the briquettes sampled, carbonized briquettes made from coffee husks mixed with starch were found to have the second highest calorific value of 22.14kj/g, a longest burning time of 180 minutes and had no smoke. This category of briquettes would suit well for industrial briquettes making ventures that are capable of producing carbonized briquettes.

iv) Gum Arabica or expired starch proved to be the best binding agent mixed at a ratio of 19:1 for the material and the binder respectively.

v) Among the raw or uncarbonized briquettes which were common for small scale or domestic briquettes making, saw dust mixed with paper were the best in this category mixed in the ratio of 9:1, respectively.

b) The properties of biomass briquettes found in Kenya had the following thermophysical properties:

i) Calorific value of surveyed briquettes ranged between 14.21kJ/g and 24.64kJ/g and competed well with wood whose average calorific was 18kJ/g

ii) A moisture content of surveyed briquettes that ranged between 5.8% and 12.4%

iii) Briquettes made of coffee husks and paper had a percentage volatile matter of 60.62 ±0.01%. When linked to the burning time, it burned for between 25-30 minutes.

iv) Briquettes made from charcoal dust with clay had a very low percentage volatile matter of 9% but with the longest burning time of 1 hour.

v) Briquettes made from sawdust and waster paper had the lowest percentage ash content of 8.12±0.01%.

vi) Briquettes made from carbonized coffee husks and starch binder had the highest ash content of 40±0.1%.

vii) Briquettes made of coffee husks and waste paper had the highest percentage breakability of 80%

viii) Briquettes made from sawdust and waste paper bonded well and had the lowest percentage breakability of 0.05%.

c) The research achieved the objective of designing and developing a briquette semi-gasifier stove based on the principle of the Modified Inverted Downdraft Gasifier Experiment, field findings and standard design equations.

d) The thermal performance of the stove was carried out using the Water Boiling Test by Bailis, (2007) protocol and summarized as follows:

   i) Average thermal efficiency was (30 ±3)%

   ii) The emission level of 1.434 ppm by the stove at the cold starts, when extrapolated for three sessions of cooking yielded averagely 4.3ppm of emission.

   iii) The stove had cooking power of (2.5±1.5) Kw.

   iv) The stove had a fuel consumption rate of (0.15 ±0.07) kg/litre which was far better than the consumption of (0.5 ±0.1) kg/litre for an open fire.

e) The economic and environmental benefits of the semi-gasifier stove are as follows:

i) Simple payback period is 27 months, 1 month and 2 weeks if a family shift from open fire wood, charcoal and kerosene mode of cooking to using semi-gasifier stove.

ii) A family that moves from using fuel wood, charcoal and kerosene will realise investment rate of return of 87%, 6100 % and 13650%, respectively during the lifespan of the semi-gasifier stove of four years.

iii) When a family shifts from open wood fire, charcoal and kerosene, the net benefit of the stove for a period of four years will be Ksh 700, 49200 and 109200 respectively

iv) If a family claimed carbon credits by using the stove, it would be entitled to up to Ksh 3200(USD40) during its entire life.

5.2 Recommendations

Based on the survey and findings of this study, the following recommendations are necessary for a successful uptake of the project:

1. All stakeholders involved in the dissemination of briquette technology should integrate the stove dissemination into their programs.
2. Stakeholders who are involved in the field of improved stove dissemination should incorporate the window of carbon credits into their project in order to reduce the cost of the project dissemination. With this, the use of briquettes and the stove will be able to compete economically with cooking using wood gathered at no cost from bushes or forest.
3. More research should be done to determine other available binding agents for various biomass waste briquettes in Kenya

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APPENDICES

Appendix A: **FIELD SURVEY QUESTIONNAIRE**

i) Briquette producers field survey questionnaire

I am an MSc student at Kenyatta University. My research area is in the field of briquette technology in Kenya. I need to gather relevant information that will help to inform the current state of briquette technology and identify the present gaps that may be filled with research.

The research questionnaire seeks to elicit information on your view about Briquette Technology in Kenya. The information gathered will be used for academic purposes and may be helpful to all projects involved in briquette technology in Kenya. All your responses to this questionnaire will be treated as strictly CONFIDENTIAL.

Your cooperation is highly appreciated. Thank you

Section A. Demographic Information

Name: ____ (optional)

Age:
- ☐ Below 20
- ☐ 21-25
- ☐ 26-30
- ☐ 31-35
- ☐ 36-40
- ☐ 41-45
- ☐ 46-50
- 50+

Gender: ☐ Male ☐ Female

Name of the organization/business………………………………………………………

Type of the organization involved in Briquetting

- ☐ Government department
- ☐ NGO CBO/Self Help Group
- ☐
- ☐
- ☐
- ☐

(please specify)

…………………………………………………………………………..…………

Location of the Briquette

Business/Project…………………………………………………………………………

Location of the Briquette Business/project

office…………………………………………………………....

Briquette Business/project

Activities…………………………………………………………………….………

Section B: Knowledge base of the Briquetting Technology

1. When was the briquetting project/business set up?
   ……………………………………………

2. Where did you learn this briquetting technology from?

   ……………………………………-
   ………………………………………………………………………………

3. How many people are involved/employed in the project/business?
   …………………………………………………………………………………….

4. a) Do you have trained people on briquetting technology in this project/business?

   ………………………………………………………………………………………

   b) i. If yes, where were they trained?

   ………………………………………………………………………………………
   ……………………………………………………………………………………
   ii. What was the cost of training one person/employee on briquetting?
   ………………………………………………………………………………………
……………………………………..

5. i) What type of press do you use?
   A) Piston
   B) Screw
   C) Other (specify)…………………………………………………………………
   ……………………….

   ii) Why do you prefer the type of the press indicated in 5 i) above?

   ………………………………………………………………………………………

…………………………………………………………………………………………
……………………………………………………………………………………

(iii) Where did you get the machine/press in use from? ....and how much did it cost? Kshs…………………………………………………………

6. How many briquettes does your press produce per day? ……………………………………………………………………………………………..

7. a) What type of briquettes does your press machine produce?

    A. Block
    B. Hollow
    C. Pellets
    D. Others (specify)…………………………………………………………………………………

b) Why do you prefer producing the type of briquette in 7a) above?
…………………………………………………………………………………………
………………………………………

Section C: Source and type of raw materials

8. (i) What type of raw materials do you use in briquetting?

    1) Agro?-based materials
    2) Manufacturing based materials
    3) Waste materials
    4) Other (Specify)
    ………………………………………………………………………………………………………

(ii) List down by order of preference the type of raw materials used in by your plant for briquetting purpose
…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………………………………………

(iii) Why do you prefer the type of raw materials named above in 8 (ii)?
…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………………………………...

9. Where do you get these raw materials from?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………………………………………………….

10. Do you use any binder in your briquetting plant?

NO ☐ Yes ☐

11. (i) if Yes, what type of binder do you use?...
(ii) Where do you get the binder from?

12. What are some the problems you encounter when sourcing for the raw materials?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…….

Section D: Production process

13. How many types of raw materials do you use in producing the various types of briquettes?
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
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…………………………………………………………………………………………………
…………………………………………………………………………………………………
…………………………………………………………………………………………………
………………………………………….

14. What are some of the proportions (mixture) of raw materials used in making various briquettes in your plant? (ratio form e.g. 3parts: 2parts:1part)
1. ………………………………………………………………….
2. ………………………………………………………………
3. ……………………………………………………………..
Other specify
……………………………………………………………………………………
……………………………………………………………………………………
…………………………………………………………………………

15. How are the proportions determined; is there any accepted standard?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………

16. Where do you get the source of power used in production of briquettes?

a) Electricity
b) Generator
c) Manual/Human labour
d) Other (specify)

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
……………………………………………………………………….

17. What is the maximum number of briquette produced in this plant per day?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………………………………………………………………

18. Estimate the amount/number and cost of producing the various types of briquettes per day in terms of the following;

Type of input	Number/Amount	Cost (Kshs.)
Power		
Human Labour		
Water		
Binder		
Storage		
Other		

19. Estimate the cost of machine maintenance per month

Kshs……………………………….

Section E: Marketing

20. Where do you sell your briquettes?

A. Supermarkets
B. Brooders
C. Restaurants
D. Domestic heating
E. Butcheries/meat roasting
F. Bakeries
G. Hotels
H. Other (specify)

21. Please state;

i) The level of demand for each of the various types of briquettes stating the type of customers/business for each

	Number ordered per Month	Type of briquette	Number supplied	Number of orders/demands unmet	Type of Customer/Business e.g. Supermarkets
1.					
2.					
3.					
4.					
5.					

A. If there are orders/demands that are unmet what are your constraints?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
………………

22. What is the retail price of one piece/unit (carton/bag) of briquette? Kshs. ....

23. On average, how many briquettes do you sell per month?...............................

24. How would describe the price of briquettes compared to charcoal or fuel wood?

☐ Very high
☐ High
☐ Fair
☐ Good

Section F: Quality of Briquettes

24. How long does your briquettes burn completely into ashes?..........................hrs
25. (i) Does the burning of your briquettes produce any smoke?

☐ Yes ☐ No

ii) If yes what colour of smoke is produced by the briquettes?

…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
…………………………………………………………………………………………
……………………….

iii) What is the type of smell produced by the briquettes?

☐ Pleasant
☐ Irritating
☐ Choking
☐ Foul

26. How would describe the strength your briquettes while handling them?

☐ Very Strong
☐ Strong
☐ Fairly strong
☐ Fragile

25. What concerns do you have concerning briquette technology in Kenya (please write down your comments here)

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ii) Briquette consumers field survey questionnaire

I am an MSc student at Kenyatta University. My research area is in the field of briquette technology in Kenya. I need to gather relevant information that will help inform the current state of briquette technology, identify the present gaps that may be filled through research.

The research questionnaire seeks to elicit information on your view about Briquette Technology in Kenya. The information gathered will be used for academic purposes and may be helpful to all projects involved in briquette technology in Kenya. All your responses to this questionnaire will be treated as strictly CONFIDENTIAL.

Your cooperation is greatly appreciated. Thank you

Respondents code ……………………………………………………………

Section A. Demographic Information

Name :……………………………………………………………………….(optional)

Age:

☐ Below 20
☐ 21-25
☐ 26-30
☐ 31-35
☐ 36-40
☐ 41-45
☐ 46-50
☐ 50+

Gender:

☐ Male
☐ Female

Marital status:

☐ Single

☐ Married

☐ Windowed

1. Where did you learn about briquettes use?

   ....
   ....

2. What is good about the use of Briquette?

   ....
   ……………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………
   ………………………………………………………………………………………

3. What type of briquette do you use?

   (i) Block

   (ii) Hollow

   (iii) Pellets

   (iv) Others (specify)……………………………………………………………………………………

4. Why do you prefer the type named above?

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   ………………………………………………………………………………………
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   ……………..

5. (i) Do you have a specialized *Jiko* for accommodating briquettes?

   ☐ NO Yes ☐

   If yes, what type of the *Jiko* do you use?.
   ....

(ii) Where did you buy the *Jiko* from?................................. and at how much?(Kshs..............)

6. a. How many bags/pieces of briquettes do you use per day? ....

   b. How many bags of charcoal/woodchips do your use per day?

   ....

   i. How much money do you spend on briquettes per month?................................

   ii. How much money do you spend on charcoal per month?..................................

   iii. How much do you spend on wood fuel per month?..

7. How many hours does it take for your briquette to burn to ashes?....................hrs

8. Does the burning of the briquettes produce any smoke?

   No ☐ es ☐

   If yes, can you describe the smell of the smoke?

   a. pleasant

   b. foul

   c. irritating

   d. choking

9. How do you get your supplies of briquettes from the producer?

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10. (i) What mode of transport do you use to carry your briquettes?

☐ Lorry

☐ Van

☐ Hand cart

(ii) Are breakages experienced while transporting your briquettes?

No ☐ Yes ☐

If yes, approximately what proportion of briquettes break?

☐ ½

☐ ¼

☐

☐ Number negligible

Do you have any other concerns about the use briquette as an alternative fuel in Kenya?

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Appendix B: BRIQUETTE SEMI-GASIFIER STOVE

The Ministry of Energy records that a typical family in Kenya uses 3394kg of wood for cooking in a year (Ministry of Energy Kenya, 2010). This translates to 9.3kg per day and 3.1kg per meal by each family. Therefore, the amount of energy required for cooking a common meal can be given by equations B-1 to B-8 (Belonio, 2005):

1. The quantity of energy required to cook a meal will be given by:

$$Q_n = C_f \text{ x } M_f \text{ x } E_s \qquad \text{(B-1)}$$

Where 3.1 kg of wood of an average 18MJ/kg is consumed per meal on open fire of 14% (Hedon, 2010), thus 18 x 3.1 x 0.14 giving 7.81MJ of energy

2. Amount of fuel needed in the above will be given by:

$$FC = \frac{Q_n}{HV_f \text{ x } g} \qquad \text{(B-2)}$$

Working with the heating value of briquettes as 16.8MJ/kg (Legacy Foundation, 2003) and working with design efficiency of the stove to be 30%- substituting in the above equation gives

$$FC= 7.25/ (16.8x.30) = 1.55 \text{ kg of briquettes} \qquad \text{(B-3)}$$

Working with the average density of briquettes to be 500kg/m^3 (Legacy Foundation, 2003), the volume of briquettes required to cook the same average meal for six people would be given as:

V= M/D, substituting the values gives:

V= 1.5/500, giving 0.003m^3 and this translates to 3000cm^3

It therefore follows that to cook such a meal, one requires at least a volume of 3000cm^3 of the stove.

The height of the gasifier should be 1.65 times the diameter (Stanley and Kobus, 2005)

Therefore the diameter of the combustion chamber would be:

3000= (1.65 D^3)/4, and solving for D gives 19 cm.Therefore, the dimensions of the fuel chamber will be D= 19cm, while the height 32cm.

In order to achieve the pre-heating effect of secondary air before it gets to the combustion chamber, two compartments were introduced as explained in the Modified Inverted Downdraft Gasifier (MIDGE) experiment (Noll, 2003). In this experiment,

1) A 12 litre can (larger) was modified by punching five equally spaced holes on its sides around the bottom (unopened end), which is called the cowling.
2) Another tin, 4 litre (Second largest), called the burner, was turned upside down and punched with as many holes as possible with a 3d nail till it looks like a sieve.
3) At least four equally spaced holes were made into the side at the bottom of the same 4 litre can untill it achieved the 12,3,6,9 O'clock positions.
4) Still on the same 4 litre can, about 16, ¼ inch equidistance holes were made around the circumference around the top end.
5) The internal burner was made to stand by measuring the height of the burner, taking the measurement and measuring from the top of the cowling (the 12 litre can) and marking that point on the cowling. This is the level where the 4 each, 2 inch sheet metal screw were screwed through the cowling wall, into the centre of the cowling
6) The 12 litre can was picked and turning upside down, the burner (the 4-litre can) was placed at the centre of it and a circle traced onto the tuna can. A hole was later cut out in the tuna can bottom, but was a little smaller than the circle drawn.
7) The three parts were then assembled by placing the burner into the cowling and centering it on the 4 screws.
8) The tuna can was then inverted and pressed into the outer until it rested on the banner.

This process helped to achieve the inverted down draft gasifier effect (Noll, 2003).

The semi-gasification effect on the stove was achieved by having two compartment for the stove, the inner compartment with a diameter of 25cm to achieve a space difference of 1cm around the out surface of combustion chamber, and the outer most compartment which was31cm in diameter (similar to the 12 litre can in MIDGE set up) hence achieved a space difference of 3cm from the inner compartment (similar to the 4litre can in the MIDGE setup) (Noll, 2003). The outer space difference was 3 times more than the inner surface to facilitate for pressure difference for secondary air hence the gasifier effect while cooking with the stove (Noll, 2003).

Appendix C: Raw Data for Emission Testing

Conducted on 29th of October 2010

		cold phase	

	CO in ppm	CO_2%	(CO/CO_2)%
	0.004523	5.6	0.080758929
	0.05305	3	1.768333333
	0.0735	2.8	2.625
	0.1392	6	2.32
	0.07715	2	3.8575
	0.0626	1.4	4.471428571
	0.0645	4.4	1.465909091
	0.0875	1.4	6.25
	0.03875	1.4	2.767857143
	0.1342	3.6	3.727777778
	0.162	5.6	2.892857143
	0.07815	4.8	1.628125
	0.0414	2.4	1.725
	0.07095	4.2	1.689285714
	0.05135	2	2.5675
	0.042	3.2	1.3125
	0.0163	3.6	0.452777778
	0.0078	1.2	0.65
Mean	**0.06694**	**3.2555556**	**2.347367249**
SD	**0.043373**	**0.15730159**	**0.152735508**

	Hot Phase		
	CO in ppm	**CO_2%**	**CO/CO_2)%**
	0.0485	5.8	0.836206897
	0.016	3.6	0.444444444
	0.0464	2.2	2.109090909
	0.0414	1.8	2.3
	0.01985	1.4	1.417857143
	0.02635	4.2	0.627380952
	0.03715	3	1.238333333
	0.0271	3.2	0.846875
	0.058	4.4	1.318181818
	0.03095	2	1.5475
	0.07595	1.2	6.329166667
	0.03485	3	1.161666667
	0.02655	1.4	1.896428571
	0.027	2.2	1.227272727
Mean	**0.036861**	**2.8142857**	**1.664314652**
SD	**0.01616**	**0.13369639**	**0.1445237363**

Simmering			
	COin ppm	**CO_2%**	**CO/CO_2)%**
	0.03185	4	0.79625

	0.02645	1	2.645
	0.03345	1	3.345
	0.0241	1	2.41
	0.01545	0.8	1.93125
	0.03015	1.2	2.5125
	0.0366	1.6	2.2875
	0.04715	1.2	3.929167
	0.0178	2.8	0.635714
	0.042	1.6	2.625
	0.0127	0.8	1.5875
	0.02455	1.2	2.045833
	0.01355	1	1.355
	0.0388	2	1.94
	0.01245	2.2	0.565909
	0.0149	1.6	0.93125
	0.08955	4	2.23875
	0.0258	4.4	0.586364
	0.0227	2.4	0.945833
	0.06445	2.2	2.929545
	0.01595	2.2	0.725
	0.015	2.6	0.576923
	0.0163	3.6	0.452778
	0.01545	0.8	1.93125
	0.00715	1.2	0.595833
	0.0281	2.6	1.080769
Mean	**0.027785**	**1.961538**	**1.677151**
SD	**0.018046**	**0.1082248**	**0.0982716**

Appendix D: Excel Spreadsheet Sample for Water Boiling Test Spreadsheets with Wood as Fuel

		COLD START HIGH POWER				HOT START HIGH POWER (OPTIONAL)				SIMMER TEST			
		Start		Finish: when Pot #1 boils		Start		Finish: when Pot #1 boils		Start:when Pot #1 boils		Finish: 45 min after Pot #1 boils	
Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	label
Time (in 24 hour units)	hr:min	14:21	t_{ci}	14:36	t_{cf}	14:41	t_{hi}	14:52	t_{hf}	14:54	t_{si}	15:39	t_{sf}
Weight of wood	g	500	f_{ci}	222	f_{cf}	500	f_{hi}	238	f_{hf}	738	f_{si}	302	f_{sf}
Water temperature, Pot # 1	ºC	23.0	$T1_{ci}$	96.0	$T1_{cf}$	24.0	$T1_{hi}$	96.0	$T1_{hf}$	[illegible]		[illegible]	$T1_{sf}$
Water temperature, Pot # 2	ºC		$T2_{ci}$		$T2_{cf}$		$T2_{hi}$		$T2_{hf}$				
Water temperature, Pot # 3	ºC		$T3_{ci}$		$T3_{cf}$		$T3_{hi}$		$T3_{hf}$				
Water temperature, Pot # 4	ºC		$T4_{ci}$		$T4_{cf}$		$T4_{hi}$		$T4_{hf}$				
Weight of Pot # 1 with water	g	3049	$P1_{ci}$	2967	$P1_{cf}$	3049	$P1_{hi}$	2978	$P1_{hf}$	2960	$P1_{si}$	2170	$P1_{sf}$
Weight of Pot # 2 with water	g		$P2_{ci}$		$P2_{cf}$		$P2_{hi}$		$P2_{hf}$				
Weight of Pot # 3 with water	g		$P3_{ci}$		$P3_{cf}$		$P3_{hi}$		$P3_{hf}$				

$T1_{si}$ is set equal to T_b because the simmer test starts after the pot has boiled.

$P1_{si}$ should be the mass remaining in pot one at the end of the hot start test ($P1_{hf}$).

Weight of Pot # 4 with water	g		$P4_{ci}$		$P4_{cf}$		$P4_{hi}$		$P4_{hf}$			
Weight of charcoal+container	g	114		131	c_c	114		135	c_h		127	c_s

Appendix E: Values used in the Water boiling tests

Table E-1: Raw Data for Water Boiling Tests

#	Type of fuel	Rate of power	Test	Initial mass of water (g)	Final mass of water(g)	Initial mass fuel	Mass of ash	Start temp of water	Final temp of water	Time of start	Time to end
1	Fuel wood	Cold start	#1	3050	2955	500	253	18	96	09:38	09:54
			#2	3049	2937	500	210	18	96	11:222	11:36
			#3	3049	2967	500	222	23	96	14:54	15:39
		Warm start	#1	3048	2955	500	232	20	96	10:03	10:21
			#2	3049	2975	500	258	18	96	11:42	11:52
			#3	3049	2978	500	238	24	96	14:41	14:52
		Simmering	#1	2924	2220	732	385	80	96	10:25	11:10
			#2	2957	2165	758	368	82	96	11:55	12:40
			#3	2960	2170	738	302	86	96	14:54	15:39
2	Paper briquettes	Cold start	#1	3200	2740	700	253	19	96	9:29	9:54
			#2	3049	2550	650	210	18	96	11:22	11:46
			#3	3049	2967	500	222	23	96	14:21	14:36
		Warm start	#1	3048	2645	700	312	20	96	10:03	10:29
			#2	3025	2640	643	258	18	96	11:52	12:12
			#3	3049	2978	500	238	24	96	14:41	14:52
		Simmering	#1	2924	2220	700	345	80	96	10:35	11:20

			#2	2957	2165	558	267	82	96	12:05	12:50
			#3	2960	2170	738	302	86	96	14:54	15:39
3	Sawdust briquettes	Cold start	#1	3200	2740	720	255	19	96	9:21	9:54
			#2	3049	2550	650	210	18	96	11:30	11:56
			#3	3049	2967	500	222	23	96	14:21	14:42
		Warm start	#1	3048	2645	700	312	20	96	10:03	10:30
			#2	3025	2640	643	258	18	96	12:02	12:23
			#3	3049	2978	500	238	24	96	14:44	14:59
		Simmering	#1	2924	2220	700	345	80	96	10:40	11:25
			#2	2957	2165	558	247	80	96	12:25	13:10
			#3	2960	2170	738	302	86	96	15:04	15:49
4	Leaves briquettes	Cold start	#1	3200	2740	720	255	19	96	9:04	9:54
			#2	3049	2550	650	210	18	96	11:30	11:56
			#3	3049	2959	500	229	21	96	14:21	14:42
		Warm start	#1	3048	2641	700	312	20	96	10:01	10:31
			#2	3025	2640	643	258	18	96	12:02	12:23
			#3	3025	2958	500	232	22	96	14:44	14:59
		Simmering	#1	2924	2224	700	345	80	96	10:40	11:25
			#2	2957	2165	558	247	82	96	12:25	13:10
			#3	2960	2170	669	278	86	96	15:04	15:49

Table E-2 Raw Data for Water boiling results using fuel wood

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	20	21	16	19.1	3.1
Temp-corrected time to boil Pot # 1	min	20	21	15	18.7	2.9
Burning rate	g/min	11	10	14	11.5	1.8
Thermal efficiency	%	24%	28%	25%	26%	2%
Specific fuel consumption	g/liter	89	93	87	89.8	2.9
Temp-corrected specific consumption	g/liter	87	91	86	87.8	2.4
Firepower	watts	3,264	3,145	4,168	3526	559.3

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	11	14	16	13.3	2.4
Temp-corrected time to boil Pot # 1	min	10	13	16	13.1	2.6
Burning rate	g/min	20	15	12	15.9	3.8
Thermal efficiency	%	25%	26%	27%	26%	1%
Specific fuel consumption	g/liter	88	86	79	84.5	4.4
Temp-corrected specific consumption	g/liter	85	84	79	83.0	3.1
Firepower	watts	6,107	4,698	3,795	4867	1,165.6

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev
Burning rate	g/min	9	9	10	9.3	0.4
Thermal efficiency	%	28%	27%	26%	27%	1%
Specific fuel consumption	g/liter	256	264	277	265.7	10.7
Firepower	watts	2,752	2,841	2,980	2858	115.2
Turn down ratio	--	1.19	1.11	1.40	1.23	0.2

Table E-3 Raw Data for Water boiling results using Paper briquettes

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	24	23	15	20.7	5.4
Temp-corrected time to boil Pot # 1	min	24	22	15	20.4	4.7
Burning rate	g/min	17	17	17	17.1	0.3
Thermal efficiency	%	34%	31%	29%	31%	3%
Specific fuel consumption	g/liter	187	203	102	164.1	54.5
Temp-corrected specific consumption	g/liter	182	195	105	160.8	49.1
Firepower	watts	3,795	4,496	3,800	4030	403.2

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	25	19	11	18.5	7.3
Temp-corrected time to boil Pot # 1	min	25	19	11	18.3	6.9
Burning rate	g/min	14	18	21	17.6	3.4
Thermal efficiency	%	35%	31%	30%	32%	3%
Specific fuel consumption	g/liter	170	165	92	142.6	43.5
Temp-corrected specific consumption	g/liter	168	159	96	141.1	39.0
Firepower	watts	3,176	4,582	4,726	4161	856.4

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev
Burning rate	g/min	11	7	10	9.1	2.0
Thermal efficiency	%	34%	41%	31%	36%	5%
Specific fuel consumption	g/liter	216	183	267	221.7	42.4
Firepower	watts	2,384	1,740	2,223	2115	335.4
Turn down ratio	--	1.59	2.58	1.71	1.96	0.5

Table E-4 Raw Data Water boiling results using sawdust briquettes

1. HIGH POWER TEST (COLD START)	**units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Time to boil Pot # 1	min	32	25	20	25.9	5.9
Temp-corrected time to boil Pot # 1	min	31	24	21	25.5	5.2
Burning rate	g/min	13	16	12	13.8	2.1
Thermal efficiency	%	31%	29%	27%	29%	2%
Specific fuel consumption	g/liter	195	203	102	166.8	56.4
Temp-corrected specific consumption	g/liter	190	195	105	163.4	51.0
Firepower	watts	3,221	4,418	2,915	3518	794.3

2. HIGH POWER TEST (HOT START)	**units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Time to boil Pot # 1	min	29	20	15	21.4	7.3
Temp-corrected time to boil Pot # 1	min	29	20	15	21.2	6.9
Burning rate	g/min	12	17	15	14.9	2.4
Thermal efficiency	%	33%	29%	28%	30%	3%
Specific fuel consumption	g/liter	170	165	92	142.6	43.5
Temp-corrected specific consumption	g/liter	168	159	96	141.1	39.0
Firepower	watts	2,956	4,646	3,722	3775	845.9

3. LOW POWER (SIMMER)	**units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Burning rate	g/min	8	7	10	8.4	1.4
Thermal efficiency	%	32%	36%	29%	32%	4%
Specific fuel consumption	g/liter	216	195	267	225.7	37.0

Firepower	watts	1,992	1,975	2,388	2118	233.7
Turn down ratio	--	1.62	2.24	1.22	1.69	0.5

Table E-5 Raw Data Water boiling results using leaves briquettes

1. HIGH POWER TEST (COLD START)	**units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Time to boil Pot # 1	min	30	28	24	27.5	3.0
Temp-corrected time to boil Pot # 1	min	29	27	25	27.1	2.2
Burning rate	g/min	14	14	10	12.9	2.4
Thermal efficiency	%	30%	29%	27%	29%	2%
Specific fuel consumption	g/liter	199	203	102	168.0	57.3
Temp-corrected specific consumption	g/liter	194	195	105	164.6	51.9
Firepower	watts	3,429	3,961	2,449	3279	767.1

2. HIGH POWER TEST (HOT START)	**units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Time to boil Pot # 1	min	26	22	20	23.0	3.0
Temp-corrected time to boil Pot # 1	min	26	22	21	22.9	2.6
Burning rate	g/min	14	15	11	13.3	2.2
Thermal efficiency	%	30%	29%	28%	29%	1%
Specific fuel consumption	g/liter	170	165	92	142.5	43.4
Temp-corrected specific consumption	g/liter	168	159	96	140.9	38.9
Firepower	watts	3,285	4,242	2,659	3395	797.2

3. LOW POWER (SIMMER)	**units**	**Test 1**	**Test 2**	**Test 3**	**Average**	**St Dev**
Burning rate	g/min	8	7	10	8.4	1.4
Thermal efficiency	%	32%	36%	29%	32%	4%
Specific fuel consumption	g/liter	216	195	267	225.7	37.0
Firepower	watts	1,992	1,975	2,388	2118	233.7

Turn down ratio	--	1.72	2.01	1.03	1.58	0.5