KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

KUMASI

COLLEGE OF ENGINEERING

DEPARTMENT OF AGRICULTURAL ENGINEERING

DESIGN, CONSTRUCTION AND TESTING OF A BIOCHARRING UNIT

A THESIS SUBMITTED TO THE DEPARTMENT OF AGRICULTURAL ENGINEERING IN PARTIAL FULFILMENT OF THE

REQUIREMENT FOR THE AWARD OF BACHELOR OF SCIENCE DEGREE IN AGRICULTURAL ENGINEERING

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DECLARATION

Having acknowledged all materials previously published by other people and materials which have been accepted for the award of any other degree of the university, I hereby declare that this piece of work is mine towards the B.Sc. Agricultural Engineering degree

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DEDICATION

This project is dedicated to Miss Theresa Owusua. Thank you for financing my education. God bless you.

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My profound gratitude goes to the sponsors of this project: MIT/IDIN Program and Technology Consultancy Centre (TCC), as well as my supervisors: Prof. Ebenezer Mensah and Dr. George Y. Obeng. I am very grateful for their immense contribution towards this project. Without them this project would not have been successful.

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My utmost gratitude goes to the Most High God for how far He has brought me. All glory and honour to Him for His grace and mercy.

ABSTRACT

The use of biomass as renewable energy sources has attracted global attention over the decades.

The shells of jatropha plant is one such source. It belongs to the Euphorbiaceae family.

One use of the seeds together with the shells is for biochar production. Biochar is a carbonaceous solid residue obtained upon heating biomass under oxygen-deficient conditions. It can be used as a soil nutrient supplement and can also be processed into briquettes for fuel. The use of plant waste also serves as another means of managing waste. There are various techniques that are used to produce biochar. The simplest ones require little equipment to manufacture. A biocharring unit is manufactured based on the type of biomass used, and the quantity required. A top-lit updraft kiln is one of such devices used to produce biochar from plant waste. It is loaded with the biomass, then fire is lit at the top of the biomass. The fire then burns downwards until all the biomass is turned to biochar. The resulting biochar can then be used as soil nutrient supplement or processed into fuel in the form of briquettes. The kiln has a good efficiency, making it suitable for burning other farm waste products to produce biochar. The unit is able to produce biochar from dry jatropha shells. The biochar produced is also of standard quality with reference to the IBI standards. It takes the unit an average time of 1 hour to complete one full burn with a capacity of 34.42kg/hr. Its efficiency is 14% with an optimum temperature of 380°C.

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CHAPTER ONE

1.0 INTRODUCTION

1.1 BACKGROUND

The use of biomass as renewable energy sources has continued to attract global attention over the last two decades and is much more pronounced in countries where agricultural activities are abundant. This is because products obtained from them have numerous prospects for a low carbon economy (Ogunjobi *et al*, 2013). The waste from agricultural plants after they have been utilised can be used for this purpose.

Jatropha curcas is a non-edible, oil bearing and draught hardy shrub with ecological advantages. It belongs to the Euphorbiaceae family. It is a multipurpose tree with medicinal properties and also as an oil-seed of significant economic importance (Latha *et al*, 2013). The plant is widely distributed in the wild or semi-cultivated in Central and South America, Africa and India. The Jatropha plants start yielding from the second year of planting, but in limited quantity. If managed properly, it starts giving 4‒5kg per tree production from the fifth year onwards and seed yield can be obtained up to 40‒50 years from the day of planting. On the average, the seed yield is up to 5 tons/hectare.

Freshly harvested Jatropha dried fruit contains about 35‒40% shell and 60‒65% seed (by weight). The fruits are 2.5 cm long, ovoid, black and 2‒3 halved. It has nearly 422 fruits per kg available after decortication of Jatropha seed for oil extraction. While lot of emphasis is being given on use of bio-diesel, which is only about 17‒18% of the dry fruit, not much attention is being given to utilize other components of fruit for energy purposes (Okeola *et al,* 2011). This project seeks to present the use of the shells as a biochar product.

1.2 PROBLEM STATEMENT

In most farms, after plants have been harvested, and further processed into other products, the waste is usually thrown away without consideration for other uses. These wastes can also be processed into other forms so they become useful as well. Waste management practices are encouraged to ensure that the environment is not polluted.

1.3 JUSTIFICATION

Biochar is the carbonaceous solid residue obtained upon heating biomass under oxygen-deficient conditions. It has potential as a nutrient recycler, soil conditioner, income generator, waste management system, and agent for long-term, safe and economical carbon sequestration.

1.4 OBJECTIVES

- The main objective is to design and construct a unit a top-lit updraft kiln for biocharring agricultural plant waste using Jatropha shells as a case study.

1.4.1 SPECIFIC OBJECTIVES

- To determine whether a top-lit updraft kiln is able to produce biochar.
- To determine the quality of biochar produced from dried jatropha shells using the top-lit updraft kiln.
- To test the biocharring unit to determine its performance.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 BIOCHARRING

Biochar is a solid material obtained from the carbonization of biomass. Biochar may be added to soils with the intention to improve soil functions and to reduce emissions from biomass that would otherwise naturally degrade to greenhouse gases. Biochar also has appreciable carbon sequestration value. Biochar is a name for charcoal when it is used for particular purposes, especially as a soil amendment. Like all charcoal, biochar is created by pyrolysis of biomass (IBI, 2014).

Biochar can be applied to soils to sequester carbon and enhance soil fertility. According to Woolf *et al* (2010), production of biochar and its storage in soils can contribute to a reduction of up to 12% of current CO_2 emissions.

Figure 1 ***Biochar produced from Jatropha shells***

During pyrolysis or carbonisation, the biomass (jatropha shells) is heated in a closed vessel of some kind, exclusive of oxygen of in the air which otherwise would allow it to ignite and burn to ashes.

2.2 JATROPHA PLANT

It is a small tree or shrub with smooth grey bark, which exudes a whitish colour, watery, latex when cut. Normally, it grows between three and five meters in height, but can attain a height of up to eight to ten meters under favourable conditions.

Figure 2 Jatropha plant

i. **Leaves**: It has large green to pale-green leaves, alternate to sub-opposite, three-to five-lobed with a spiral phyllotaxis.

Figure 3 Jatropha plant leaves

ii. **Flowers**: The petiole length ranges between 6-23 mm. The inflorescence is formed in the leaf axil. Flowers are formed terminally, individually, with female flowers usually slightly larger and occurs in the hot seasons. In conditions where continuous growth occurs, an unbalance of pistillate or staminate flower production results in a higher number of female flowers.

Figure 4 Jatropha plant flowers

iii. **Fruits:** Fruits are produced in winter when the shrub is leafless, or it may produce several crops during the year if soil moisture is good and temperatures are sufficiently high. Each inflorescence yields a bunch of approximately 10 or more ovoid fruits. A three, bi-valved cocci is formed after the seeds mature and the fleshy exocarp dries.

Figure 5 Jatropha fruits

iv. **Seeds**: The seeds become mature when the capsule changes from green to yellow, after two to four months.

Figure 6 Jatropha seeds

Figure 7 Jatropha curcas shells

2.3 HISTORY OF CARBONIZING TECHNOLOGIES

For as long as human history has been recorded, heating or carbonizing wood for the purpose of manufacturing biochar has been practiced. Carbonization is as old as civilization itself. In ancient times, the production of biochar was not the only intention. It appears that ancient peoples were also well acquainted with the method of liquid product recovery. This can be seen in the remains of the ancient Egyptian societies that indicate they used liquid products like fluid wood-tar and pyro ligneous acid to embalm their dead. The preserving agent in this ancient tradition was a watery condensate collected from the charring process (Kruger *et al,2010*). According to the writings of Theophrastus, the Macedonians obtained wood tar from burning biochar in pits. Wood tar had many applications such as house paints, caulking for sealing wood barrels, and use in shipbuilding. Dating as far back as 6,000 years, evidence shows that wood tar was used to attach arrowheads to spear shafts (Emrich, 1985).

In the early development of pyrolysis, producing biochar was the sole objective of wood carbonization. Throughout history the process has evolved from using wasteful biochar pits to modern, fast pyrolysis and bio-oil refineries. At the end of the eighteenth century, new technologies were developed to recover and utilize the volatile compounds produced from pyrolysis (Klark, 1925). This resulted in a crude process using brick kilns to recover the condensable gases that were normally lost in biochar pits. Following brick kilns was the use of iron retorts (vessels) placed in “batteries” of two each in long bricked up rows. By the end of the nineteenth century, labor and time saving steel ovens were developed, contributing significantly to the success of the wood distillation industry. In the 1970’s the fast pyrolysis reactor was introduced, influencing progress in bio-oil refining.

The maturity of pyrolysis and bio-oil refining technologies now has the potential to support a new biomass economy capable of competing with the prevailing petroleum-based economy.

2.3.1 HISTORY OF BIOCHAR

The use of biochar can be traced to the dark, fertile, human-modified soil found in the Amazon Basin known as “terra preta,” meaning “black earth” in Portuguese. Terra preta owes its name to its high charcoal content, and it was made by adding a mixture of charcoal, bone, and manure to the otherwise relatively infertile Amazonian soil over many years (Mann 2006). Terra preta promotes high levels of micro-organism activity, including fungi that are beneficial to plant growth. It is less prone to nutrient leaching, a major issue in rainforest soils (Lehmann and Joseph 2009).

Soil scientists have determined that the terra preta dates back at least to 450 BC, depending on location. The soil’s depth reaches up to two meters (six feet) (Sombroek 1966). It is widely accepted that these soils are a product of indigenous soil management involving a labor-intensive technique termed slash-and-char (Sombroek 1966). The technique involves a low temperature burn that produces more charcoal than ashes and is a tool for soil improvement. The method used relied on initially igniting slashed biomass, then burying the burning material to deny it oxygen, thereby preventing combustion and promoting pyrolysis (Lehmann et al. 2002). The continued presence and fertility of terra preta underscores its nature as a stable carbon storage tool.

2.4 CARBONIZING UNIT

2.4.1 CRITERIA TO SELECT PYROLYSIS/CARBONIZING REACTORS

This section discusses criteria for selecting the heart of the pyrolysis plant, "the reactor." A strong regional and global biomass economy requires development of more selective, controlled, multi-product, flexible, and integrated pyrolysis units (Pelaez-Samaniego et al., 2008).

An in-depth understanding of the socioeconomic context of pyrolysis must govern specific choices of pyrolysis technologies. Pyrolysis units should be designed with a clear business model in mind; even if a set formula has produced good results in other contexts, it should be applied cautiously (Girard, 2002).

Achieving the highest energy yield from the raw material under consideration is one of the most important criteria however. This project seeks a means for balanced recovery of fuel with stable carbon (biochar) for improving soil productivity and sequestering atmospheric carbon.

2.4.2 PYROLYSIS REACTORS

To differentiate between the different pyrolysis reactors, the nomenclature recommended by Emrich (1985) was employed:

a. **Kiln (Top-lit updraft)** – Kilns are used in traditional biochar making, solely to produce biochar.

b. **Retorts and converters** – Industrial reactors that are capable of recovering and refining not only the biochar but also products from volatile fractions (liquid condensates and syngases) are referred to as retorts or converters.

c. **Retort** – The term retort refers to a reactor that has the ability to pyrolyze pile-wood, or wood logs over 30 cm long and over 18 cm in diameter (Emrich, 1985).

d. **Converters** produce biochar by carbonizing small particles of biomass such as chipped or pelletized wood.

e. **Slow pyrolysis** refers to a process in which large biomass particles are heated slowly in the absence of oxygen to produce bio-char.

f. **Fast pyrolysis** refers to reactors designed to maximize the yields of bio-oil and typically use powdery biomass as feedstock.

A vast number of existing pyrolysis technologies make it difficult to identify which type of reactor is better suited for a targeted application. Classification of reactors varies according to several factors (listed in Table 1). A thorough analysis of the advantages and disadvantages of each existing design will improve selection of an appropriate design for a given application.

Table 1 Key criteria for selecting appropriate pyrolysis technology

Reactor type	Final products	Heat Transfer Rate	Particle Size (Pretreatment)	Mode of operation	Heating Method	Construction Materials	Portability	Reactor Position	Loading Method
Fixed Bed	Bio oil	Slow	Logs; large particles	For intermittent operation	Heating by direct admission of air(Auto thermal)	Earth pits	Stationary	Vertical	Manual
Fluidized Bed	Bio oil	Slow	Chips	For nearly continuous operation	Heating by direct admission of air(Auto thermal)	Earth pits	Stationary	Vertical	Manual
Circulating Bed	Syn-Gas	Slow	Chips	For nearly continuous operation	Heating by direct admission of air(Auto thermal)	Brickwork	Semi-portable	Vertical	Manual
Ablative Auger	Bio-char	Fast	Fine particles	For nearly continuous operation	Heating by direct contact of biomass with furnace gases on the wood	Brickwork	Semi-portable	Horizontal	Mechanical Loading
Rotary drums	Hydrogen	Fast	Fine particles	For continuous operation	Heating by direct contact of biomass with furnace gases on the wood	Steel	Portable	Horizontal	Manual
Moving Beds	Heat	Fast	Fine particles	For continuous operation	Indirect heating	Steel	Portable	Horizontal	With cars
Auger Reactors	Electricity	Fast	Fine particles	For continuous operation	Internal radiator heating through the wall	Steel	Portable	Horizontal	With cars
Top-lit Updraft kiln	Biochar	Slow	Chips	For nearly continuous operation	Heating by direct contact of biomass with furnace gases	Steel	Semi-portable	Vertical	Manual

The reactor type employed in this project is the kiln (top-lit updraft (TULD). The main focus is to produce a unit that will be used to produce biochar for local farmers.

2.4.3 TOP-LIT UPDRAFT KILN

A Top-lit updraft gasifier (TLUD) is a kiln used to produce charcoal, especially biochar, and heat. A TLUD pyrolysis organic material, including wood or manure, and uses a reburner to eliminate volatile byproducts of pyrolisation. The process leaves mostly carbon as a residue, which can be incorporated into soil to create terra preta.

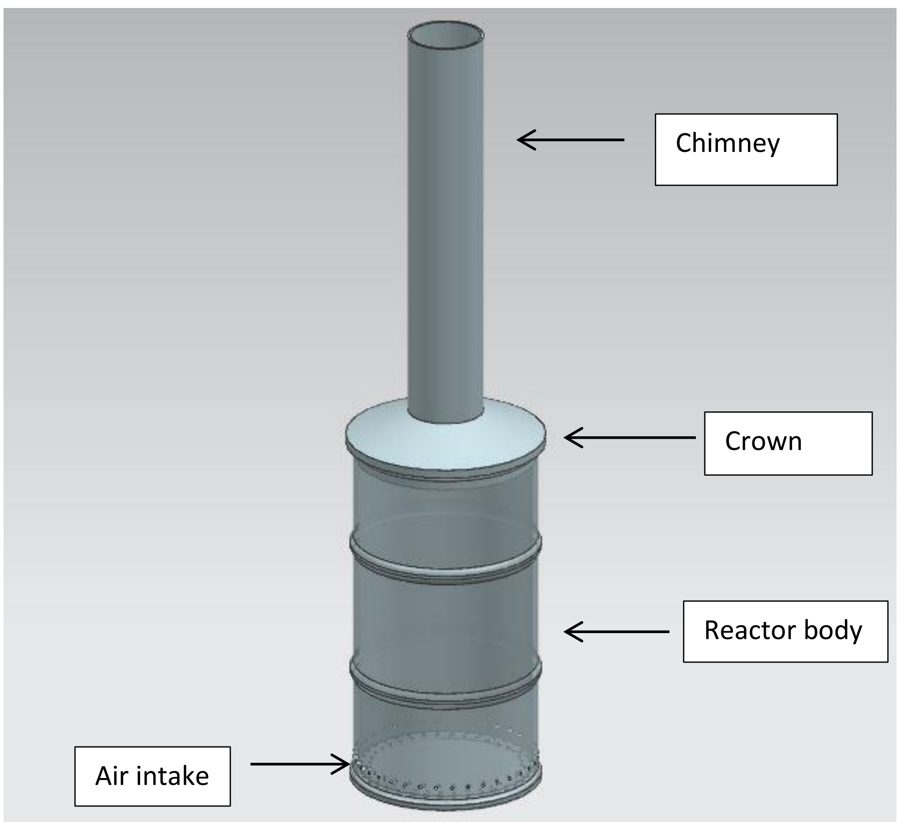

Figure 8 Top-lit Updraft Kiln

2.4.4 FINAL PRODUCTS

The first criteria to consider are the targeted final products:

(1) biochar and heat,

(2) biochar, bio-oil and gases,

(3) biochar, carbon black, and syngas (gas mixtures that contains varying amounts of CO and H),

(4) syngas (Pelaez-Samaniego *et al*, 2008).

In this report, the targeted final product that will be considered is the production of biochar.

Figure 9 Left - a nutrient-poor oxisol; Right - an oxisol transformed into fertile terra preta using biochar

Figure 10 Biochar produced from jatropha shells

Like all charcoal, biochar is created by pyrolysis of biomass. Biochar is under investigation as an approach to carbon sequestration to produce negative carbon dioxide emissions (Lean, 2008). Biochar thus has the potential to help mitigate climate change, via carbon sequestration. Independently, biochar can increase soil fertility, increase agricultural productivity, and provide protection against some foliar and soil-borne diseases. Furthermore, biochar reduces pressure on forests. Biochar is a stable solid, rich in carbon and can endure in soil for thousands of years (Ndameu, 2011).

2.4.5 STORAGE OF BIOCHAR

Although biochar is very stable once it has cooled, precautions must be taken to prevent spontaneous combustion during storage. Immediately after biochar has been removed from the kiln, it tends to absorb oxygen, which can lead to combustion and thus loss of product. Biochar fines should be removed before the biochar is stored (Toole, 1961; FAO, 1985). Occasionally, material that is still burning is missed during removal of the charge even after the cooling cycle. It is important to prevent this hot coal from reaching the storage area by allowing it to sit in an open dry area for a few hours before it is stored (Toole, 1961).

During this safe cooling period, the biochar should be protected from rain in an open shed or under a tarpaulin. Once the biochar has been safely cooled and there is no evidence of heat or active fire, it is considered safe for warehouse storage (Toole, 1961).

2.5 IMPORTANCE OF BIOCHAR

1. Biochar is a very low cost soil amendment that greatly improves quality of soil, increases water retention, greatly reduces fertilizer leaching and ultimately increases the plant yield of vegetation grown in biochar amended soil.
2. Biochar is carbon negative. CO_2 is first removed from the atmosphere through photosynthesis in plants; then, after biocharring these plants, it is amended into soil for thousands of years. Biochar helps the natural carbon cycle put black carbon back into the ground – where it came from in the first place.
3. Biochar reduces climate change caused by emissions of carbon dioxide (CO2) and other greenhouse gases (GHG). Biochar is a way for carbon to be drawn from the atmosphere and is a solution to reducing the global impact of farming and in reducing the impact from all agricultural waste.

Since biochar can sequester carbon in the soil for hundreds to thousands of years, it has received considerable interest as a potential tool to slow global warming. The burning and natural decomposition of trees and agricultural matter contributes a large amount of CO_2 released to the atmosphere.

Biochar can store this carbon in the ground, potentially making a significant reduction in atmospheric Green House Gases (GHG) levels; at the same time its presence in the earth can improve water quality, increase soil fertility, raise agricultural productivity and reduce pressure on old growth forests. (http://www.airterra.ca/biochar-what-is-biochar/why-is-biochar-important)

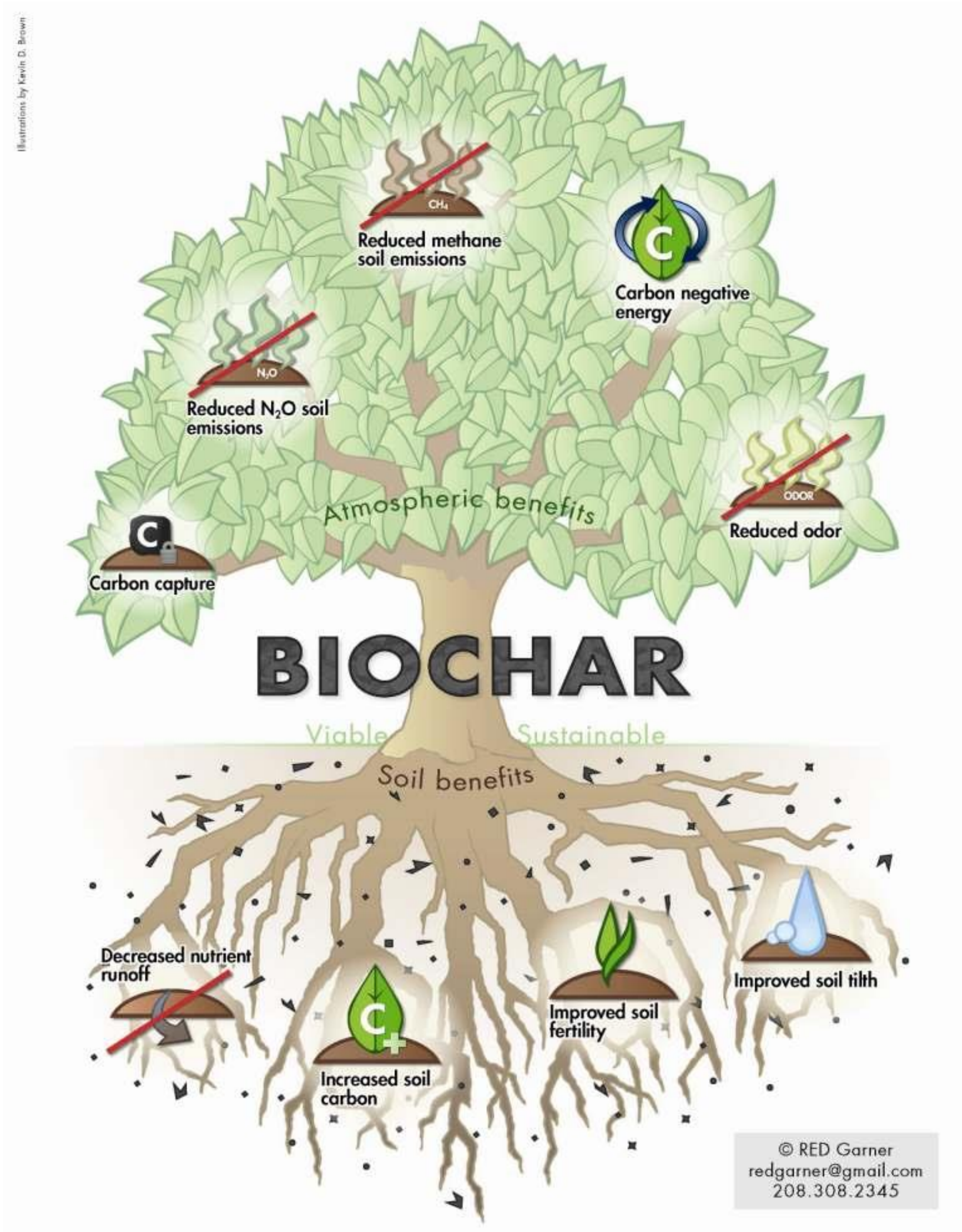

Figure 11 Diagram illustrating biochar and its benefits

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 EQUIPMENT

The equipment and materials used in this project are listed below:

- Rake/stick for spreading out hot biochar material
- Matches
- 45L oil barrel
- Laser thermometer
- Electronic balance
- Hammer and chisel
- Automatic sieve shaker

3.1.1 MATERIALS

- Dry Jatropha shells
- Steel
- Dried leaves

3.2 DESIGN CONSIDERATION

To construct a unit that will be used by local farmers to burn agricultural plant waste to produce biochar, the following design considerations were employed:

- Availability
- Affordability
- Workability
- Strength
- Suitability

The unit is a redesign of existing ones. The site that was selected was an open and clear area (at the Food Processing Unit section of the Technology and Consultancy Center (TCC). The area was suitable for the process.

3.3 DESIGN OBJECTIVES

- **SPECIFICATION**

- Simple to manufacture, assemble and operate
- Easy for two people to transport
- Achieve a yield of 30kg biochar or more per day

➢ FUNCTION TREE

A function tree illustrating the requirements of the unit is shown below:

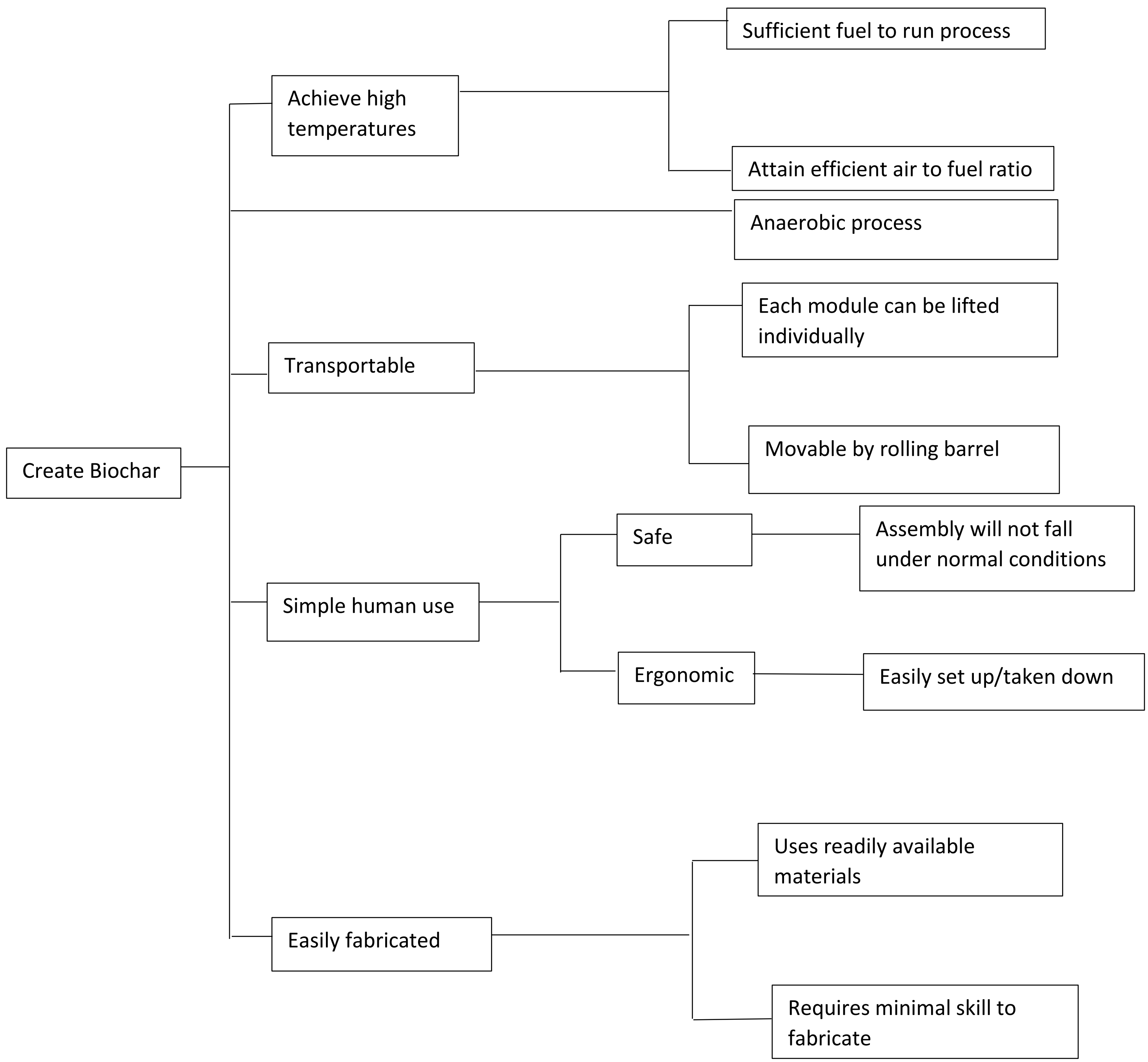

Figure 12 Function tree of unit

3.4 THEORETICAL DESIGN AND PERFORMANCE PARAMETERS

3.4.1 DESIGN CONCEPT DEVELOPMENT

Two designs were considered for the construction of the unit. The following gives the description of the designs considered.

DESIGN A

The initial design that was selected had features similar to the final design. The only difference was the absence of holes (for entry of air) at the bottom of the reactor body. During the testing of this design, it was realized that it took a considerably longer time for the burning process to complete. This was due to the lack of very low oxygen content in the reactor. It took approximately 23 hours to complete one burn (at full capacity).

DESIGN B

The final design was obtained through a combination of trial-and-error testing, CAD modeling and conversations with experts. The guiding objective during this process was to successfully convert all of the jatropha shells inserted into the reactor body into biochar. Design B was able to accomplish this objective.

Table 2 Design concepts

	TIME FOR PROCESS TO COMPLETE	ASH PRODUCTION	FUEL FOR STARTING FIRE	ERGONOMICS
DESIGN A	Longer	Higher	Biomass as fuel	Easy to set up
DESIGN B	Shorter	Lower	Biomass as fuel	Easy to set up

3.4.2 VOLUME OF REACTOR BODY

The reactor body is a 45L barrel. The unit is made of steel. It is semi-portable and hence can be moved from the site after it has been used to a storage area. The unit consists of the following components: chimney, crown, reactor body and supports (bricks).

The dimensions of the various parts are as follows:

Chimney:	Height	= 120cm
	Diameter	= 21cm
Crown:	Height	= 25cm
	Diameter	= 54.5cm
Reactor body:	Diameter	= 55cm
	Height	= 105cm

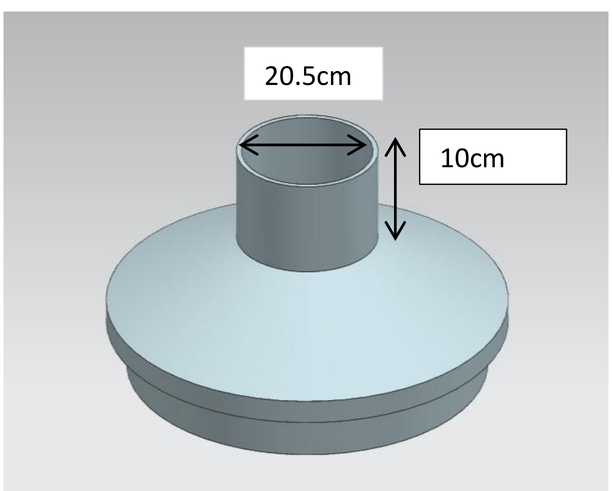

Figure 13 Crown

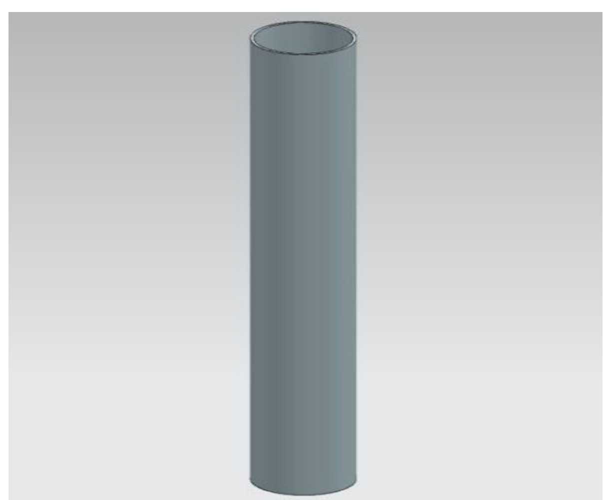

Figure 14 Chimney

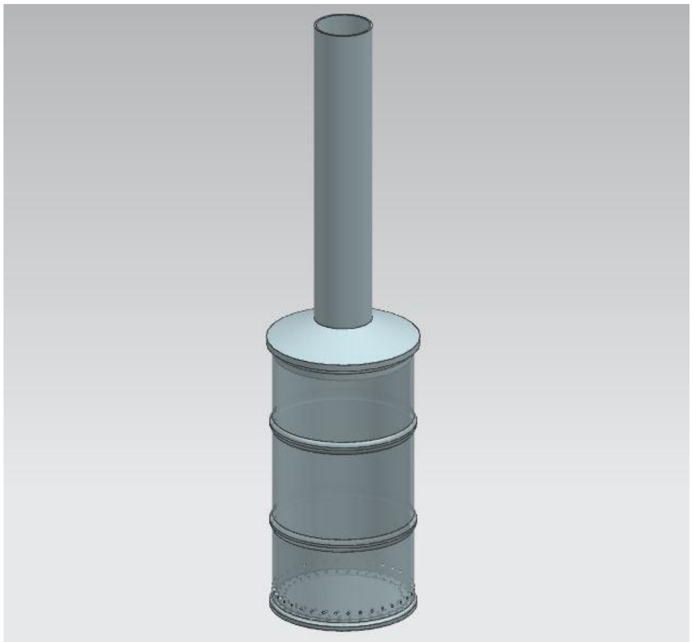

Figure 15 Assembled Unit

Figure 16 Reactor Body

Figure 17 Top-lit Updraft kiln

3.4.3 SELECTION OF MATERIALS

3.4.4 STEEL

Steel is used as the main material due to its ability to withstand high temperatures. The unit was used to burn jatropha shells at high temperatures. The melting point of steel is between 1425 - 1540°C. The temperature range for the pyrolysis is well below this value (300 - 700°C), hence making the material suitable. The crown and chimney were molded using steel metal sheets as well.

3.5 MANUFACTURING PROCESS

The unit was constructed with metallic materials (steel). The reactor body, as well as the crown and chimney are made of steel. The crown and chimney were both molded at the Agricultural Engineering workshop, with the help of the technicians.

The reactor body was bought from a shop. Thin metallic sheets were used to construct the crown and chimney. The chimney was molded according to the specification given. The crown also consisted of two parts, the upper and the lower, that were rolled and molded separately, and then welded together.

3.5.1 DATA COLLECTION

Data that was collected during the process included the following:

- Temperature of unit: Measured using an infrared thermometer.
- Time for burning process to complete: Measured using a stop watch
- Mass of biomass (dry jatropha shells): Measured using an electronic scale
- Mass of biomass produced: Measured using an electronic scale

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 MOISTURE CONTENT OF RESIDUE

The moisture content of the biomass was reduced in order to facilitate the process and hence help reduce the time required for the burning time to complete.

Moisture content (dry basis) of the residue was calculated as follows:

MCdb = $\frac{A-B}{B}\ x\ 100\%$

Where:

MCdb = Moisture content (dry basis)

A = Mass of sample before drying

B = Mass of sample after drying

The oven method for moisture content determination was used. The triplicate method was used for three samples (Reeb *et al*, 1999).

Table 2 Moisture content of samples

SAMPLE	MOISTURE CONTENT (%)
1	11
2	9.4
3	12.4

Average moisture content of biomass = **10.9%**

The value obtained for the average moisture content is slightly lower than literature data (11.77%) recorded by (Pradhan *et al*, 2009). However the value is close and hence compares well with literature data. Also, most biocharring units work best using a moisture content in the range of 10 – 20% (Cummer and Brown, 2002).

4.2 ANALYSIS OF UNIT

The unit was able to produce biochar using dried jatropha shells. Data was collected during the production process. The data collected during the process is given in the table below. It gives value for input of biomass (capacity of reactor), output of biochar produced, time it takes to complete one burning and the temperature of the whole unit during the process.

Table 3 Values recorded for input, output, time and temperature

SAMPLE	INPUT OF BIOMASS (kg)	OUTPUT OF BIOCHAR (kg)	TIME (mins)	TEMPERATURE OF KILN (°C)
A	36.83	4.15	70	390
B	36.83	5.5	65	384
C	36.83	4.6	71	388
D	36.83	4.82	73	396
E	36.83	5.1	64	380
F	36.83	4.22	72	382
Standard Deviation	7.10543E-15	0.99	7.10	5.37

Average output of biochar = 4.73kg

Average time for burning process to complete = 60 minutes

Average temperature of kiln during burning process = 386°C

Capacity of unit = $\frac{36.83kg}{1.07hr}$ = 34.42kg/hr

Also, there was the need for constant monitoring of the device whiles the burning was ongoing. The reason being that, after the residue has been completely charred, the heat that remains in the unit can further burn the charred product to ashes.

4.2.1 EFFICIENCY OF UNIT

The efficiency of the unit was calculated as follows:

$$\text{Efficiency} = \frac{Output}{Input}\ x\ 100\ \%$$

Table 4 Efficiency of unit

SAMPLE	EFFICIENCY (%)
A	11.28
B	14.93
C	12.89
D	13.09
E	13.85
F	11.46

Average efficiency = **12.92%**

The efficiency, when compared to the Improved Charcoal Production Sysytem (ICPS) is relatively good. It has an efficiency of 35% (source: http://www.biocoal.org/3.html date accessed: April 28, 2014). This is so because the ICPS has a high volume compared to the top-lit updraft kiln used in this report.

4.2.2 EFFICIENCY OF UNIT WITH TIME

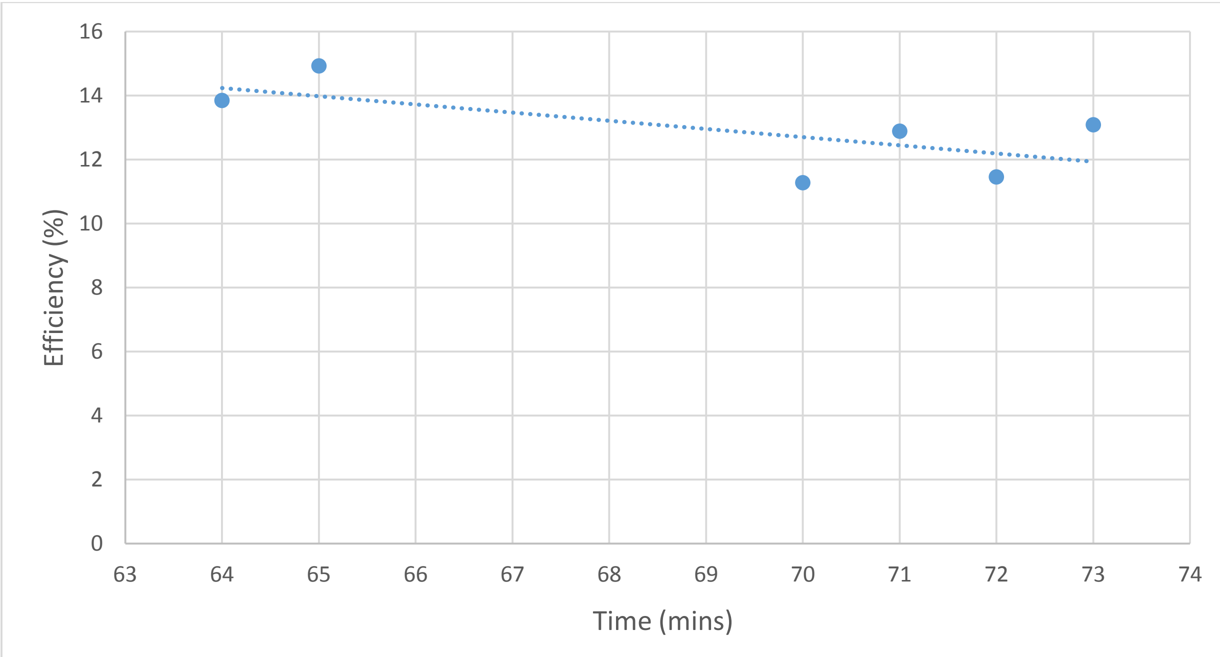

Figure 18 Graph of efficiency against time

It can be seen from the graph that the unit is more efficient at a lower time duration. This is due to the fact that the lesser the time, the more biochar that is produced. This is also because as the time it takes to complete one burn is reduced, less ash is produced, giving a higher percentage of biochar. From the graph, the longer time it takes for the process to be completed, the lower the efficiency. The optimum efficiency is 14%, with an accompanying time of 64minutes.

4.2.3 TEMPERATURE OF UNIT

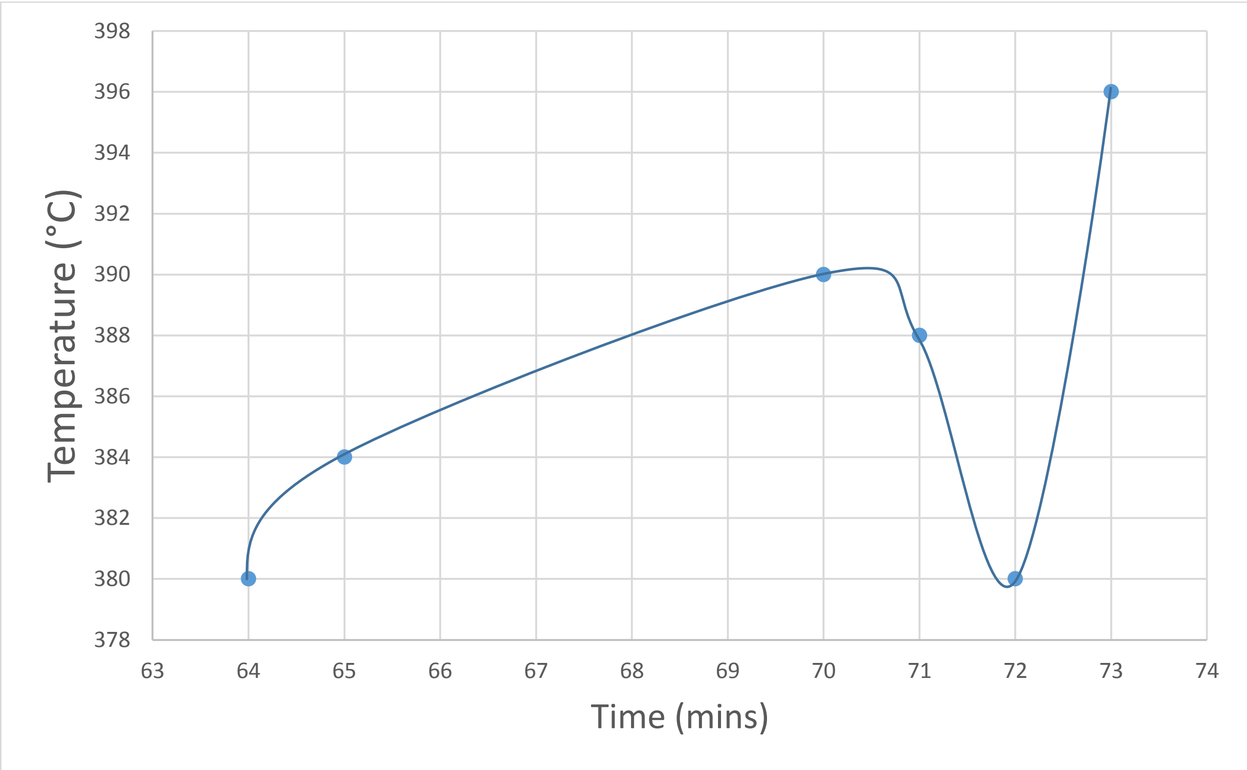

Figure 19 Graph of temperature against time

The graph above gives an indication of the temperature of the unit with respect to the time it takes to complete one burn. The highest temperature occurs at 396 °C with a corresponding time of 73 minutes. Optimum temperature is 380°C. At this temperature, a high efficiency occurs with a corresponding lower time.

4.2.4 OUTPUT OF UNIT

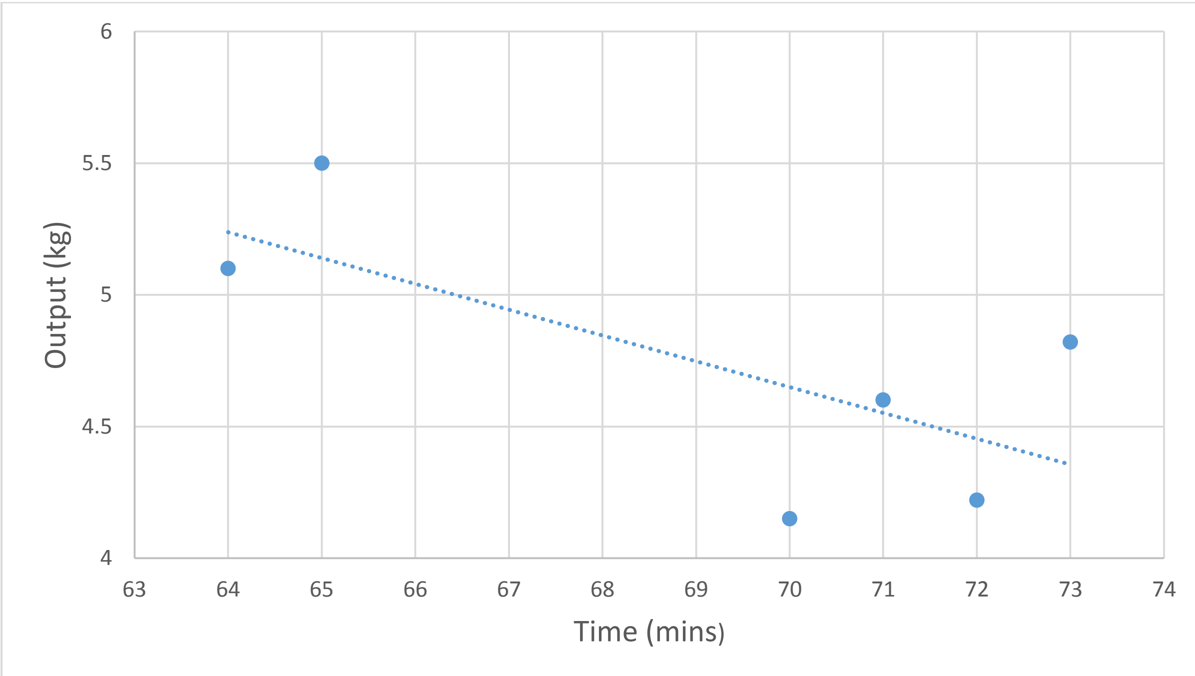

Figure 20 Graph of Output of biochar against Time for burning to complete

From the graph, it can be observed that the longer it takes for the process to complete, the lower the output the unit produces. The extra time it takes to complete the process burns the biomass further to ash.

4.3 CHEMICAL ANALYSIS OF BIOCHAR

Test Category A (IBI, 2013)

Basic Utility Properties

According to the International Biochar Initiative, all biochar that are produced should have a certain quality in order for it to be used in soils (IBI, 2011). The following table highlights the test that was performed on the biochar produced according to these standards.

There are three test categories that can be performed on any biochar produced. They are:

- Test category A - Basic Utility Properties
- Test category B - Toxicant Reporting
- Test category C - Advanced Analysis and Soil Enhancement Properties

The test category A was chosen for this project as it highlights the basic properties that are required for all biochars.

Table 5 Biochar standards

BIOCHAR BASIC UTILITY PROPERTIES	
Material type	Biochar made from dry jatropha shells
Moisture (at time of analysis)	5.12%
Carbon	32.90%
Total Ash	11.145%
Total Nitrogen	0.740%
pH	9.94%

- **Carbon content**

The value for carbon content falls in line with literature data specified by the International Biochar Initiative (IBI, 2011). This value indicates that the biochar is a Class 2 biochar. The Biochar Standards grade biochar in terms of its carbon content as:

- Class 1 biochar contains 60% carbon or more
- Class 2 biochar has between 30% and 60% carbon
- Class 3 biochar has between 10% and 30% carbon

- **Ash content**

The ash content, an important parameter for pyrolysis, was 2.45%. This value is in line with literature data (2.1 – 6 wt%) depending on the variety (Makkar *et al,* 1998). This indicates that the residue could be used to produce briquettes for fuel.

- **Nitrogen content**

The value for nitrogen was higher than that reported by the literature (0.67%) (Wever *et al,* submitted for publication). The difference may be due to other materials such as small wood chippings and dried leaves that were present in the sample, which may have affected the value of the nitrogen content.

- **pH**

The pH was 9.94 indicating an alkaline property. This is essential for soils having an acidic property as it can be applied to them to reduce the acidic content.

Table 6 Particle size distribution

Particle Size (mm)	Amount (%)
< 3mm	36
4 – 6mm	39
6 – 10mm	19.5
>10mm	5.5

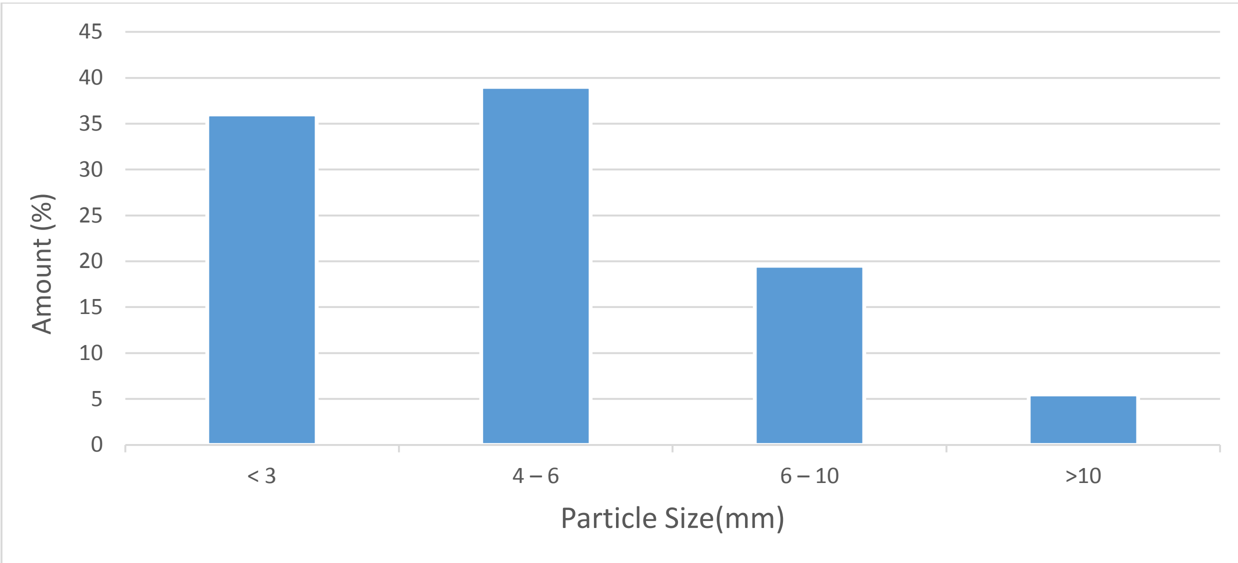

Figure 21 Particle Size Distribution of biochar

Initially, particle size distribution in biochar is influenced mainly by the nature of the biomass feedstock and the pyrolysis conditions (Cetin *et al*, 2004). Shrinkage and attrition of the organic material occur during processing, thereby generating a range of particle sizes of the final product. The intensity of such processes is dependent on the pyrolysis technology (Cetin *et al*, 2004).

The graph illustrates the particle size distribution of the biochar produced from the jatropha shells. It can be observed that a higher percentage of the size lies in the 4 – 6mm range, with the least being those greater than 10mm.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Jatropha shells have a potential to be used as a residue for producing biochar. After harvesting, the shells together with the seeds can be processed into biochar using simple means.

Techniques used to produce biochar are usually done on a large scale. In order to encourage local farmers to adopt this technique of converting waste into useful product, it is necessary to introduce simple methods for this purpose. A kiln is a structure that is used to burn wood or other farm products under limited supply of oxygen. This is to ensure that the residue does not completely burn to ashes. The kiln used in this study is the top-lit updraft kiln.

From the study, it was found that:

- The top-lit updraft kiln is able to produce biochar of an average output of 4.73kg from an average input of 36.83kg in an average time of 1 hour
- The biochar produced is of good standard according to the IBI standards
- The biocharring unit is able to produce biochar in an average time of 60 minutes at an average temperature of 380°C. It has a capacity of 34.42kg/hr and an efficiency of 14%.

5.2 RECOMMENDATIONS

- Further tests can be conducted on the biochar to find out whether it has the potential to be used as briquette for fuel.
- The unit can also be used to burn other farm residues to produce biochar.

REFERENCES

1. AOAC (Association of Analytical Communities) International (2005) AOAC Official Methods of 1 Analysis. 18th Edition. Latimer, G. (Ed.) www.eoma.aoac.org (accessed September 2011).
2. ASTM International (2007) ASTM D1762-84 (2007) Standard Test Method for Chemical Analysis of Wood Charcoal http://www.astm.org/Standards/D1762.htm (accessed September 2011).
3. ASTM International (2009) ASTM D6556-10 Standard Test Method for Carbon Black—Total and External Surface Area by Nitrogen Adsorption http://www.astm.org/Standards/D6556.htm (accessed January 2012).
4. Ayhan Demirbas. Department of Chemical Engineering, Selcuk University, 42031 Konya, Turkey. Effects of temperature and particle size on bio-char yield from pyrolysis of agricultural residues
5. Benoit Anthony Ndameu (November 2011). ‘’Biochar Fund Trials in Cameroon: Hype and Unfulfilled Promises’’
6. Blackwell, P., G. Riethmuller, and M. Collins. 2009. Biochar application in soils. Biochar for environmental management, ed. J. Lehmann and S. Joseph, 207-226. London: Earthscan Publications Ltd.
7. Brown, R. 2009. Biochar production technology. In Biochar for environmental management, ed. J. Lehmann and S. Joseph, 127-146. London: Earthscan Publications Ltd.

8. Chan, K. Y., and Z. Xu. 2009. Biochar: Nutrient properties and their enhancement. In Biochar for environmental management, ed. J. Lehmann and S. Joseph, 67-84. London: Earthscan Publications Ltd
9. Cummer K.R., Brown R.C: Ancillary equipment for biomass gasification. Biomass and Bioenergy 23 (2002) 113-128.
10. Downie, A., A. Crosky, and P. Munroe. 2009. Physical properties of biochar. In Biochar for environmental management, ed. J. Lehmann and S. Joseph, 12-32. London: Earthscan Publications Ltd
11. European Commission Agriculture and Rural Development (2010) Biomass Potential http://ec.europa.eu/agriculture/bioenergy/potential/index_en.htm (accessed September 2011).
12. Garcia-Prez M., T. Lewis, C.E. Kruger, 2010. Methods for Producing Biochar and Advanced Biofuels in Washington State. Part 1: Literature Review of Pyrolysis Reactors. First Project Report. Department of Biological Systems Engineering and the Center for Sustaining Agriculture and Natural Resources, Washington State University, Pullman, WA, 137 pp.
13. International Biochar Initiative, 2011. "Standardized Product Definition and Product Testing Guidelines for Bichar That is used in Soil". http://www.biochar-international.org/characterizationstandard
14. International Biochar Initiative. 2008. Biochar: A soil amendment that combats global warming and improves agricultural sustainability and environmental impacts. http://www.biochar-international.org/publications/IBI
15. J. Lehmann & S. Joseph. Biochar for Environmental Management ed. Published by Earthscan, 2009.

16. Jim Reeb, Mike Milota. Oregon State University Corvallis, OR. Moisture Content by the Oven-dry Method For Industrial Testing (1999).
17. Lean, Geoffery (2008). ‘’Ancient skills could reverse global warming’ ‘’. The Independent. Retrieved 1 October 2011
18. Lehmann, J. 2007. Frontier Ecology and Environnent5:381-387
19. Lehmann, J., and S. Joseph, eds. 2009. Biochar for environmental management. London: Earthscan Publications Ltd
20. Lehmann, J., C. Czimczik, D. Laird, and S. Sohi. 2009. Stability of biochar in the soil. In Biochar for environmental management, ed. J. Lehmann and S. Joseph, 183-205. London: Earthscan Publications Ltd
21. Lehmann, J., D. C. Kern, B. Glaser, and W. I. Woods, eds. 2003. Amazonian dark earths: Origin, properties, management. The Netherlands: Kluwer Academic Publishers
22. Lehmann, J., J. Gaunt, and M. Rondon. 2006. Bio-char sequestration in terrestrial ecosystems--A review. Mitigation and Adaptation Strate-gies for Global Change11:403–427
23. Liang, B., J. Lehmann, D. Solomon, J. Kinyangi, J. Grossman, B. O’Neill, J. O. Skyemstad, J. Theis, F. J. Luizao, J. Peterson, and E. G. Neves. 2006. Black carbon increases cation exchange capacity in soils. Soil Science Society of America Journal 70:1719-1730
24. Michael Halwachs, Gerhard Kampichler, Hermann Hofbauer. Institute of Chemical Engineering, Vienna University of Technology, Getreidemarkt 9/166
25. Odebunmi E.O. and Okeola O.F. 2001. Preparation and characterization of activated carbon from waste materials. J. Chem. Soc. Nig., 26(1): 149 – 155.

26. Ogunjobi JK, Production and characterisation of bio-oil and bio-char from selected slow-pyrolysed plant-based agricultural wastes (2012) M.Tech. Thesis, The Federal University of Technology, Akure, Nigeria.
27. Okeola F. O., Odebunmi E. O. and *Ameen O. M. Department of Chemistry, University of Ilorin, Ilorin, Nigeria. Advances in Biotechnology & Chemical processes 1 (2011) 17-21
28. Paul S. Anderson, PhD ETHOS Conference of 2012 --- Seattle-Kirkland, WA 29 January 2012
29. R. C. Pradhan, S. N. Naik, N. Bhatnagar and V.K. Vijay. Physical Properties of Tree Borne Oil Seed: Potential Biodiesel Feedstock in India. Center for Rural Development and Technology, IIT Delhi-11016, India. Mechanical Engineering Department .
30. Robert Prins, Wayne Teel, John Marier, Geoff Austin, Tim Clark, and Brandon Dick James Madison University. Design, Construction, and Analysis of A Farm-Scale Biochar Production System (2010)
31. S. P. Sohi, E. Krull, E. Lopez-Capel, and R. Bol, A Review of Biochar and Its Use and Function in Soil. In DONALD L. SPARKS editor: ADVANCES IN AGRONOMY, Vol. 105, Burlington: Academic Press, 2010, pp.47-82.
32. Sombroek, W. G. 1966. Amazon soils: A reconnaissance of the soils of the Brazilian Amazon region. Wageningen: Agricultural Publications and Documentation 672:283
33. Wei Zheng; B.K. Sharma; Using Biochar as a Soil Amendment for Sustainable Agriculture. Nandakishore Rajagopalan Illinois Sustainable Technology Center University of Illinois at Urbana-Champaign.
34. Cetin, E., Moghtaderi, B., Gupta, R., Wall, T.F., 2004. Influence of pyrolysis conditions on the structure and gasification reactivity of biomass chars. Fuel 83, 2139-2150