JIMMA UNIVERSITY
JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF MECHANICAL ENGINEERING

SUSTAINABLE ENERGY ENGINEERING MASTERS PROGRAM

RECYCLING ORGANIC SOLID WASTES BY USING PYROLYSIS TECHNIQUES OF ENERGY AND BIOCHAR PRODUCTION: THE CASE OF KHAT IN JIMMA TOWN.

A thesis submitted to the School of Graduate Studies of Jimma University in partial fulfillment of the requirements for award of Degree of Masters in Sustainable Energy Engineering.

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Jimma, Ethiopia

Declaration

I, the under singed declare that the thesis entitled "Recycling organic solid wastes by using pyrolysis techniques of Energy and Biochar Production: the case of khat in Jimma town is my original work and has not been presented by any other person for an award of a degree in this or any other university.

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Executive summary

Biochar is a carbon-rich solid material produced during pyrolysis, which is the thermochemical conversion of biomass in the absence of oxygen. Biochar can be used for soil and compost amendment to increase agronomic productivity. It reduces greenhouse gases, such as carbon dioxide and methane, are released into the atmosphere imparting on global warming. When the objective of these thesis was to process recycling organic solid wastes by using pyrolysis techniques of energy and biochar production from khat waste (local name in leftover Geraba). The method was purely experimental in the laboratory as well as in the field where samples to tested by using laboratory equipment. Procedurally, organic waste (khat) was changed into the energy and biochar in pyrolysis techniques by selected stoves. When the biochar production used for soil fertility, which was described their effects by growing the same species like maize with biochar and without biochar. The temperature profile during pyrolysis was determined using a K-type thermocouple. The production of biochar from normal nelia and continuous feeding type anelia stove at the same heating temperature and time through measuring biomass bed temperature of stove was undertaken. For the comparison the same two points was selected in the solid domain of the stove geometry from 10cm below from top and 10 cm above from the bottom, the data was measured by inserting K-type thermocouple by the help of Digital thermometer in ten minute difference up to 60 minutes. Bulk density, pH and surface area of the biochar was measured. The biochar produced is highly alkaline, with all pH values recorded in 60 minute the pH 8.2 for N.A stove and C.A stove in solar (open drying) test, and N.A stove and C.A stove in oven tes is 8.3 and 7.8 respectively. After the experimental test results, the continuous anelia feeding type stove is modeled based on experimental temperature results to validate its temperature profile distribution differences by CFD simulation. When the CFD simulation temperature profile distribution is greater than the experimental, and generally it shows that the experimental temperature more accurate than the simulation temperature.

Key words:-organic solid wastes (khat), biochar, test, CFD simulation and stoves compassion.

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Table of Contents

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List of Figure

`

`

List of Table

`

Nomenclature

0.1NHCl 0.1	Normal hydrochloric acid
0.1NNaOH 0.1	Normal sodium hydroxide
A	Surface Area
ASTM	American society Testing and material
BD	Bulk density
C	Carbon
°C	Degree centigrade
C.A	Continuous feeding Anila type stove
CH4	Methane
CO	Carbon Monoxide
EHV	Effective Calorific Value
GHG	Greenhouse Gas
gm	Gram
h	Hour
HHV	Higher Heating Value
LHV	Lower Heating value

CHAPTER ONE

Introduction

1.1 Background of the Study

Biochar is a charred by product of biomass pyrolysis produced from biological wastes, crop residues, animal poultry manure, or any type of organic waste material. Pyrolysis is the chemical breakdown of a substance under extremely high temperatures in the absence of oxygen. Biochar production through pyrolysis is considered a carbon-negative process because the biochar sequesters carbon while simultaneously enhancing the fertility of the soil. Biochar has the capability to both mitigate greenhouse gas emissions and other environmental hazards. It can also be used as a soil amendment and source of alternative energy. The major potential benefits of biochar are carbon sequestration, greenhouse gases (GHG) emission reduction, and enhancement in soil fertility.

Carbon sequestration is the capture and storage of carbon to prevent it from being released to the atmosphere. Studies suggest that biochar sequesters approximately 50% of the carbon available within the biomass feedstock being pyrolyzed, depending upon the feedstock type (Lehmann, et al., 2006) (1).

Biochar is produced by pyrolysis (Lehmann et al. 2006). Pyrolysis is generally categorized by the temperature and length of time that the feedstock is heated; ‘’fast’’ pyrolysis typically happens on the order of seconds (heating rates ≥1000 ºC /minute) at temperatures above 500 ºC, and this condition maximizes the generation of bio-oil. ’’Slow’’ pyrolysis usually takes at least 30 minutes to several hours (heating rates ≤ 100 ºC /minute), within the temperature range 250 – 500 ºC for the feedstock to fully pyrolyze, and yields more biochar (Wright, & Brown, 2011) (2).

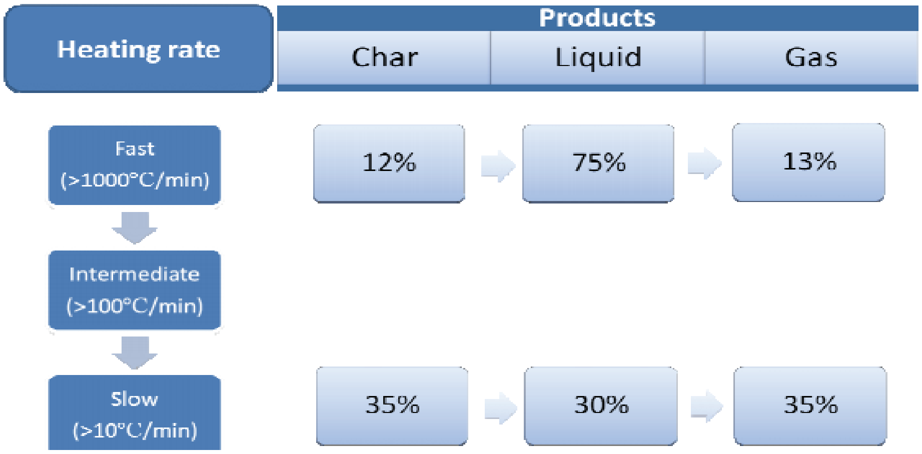

Figure 1.1 Role of heating rate on pyrolysis products **(Source: Masek, 2009)**

Biochar is a fine-grained porous carbonaceous solid, high in organic carbon and largely resistant to decomposition. It is characteristically comparable to charcoal produced from agricultural residues. Produced by heating biomass materials in the absence (or under reduction) of air has physiochemical properties suitable for the safe and long-term storage of carbon in the environment and, potentially, soil improvement (Lehmann *et al* 2009) (3).

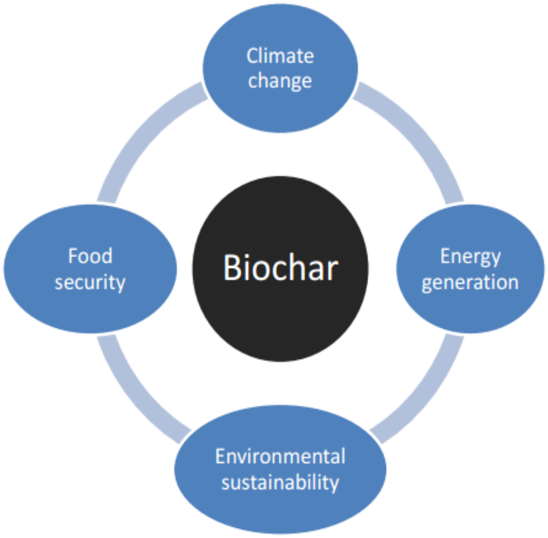

Figure1.2.The centrality of biochar to global issues (source: ecowas regional bioenergy forum bamako, mali 19 - 22. march 2012)

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Production of biochar from solid waste is one of the solutions for waste reduction and converts into usable products. Biochar is the charcoal produced from biomass by burning in the absence of oxygen or in the presence of little oxygen by methods of pyrolysis. Thermal treatment such as pyrolysis has been considered as a sustainable technology for biodegradable waste treatment as it has the potential to convert biomass into a biochar that can be used as soil fertilizer, produced green energy and mitigate greenhouse gas emissions. At the same time, it could help local authorities to divert waste from landfills (Ibarrola, *et al.*, 2010).

Biochar formed through the gasification of biomass in a process known as pyrolysis. This is accomplished by placing woody biomass inside an oxygen-limited container and heating it. As the biomass heats up, any moisture in the biomass is vaporized. The formation of the resulting water vapor creates positive pressure in the container, displacing the initial charge of air. Without oxygen to ignite the material in the container, the biomass goes through a gasification cycle where most of its volatile components are released from its carbon structure in the form of hydrogen, carbon monoxide, and methane, which is called syngas. These gases are flared as they leave the container, stored for other uses, to supplement the heat source that is driving the pyrolysis process (International Biochar Initiative, 2008).

1.1.2 Problem statement

- Unaddressed Disposal waste of khat that leads to environmental pollution
- It mitigate greenhouse gas like co_2 ,nitrous oxide emission and methane
- It increases transportation cost when it took to the disposal area.
- It wastes more energy and time when collecting from disposed place.
- It blocks the drainage ditches.

1.1.3. Objective of the project

1.1.4 General Objectives

The general objective of this thesis is to Recycling organic solid wastes by using pyrolysis techniques of Energy and Biochar Production: the case of khat in Jimma town.

1.1.5 Specific Objectives

- To collect khat wastes and change into biochar.

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- To determine the biomass bed temperature difference selecting two point in top and bottom of the stove.
- To describe the biomass bed temperature difference in ten minutes by using the chart graph
- To determine the biochar effect by plotting the same species like maize with and without biochar.
- To measure the moisture content difference with solar (open drying) and home (closed drying) by experimentally.
- To compare the pH value over the two stoves normal anelia and continuous feeding anelia stove.
- To validate the experimental temperature result by using CFD simulation.

1.1.6. Significance of the Study

Recycling the khat waste into biochar gives following advantages

- create good and green environment
- reduces green gas emission like co_2 ,reducing methane and nitrous oxide from the soil
- reduce the transportation cost and nutrient leaching
- Save energy.
- soil carbon sequestration and enhancement
- increase water holding capacity and microbial activity
- Enhance nutrient retention, cation exchange capacity and crop nutrient bioavailability
- pH amelioration

1.1.7. Scope of the Study

The scope of this study focuses only the khat wastes that changes into the Energy and biochar production which is checked its effect and differentiate the experimental temperature distribution by CFD Simulation.

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CHAPTER TWO

Review of Related Literature

2.1 Definition of Biochar and Pyrolysis

2.1.2 What is Biochar

Biochar is defined as ―the carbon rich product when biomass is heated with little or no available oxygen; produced with the intent to be applied to soil as a means to improve soil health, to filter and retain nutrients from percolating soil water, and to provide carbon storage.‖ This definition adopted by the International Biochar Initiative (IBI) specifies the need for purposeful application of the material to soil for agricultural and environmental gain. They thus define biochar primarily by its purpose, not by its physical or chemical properties. Lehman (2007) also defined biochar as "a carbon-rich product obtained when organic biomass is heated under limited or without oxygen conditions‘‘.

The term biochar was originally associated with a specific type of production, known as _slow pyrolysis. However, the term biochar has since been extended to products (char) of short duration pyrolysis at higher temperatures known as _fast pyrolysis and other techniques such as gasification (Sohi *et al*., 2009). The central quality of biochar that makes it attractive as a soil amendment is the high affinity of nutrients to biochar and appears to be more stable and have been observed to remain in soil for hundreds or even thousands of years (Lehman *et al*., 2006).

In addition, biochar is highly absorbent and therefore increases the soils ability to retain water, nutrients and agricultural chemicals, preventing water contamination. It also contains most of the nutrients that were in the biomass, can release them slowly and is a liming agent (Laird, 2008). Hence, these properties can be used effectively to address some of the most urgent environmental problems including soil degradation and food water pollution from agrochemicals and climate change (Laird, 2008).

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2.1.3 Biochar Production

2.1.4 Pyrolysis

The pyrolysis of biomass is an ancient technology, which is still relevant within energy production and conversion of biomass (Antal and Grønli, 2003; Demirbas and Arin, 2002). Charcoal has been produced from pyrolysis of (woody) biomass for thousands of years, and recently the technology has also become interesting for use in the production of biochar (Laird, et al., 2009).

Pyrolysis allows the production of biochar by heating with essentially little to no oxygen present. In addition to the biochar, the process also results in bio-oils and synthesis gas or syngas that are used for further combustion and renewable fuels, the process can be seen in Figure 2.2 (Kwapinski et al**.** 2010). The charcoal solid, termed biochar, if deliberately made for soil application, is generally of high carbon content, up to 50 % of the original plant-carbon.

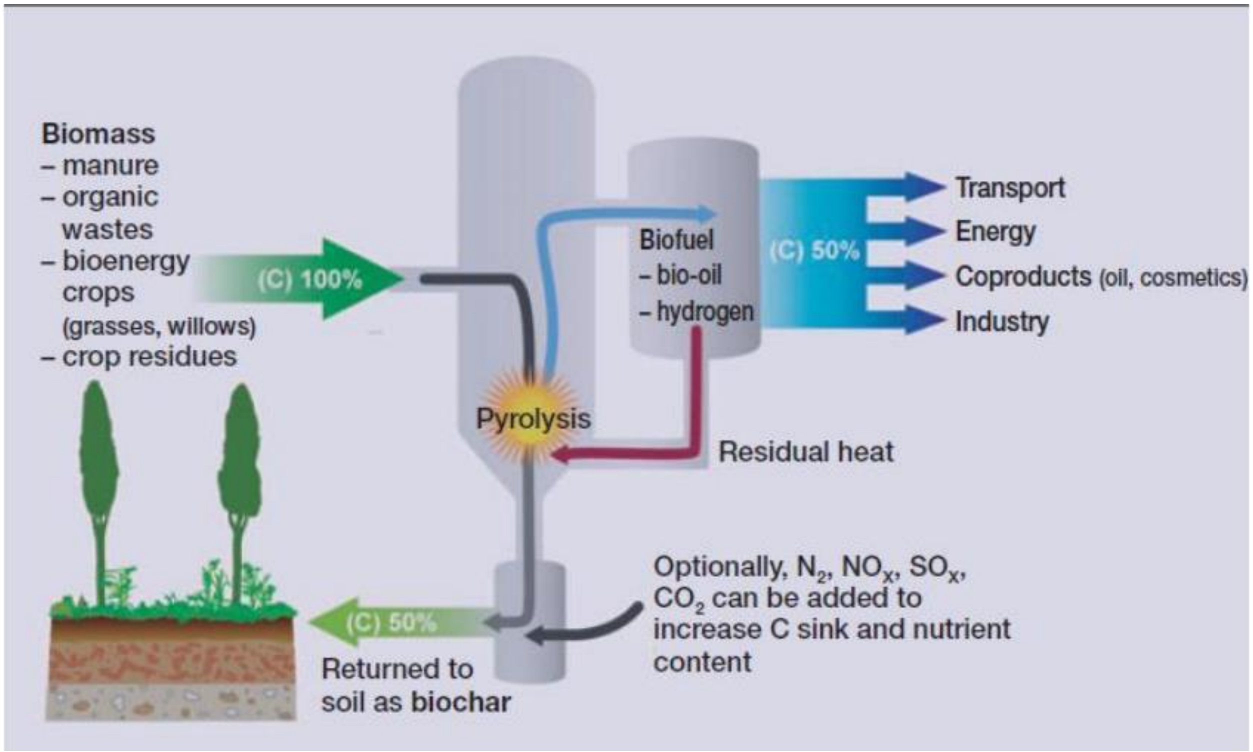

Figure 2.3 Pyrolysis of biomass, typically, about 50% of the pyrolyzed biomass is converted into biochar and can be returned to soil (Source: Stoyle, 2011)

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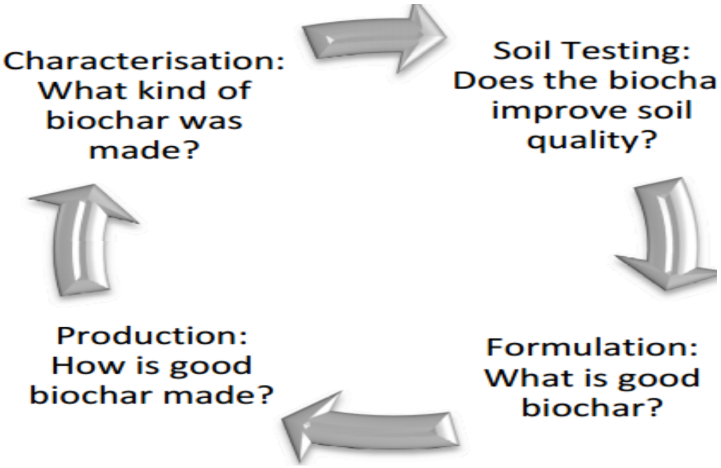

Figure.2.4 The 'trial and error' approach necessary for linking pyrolysis technology and resulting bio-chars with soil quality improvement.(**Source:** Adapted from www.cset.iastate.edu/researchprojects/bio-char.html)

2.1.5 Chemical Composition

The composition of biochar is highly heterogeneous, containing both stable and labile components (Sohi et al., 2009). However, carbon, volatile matter, mineral matter (ash) and moisture are generally regarded as its major constituents (Antal and Gronli, 2003). Table 2.1 summarizes their relative proportion ranges in biochar as commonly found for a variety of source materials and pyrolysis conditions. The relative proportion of biochar components determines the chemical and physical behavior and function of biochar as a whole (Brown, 2009), which in turn determines its suitability for a site specific application, as well as transport and fate in the environment (Downie, 2009). For example, coarser and more resistant bio-chars are generated by pyrolysis of wood-based feedstocks (Winsley, 2007).

Table 2.1 Relative proportion range main components of biochar

Component	**Proportion (wt %)**
Fixed carbon	23-90
Volatile matter	0-40
Moisture	1 – 10
Ash (mineral matter)	0.5-75

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Relative proportion range main components of biochar as commonly found of the four for a variety of source materials and pyrolysis conditions (adapted from Brown, 2009; Antal and Gronli, 2003; Deenik and McClellan, 2011, Sukartono *et al.*, 2011)

2.1.6 Significant Climate Mitigation Is Available from Biochar

Turning biomass into “biochar” (also known as “agri-char”) can store massive amounts of carbon in soils on a time scale of hundreds to thousands of years. This high-carbon, fine grained residue can be produced either by smoldering biomass utilizing centuries-old techniques (i.e., covering burning biomass with soil and letting it smolder) or through modern pyrolysis processes. Pyrolysis is the direct thermal decomposition of biomass in the absence of oxygen to obtain an array of solid (biochar), liquid (bio-oil) and gas (syngas) products. This process is energy-positive, and carbon-negative. The specific yield from the pyrolysis is dependent on process conditions, and can be optimized to produce either energy or biochar. Even when optimized to produce char rather than energy, the energy produced per unit energy input is higher than for corn ethanol.

In addition to its potential for carbon sequestration, biochar has numerous co-benefits when added to soil. It can prevent the leaching of nutrients out of the soil, increase the available nutrients for plant growth, increase water retention, and reduce the amount of fertilizer required. Additionally, it has been shown to decrease N_20 and CH_4 emissions from soil, thus further reducing GHG emissions. Biochar can be utilized in many applications as a replacement for or coterminous strategy with other bio-energy production strategies. One of its most immediate uses is in switching from “slash-and-burn” to “slash-and-char” to prevent the rapid deforestation and subsequent degradation of soils.

“Biochar sequestration does not require a fundamental scientific advance and the underlying production technology is robust and simple, making it appropriate for many regions of the world.” Johannes Lehmann, of Cornell University, estimates that pyrolysis will be cost feasible when the cost of a CO_2 ton reaches $37 (as of the end of June 2008, CO_2 is trading at ~$45/ton on the ECX) – so using pyrolysis for bio-energy production is feasible, even though it may be more expensive than fossil fuels at the moment.

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2.1.7 Pyrolysis of biomass as a carbon sink (biochar)

Biochar can be used to sequester carbon on centurial or even millennial time scales. Plant matter absorbs CO_2 from the atmosphere while growing. In the natural carbon cycle, plant matter decomposes rapidly after the plant dies, which emits CO_2. Instead of allowing the plant matter to decompose, pyrolysis can be used to sequester the carbon in a much more stable form. Biochar thus removes circulating CO_2 from the atmosphere and stores it in virtually permanent soil carbon pools, making it a truly carbon-negative process. In places like the Rocky Mountains, where beetles have been killing of vast swathes of pine trees, the utilization of pyrolysis to char the trees instead of letting them decompose into the atmosphere would offset substantial amounts of CO_2 emissions. Although some organic matter is necessary for agricultural soil to maintain its productivity, much of the agricultural waste can be turned directly into biochar, bio-oil, and syngas. The use of pyrolysis also provides an opportunity for the processing of municipal waste into useful clean energy rather than increased problems with land space for storage. Biochar is believed to have long mean residence times in the soil. While the methods by which biochar mineralizes (turns into CO_2) are not completely known, evidence from soil samples in the Amazon shows large concentrations of black carbon (biochar) remaining after they were abandoned thousands of years ago. The amount of time the biochar will remain in the soil depends on the feedstock material, how charred the material is, the surface: volume ratio of the particles and the conditions of the soil the biochar is placed in. Estimates for the residence time range from 100 to 10,000 yrs, with 5,000 being a common estimate. Lab experiments confirm a decrease in carbon mineralization with increasing temperature, so carefully controlled charring of plant matter can increase the soil residence time of the biochar C. Under some circumstances, the addition of biochar to the soil has been found to accelerate the mineralization of the existing soil organic matter, but this would only reduce the net benefit gained by sequestering carbon in the soil by this method.

2.1.8 Production of biochar

The yield of products from pyrolysis varies heavily with temperature. The lower the temperature, the more char is created per unit biomass. High temperature pyrolysis is also known as gasification, and produces primarily syngas from the biomass. The two main methods of pyrolysis are “fast” pyrolysis and “slow” pyrolysis. Fast pyrolysis yields 60% bio-oil, 20% biochar, and 20% syngas, and can be done in seconds, whereas slow pyrolysis can be optimized to produce substantially more char (~50%), but takes on the order of hours to complete. For typical inputs, the energy required to run a "fast" pyrolyzer is approximately 15% of the energy that it outputs. Modern pyrolysis plants can be run entirely off of the syngas created by the pyrolysis process and thus output 3-9 times the amount of energy required to run. The ancient method for producing biochar as a soil additive was the "pit" or "trench" method, which created terra preta, or dark soil. While this method is still a potential to produce biochar in rural areas, it does not allow the harvest of either the bio-oil or syngas, and releases a large amount of CO_2, BC (black carbon), and other GHGs (and potentially, toxins) into the air. Modern companies are producing commercial-scale systems to process agricultural waste, paper byproducts, even municipal solid waste.

2.1.9 Main Factors Affecting Biomass Pyrolysis

- **Temperature Profile Control**

The temperature profile is the most important aspect of operational control for pyrolysis processes (Brown, 2009). For fast pyrolysis a rapid heating rate and a rapid rate for cooling primary vapours are required to minimize the extent of secondary reactions. These reactions not only reduce the liquid yield but also tend to reduce its quality, giving a more complex mixture, an increased degree of polymerisation and higher viscosity (Bridgwater and Peacocke, 2000). Conversely, in slow pyrolysis there is some evidence that slow heating leads to higher char yields, but this is not consistent (Antal and Grønli, 2003).

Peak temperature, however, has an unequivocal effect on char yields and properties. Higher temperatures lead to lower char yield in all pyrolysis reactions. This results from the main controlling variable of pyrolysis reaction kinetics being temperature (Antal and Grønli, 2003).

The effect can be thought of as more volatile material being forced out of the char at higher temperatures reducing yield but increasing the proportion of carbon in the char. For example, Bio-char yield from switchgrass pyrolysis conducted by Imam and Capareda (2011) decreased from 48 % to 43 % from samples pyrolysed at 400 and 500 ^{0}C, respectively; the biochar yield decreased markedly from 43 % to 25 % between samples pyrolysed at 500 and 600 ^{0}C.

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Many researchers have attributed this decrease in the char yield with increasing temperature, either to primary decomposition of the feedstock at higher temperatures or to secondary decomposition of the biochar. At very low temperatures the biochar formation is high. This is because the heating rate is lower, and therefore slow pyrolysis is simulated.

Temperature also has an effect on char composition, chars produced at higher temperatures having higher carbon contents. This may have important implications for biochar stability in soils. Solid residence time is also important but to a lesser degree than peak temperature, longer time at temperature leading to lower char yield(Brownsort 2009). Kuzyakov et al. (2009) and Peng et al. (2011) also reported yield decreased with increasing charring duration for the same temperature.

Temperature effect on liquid and gas yield is more complex. Liquid yields are higher with increased pyrolysis temperatures up to a maximum value, usually at 400-550 °C but dependent on equipment and other conditions. Above this temperature secondary reactions causing vapour decomposition become more dominant and the condensed liquid yields are reduced. Gas yields are generally low with irregular dependency on temperature below the peak temperature for liquid yield; above this gas yields are increased strongly by higher temperatures, as the main products of vapour decomposition are gases. For fast pyrolysis the peak liquid yields are generally obtained at a temperature of around 500°C. Peak liquid yields for slow pyrolysis are more variable. Demirbas (2001) reports peak liquid yields of 28- 41 % at temperatures between 377 °C and 577 °C, depending on feedstock, when using a laboratory slow pyrolysis technique.

- **Feedstock Composition**

Generally, biomass is composed of three main groups of natural polymeric materials: cellulose, hemicellulose and lignin. Other typical components are grouped as ‘extractives‘(generally smaller organic molecules or polymers) and minerals (inorganic compounds).

These are present in differing proportions in different biomass types and these proportions influence the product distributions on pyrolysis. Primary products of hemicellulose and cellulose decomposition are condensable vapours (hence liquid products) and gas. Lignin decomposes to liquid, gas and solid char products. Extractives contribute to liquid and gas products either through simple volatilisation or decomposition. Minerals in general remain in the char where

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they are termed ash (Antal and Grønli, 2003).Vapours formed by primary decomposition of biomass components can be involved in secondary reactions in the gas phase, or at hot char surfaces, resulting in the formation of secondary char (Antal and Grønli, 2003). Also minerals in biomass can have a catalytic effect on pyrolysis reactions leading to increased char yields in some circumstances, in addition to the effect of ash contributing directly to char yield (Brown, 2009).

- **Heating Rate**

Length of heating and its intensity affect the rate and extent of pyrolytic reactions, the sequence of these reactions, and composition of the resultant products. Pyrolytic reactions proceed over a wide range of temperatures; hence, products formed earlier tend to undergo further transformation and in a series of consecutive reactions. Further, various products are formed as secondary reactions to continuous heating of the initial products. Long heating periods allow the sequence of these reactions to take place whereas rapid heating (fast pyrolysis) tends to reduce these secondary reactions and the further degradation of the earlier formed products. If heat is supplied fast enough during pyrolysis, little or no char result.

The yield of volatile products (gases and liquids) increases with increasing heating rate while solid residue decreases. The effect of heating rate can be viewed as the effect of temperature and residence time. As the heating rate increases, the residence time of volatiles at low or intermediate temperatures decreases. Most of the reactions that favour conversion to gas occur at higher temperatures. At low temperature, char is the dominant product. Heating rate is a function of the feedstock size and the type of pyrolysis equipment. The rate of thermal diffusion within a particle decreases with increasing particle size, thus resulting in lower heating rate. Liquid products are favored by pyrolysis of small particles at high heating rates and high temperature, while char is maximized by pyrolysis of large particles at low heating rates and low temperatures as mentioned earlier.

Ayll'on et al. (2006) studied pyrolysis of meat and bone meal in a fixed bed reactor and investigated the influence of the final pyrolysis temperature and heating rate on the product (char, tar and gas) distribution and composition as well as char characterization. Two sets of experiments were performed at different final pyrolysis temperatures between 300 and 900 °C and heating rates from 2 to 14°C/min. Their results showed that the effect of the final pyrolysis temperature is more important than the effect of the heating rate.

2.2 Pyrolysis and Biomass components

Figure 2.2 shows a schematic pattern of biomass decomposition via pyrolysis. Pyrolysis of biomass can be described in terms of the behavior of these components, each of which is discussed separately in the following sections. Each component contributes to the behavior to an extent proportional to its weight percent contribution to the composition of the raw biomass.

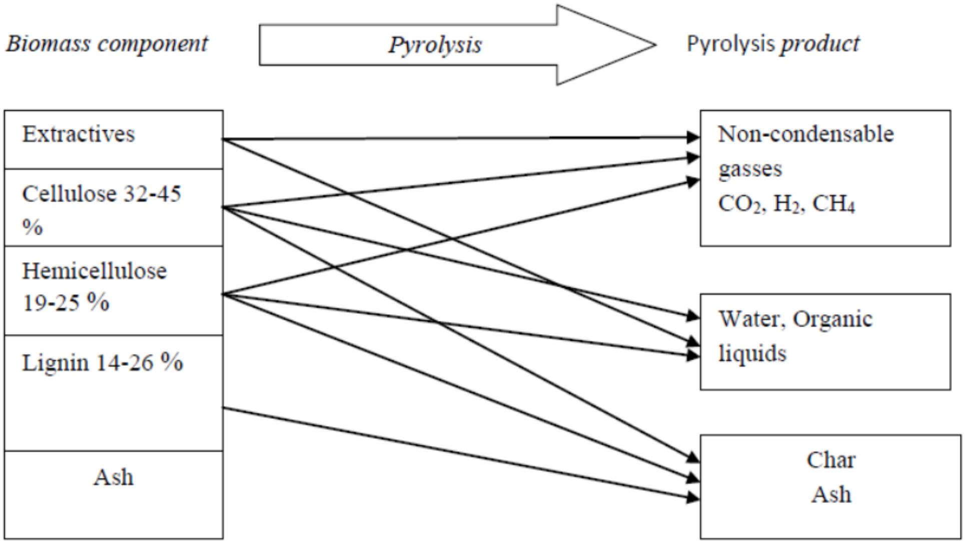

Figure 2.5 Generalised decomposition pattern of biomass from thermal decomposition in pyrolysis. *(Source: Adapted from Brownsort 2009)*

2.2.1 Pyrolysis of Cellulose

Of the principal components of biomass, cellulose is the most widely studied. This is mainly because it is the major component of most biomass (43%). In addition, it is the least complicated, best defined component of biomass. Cellulose is the major source of the combustible volatiles that fuel flaming combustion. Cellulose also appears natural naturally almost in its pure state (e.g., cotton).

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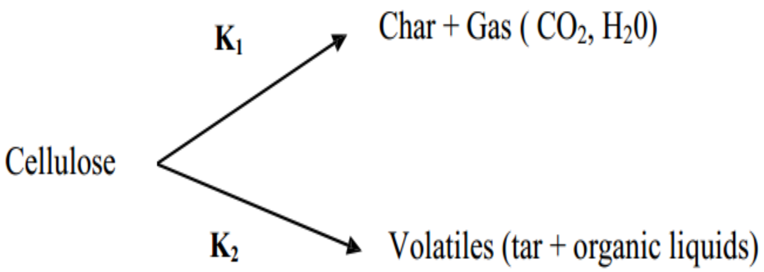

Figure 2.6 Simplified reaction model for cellulose decomposition *[source Slow Pyrolysis of Maize Stover for Biochar Production SEASSEY RAYMOND, July 2013.]*

Reaction 1 dominates at low temperatures while reaction 2 dominates at high temperatures. The existence of the two pathways is demonstrated by studies of the rates of weight loss of cellulose in nitrogen; the transition is found to occur at about 300°C. Below this temperature, the following chemical reactions may occur: reduction of molecular weight, the appearance of free radicals, oxidation, dehydration, decarboxylation, and decarbonylation. The products are mainly CO_2, H_20, and a char residue.

The second pathway occurs at temperatures above 300°C and involves decomposition of cellulose to tarry pyrolyzate-containing levoglucosan as the major component (22-50%), which vaporizes and then decomposes with increasing temperature. As the temperature is increased from 300°C to 500°C, the amount of tarry products increases while the proportion of char component diminishes and the yields of levoglucosan remain almost constant.

The major products of pyrolysis of cellulose below 500°C are char, tar, water and CO_2 (Funakuzuri et al., 1986). The yield of light hydrocarbons, i.e., C1 - C4, is negligible below 500°C but becomes considerable at high temperatures (Scott et al., 1988).

2.2.2 Pyrolysis of Hemicellulose

Glucoronoxylans (commonly referred to as xylan) are the most important hemicelluloses of hardwoods, and glucomannan is the predominant hemicellulose in softwoods. Xylan has been used in several studies (Koufopanos et al., 1989) to model the pyrolysis of hemicelluloses. Hemicelluloses are the most reactive major component of wood decomposing in the temperature range 200-260ºC. The thermal instability of hemicelluloses is probably due to their lack of crystalline. Decomposition of hemicellulose under pyrolytic conditions is postulated to occur in

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two steps (Soltes and Elder, 1981). First is the breakdown of the polymer into water soluble fragments followed by conversion to monomeric units, and finally decomposition of these units to volatiles. Hemicelluloses produce more gases and less tar than cellulose. They also produce more methanol and acetic acid than cellulose.

2.2.3 Pyrolysis of Lignin

Lignin, the third major component of woody biomass, is a highly linked (3-D network polymer), amorphous, high molecular weight phenolic compound. Lignin serves as cement between the wood fibers and as a stiffening agent within them. Lignin is the least reactive component of biomass; higher temperatures are necessary for the pyrolysis of most lignin. The time required for complete pyrolysis of woody biomass at a given temperature is controlled by the pyrolysis rate of lignin at the operating conditions. Thermal decomposition of lignin occurs in the temperature range 280°C to 500°C, although some physical and/or chemical changes (e.g., depolymerization, loss of some methanol) may occur at lower temperatures (Koufopanos et al., 1989). At a slow heating rate, lignin loses only about 50% of its weight when the pyrolysis is stopped at 800°C.Pyrolysis of lignin yields more char and tar than cellulose. Soltes and Elder (1981) have reported a product composition of 51-66 % char, 14-15 % tar and about 12 % gaseous products (consisting mainly of CH_4 and C_2H_6).

2.2.4 Reactions Involved In Pyrolysis Process

The biomass is directly and visibly affected as the pyrolysis process proceeds. For example, the color of the biomass changes from white to brown to black. Size and weight are reduced while flexibility and mechanical strength are lost. At temperatures around 350ºC, weight loss reaches about 80% and the remaining biomass is converted to char. Prolonged heating or exposure to temperatures of about 600ºC reduces char fraction to about 9% of the original biomass weight. The primary pyrolysis reactions are either dehydration or fragmentation reactions. Thereafter, several products will be produced.

The reaction mechanisms of biomass pyrolysis are complex but can be defined in three main steps:

- Biomass Water + Unreacted residue …………………………………………… (1)
- Unreacted residue $(Volatile)_1 + (Gases)_1 + (Char)_1$ …………………………… (2)

- Char (Volatile) $_2$ + (Gases) $_2$ + (Char) $_2$…………………………………………....... (3)

Pyrolysis proceeds in three steps: in the initial step moisture and some volatile loss (equation (1)). In the secondary step, primary bio-char is formed (equation (2)). The last fast step follows by a slower step including some chemical rearrangement of the bio-char. During the third step, the bio-char decomposes at a very slow rate and carbon-rich residual solid forms. The formation of secondary charring (equation (3)) makes the char less reactive (Demirbas, 2004).

2.2.5 Co-benefits of pyrolysis.

Biochar can be used as a soil amendment to increase plant growth yield, improve water quality, reduce soil emissions of GHGs, reduce leaching of nutrients, reduce soil acidity, and reduce irrigation and fertilizer requirements. These properties are very dependent on the properties of the biochar, and may depend on regional conditions including soil type, condition (depleted or healthy), temperature, and humidity. Modest additions of biochar to soil were found to reduce N_2O emissions by up to 80% and completely suppress methane emissions. Switching from slash-and-burn to slash-and-char techniques in Brazil can both decrease deforestation of the Amazon and increase the crop yield. Under the current method of slash-and burn, only 3% of the carbon from the organic material is left in the soil. Switching to slash and-char can sequester up to 50% of the carbon in a highly stable form. Adding the biochar back into the soil rather than removing it all for energy production is necessary to avoid heavy increases in the cost and emissions from more required nitrogen fertilizers.

2.2.6 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 bio-charring 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.

Figure 2.7 importance of biochar Sources (new biochar-powered farming with the innovative pro-natural newsletter april **2013)**

3. Biochar reduces climate change caused by emissions of carbon dioxide (CO_2) 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. **Source** (http:// www.airterra.ca/biochar-what-is-biochar/why-is-biochar-important)

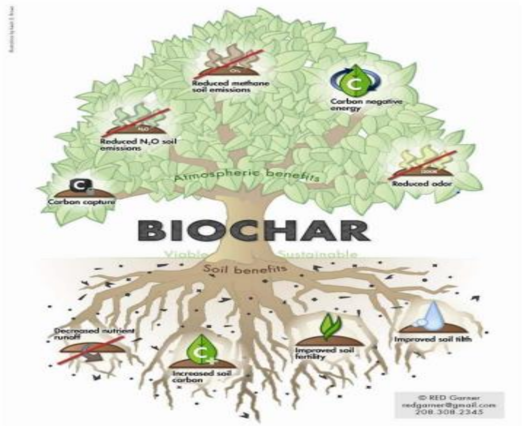

Figure 2.8 Diagram illustrating biochar and its benefits (**Source** (http:// www.airterra.ca/biochar-what-is-biochar/why-is-biochar-important))

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2.2.7 Biochar to produce energy

Capturing energy during biochar production and, conversely, using the biochar generated during pyrolysis bioenergy production as a soil amendment is mutually beneficial for securing the production base for generating the biomass (Lehmann, 2007a), as well as for reducing overall emissions (Gaunt and Lehmann, 2008). Adding biochar to soil instead of using it as a fuel does, indeed, reduce the energy efficiency of pyrolysis bioenergy production; however, the emission reductions associated with biochar additions to soil appear to be greater than the fossil fuel offset in its use as fuel (Gaunt and Lehmann, 2008). A biochar vision is therefore especially effective in offering environmental solutions, rather than solely producing energy.

This appears to be an appropriate approach for bioenergy as a whole. In fact, bioenergy, in general, and pyrolysis, in particular, may contribute significantly to securing a future supply of green energy. However, it will, most likely, not be able to solve the energy crises and satisfy rising global demand for energy on its own.

2.2.8 Using Biochar Systems to Sequester Carbon

Biochar that is used for energy is similar to bioenergy from crop and plantations and from agricultural and forestry residues. Only soil sequestrations of bio-char, or any other permanent storage of biomass, are carbon-negative: CO_2 is removed from the atmosphere and then sequestered (assuming sequestration last sufficiently long). With pyrolysis, biochar and energy can be co-produced, enabling energy production to be carbon-negative through sequestration of its co-product.

- Carbon Positive (increases atmospheric carbon) Takes sequestered carbon and emits it into the atmosphere (e.g. burning fossil fuels)

- Carbon Neutral (no change in atmospheric carbon) Takes atmospheric carbon and emits it back into the atmosphere (e.g. natural carbon plant cycle) Takes sequestered carbon and sequesters it again (e.g. fossil fuel burning with carbon capture and sequestration).
- Carbon Negative (decreases atmospheric carbon) Takes atmospheric carbon and sequesters it (e.g. biochar)

`
Biochar systems have the potential to provide large amounts of high quality carbon offsets that can be purchased by the capped industries to meet their emission reduction requirements. The sale of these offsets can generate an income stream for the producers of the offsets. This sets the stage for the creation of a growth industry which can provide substantial economic benefits for rural agricultural areas around the world.

2.2.9 Analysis of the potential size of the Biochar system to provide carbon offsets.

2.3. Analysis assumptions

An analysis of the potential size of the biochar systems was conducted by the International Biochar Initiative. To understand the analysis of these biochar systems for creating carbon offsets, examining the processes involved and the basic assumptions underlying the analysis.

Availability of biomass: - Biomass is the feedstock for the biochar systems. Primary Production is the term used to represent the production of organic compounds from atmospheric or aquatic carbon dioxide, principally through the process of photosynthesis. Net Primary Production is the difference between the rate at which the plants in ecosystem produce useful chemical energy and the rate at which they during respiration. The analysis assumes the usage of a portion of the worlds Net Primary Production in the biochar systems. So, the analysis includes just biomass residue from crops and forests.

Table 3.3: Various scenarios of biomass usage for biochar systems

Scenario	Residue from crop and forests	Net primary production
Conservative	27%	1.2%
Moderate	50%	2.1%
Optimistic	80%	3.2%

Availability of land for sequestration:–Adequate land area is available for sequestration by returning the biochar to the land from which the biomass was taken. Although the removal of biomass of crop residues from fields can result in the reduction in soil productivity through reduced soil organic matter, returning a portion of the biomass in the form of biochar will more than offset this reduction and actually improve the productivity of the land.

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Modern biochar technology**:** – The analysis assumes that modern high-yielding technology of slow pyrolysis systems is used. The system assumes a 40 percent carbonization rate. In addition to producing biochar, the system produces renewable energy that can be used to substitute for fossil fuel energy and thereby reduce carbon emissions.

Stability of sequestered biochar carbon: – The value of sequestered carbon is highly dependent on the stability of the sequestration. The danger of a reversal or leakage of the sequestered carbon greatly impacts its value as a viable carbon offset. Biochar has been proven to be a very stable carbon storehouse. Biochar carbon remains sequestered in the soils for hundreds of years or longer.

2.3.1 Carbon sequestration from biochar

Estimates of the amount of carbon sequestered from biochar are presented in Figure. The Conservative, Moderate and Optimistic scenarios are based on the amount of biomass used in the biochar systems and is outlined above in Table. The term wedge represents one billion tons (gigatons) of carbon sequestered per year. As shown in Figure, after reaching its full potential, biochar has the ability to sequester from slightly above 0.2 to almost 0.8 billion tons of carbon per year. The moderate scenario sequesters about half a billion tons of carbon. The optimistic plus scenario sequesters over a billion tons annually by the year 2050.

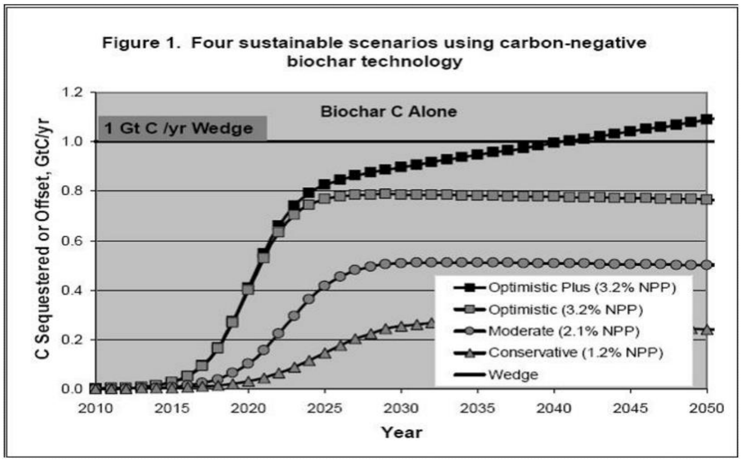

Figure 2.9: Four sustainable Scenarios using carbon-negative biochar technology (source: International Biochar Initiative)

Research indicates that biochar also has the potential to reduce soil emission of nitrous oxide ($N2O$), an extremely potent greenhouse gas. For example, approximately half of the greenhouse gas emissions from producing corn are nitrous oxide. Also applying biochar to soil has the effect of increasing the productivity of the soil.

The Optimistic Plus scenario shown in Figure includes the impact of these two factors. Nitrous oxide emissions are assumed to be reduced by 50 percent and the application of biochar to the soil has the potential to produce 25 percent more biomass due to increased soil productivity from the application of biochar.

2.3.2 Carbon sequestration from biochar and fossil carbon offsets

The biochar systems involve more than just converting biomass to biochar. These systems have the potential to produce significant amounts of bioenergy as discussed in the previous article. The bioenergy is carbon neutral because it emits carbon that was originally atmospheric carbon (converted to plant carbon through photosynthesis). Conversely, fossil fuel (coal) energy is carbon positive because it emits carbon into the atmosphere that was originally sequestered deep in the earth. The bioenergy produced by the biochar systems reduces carbon emissions and generates carbon offsets by substituting carbon neutral bioenergy for carbon positive fossil fuels. In addition, carbon dioxide emissions generated during the biochar production system can be sequestered through a carbon capture and sequestration process similar to the system being developed for the coal industry. The resulting carbon offsets are shown in Figure

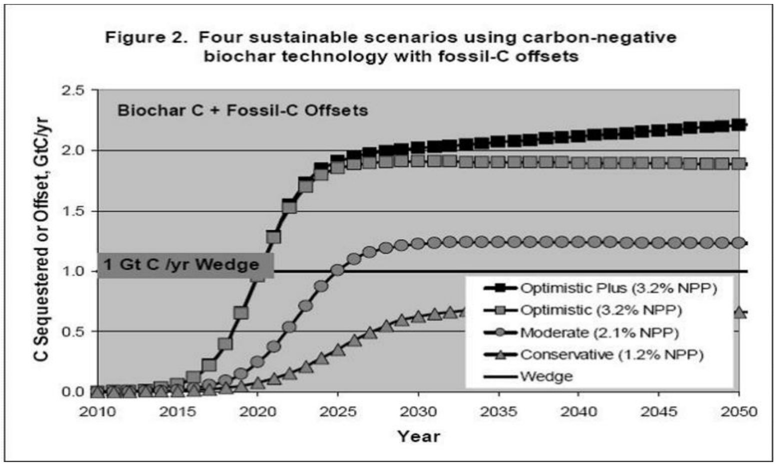

Figure 2.10: Four sustainable Scenarios using carbon-negative biochar technology with fossil-C offsets (source: International Biochar Initiative)

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When fully implemented, the reductions range from over one-half billion tons of carbon per year under the conservative scenario to almost two billion tons of carbon under the optimistic scenario. The moderate scenario results in about 1.25 billion tons per year. The optimistic plus scenario increases gradually over time resulting in about 2.20 billion tons by the year 2050.

2.3.3 Impact of biochar systems

To keep GHG levels at the level of 2004, it is estimated that we will need to reduce world greenhouse gas emissions by about seven billion tons per year by the year 2054. Worldwide, biochar systems can make an important contribution to this reduction as shown in table 3.4. Biochar alone could contribute about 10 percent of this reduction. When combined with the other offsets, the entire biochar system could contribute about 20 to 30 percent of the reduction.

Table 3.4: Estimated potential GHG emission offsets by 2050 from biochar systems under various scenarios.

Scenario	Biochar Alone	Biochar and Fossil offsets
Conservative	3%	10%
Moderate	7%	18%
Optimistic	11%	27%
Optimistic plus	15%	31%

U.S cap and trade legislation allows capped industries to purchase and utilize both domestic and international carbon offsets. Biochar system can provide a large supply of these carbon offsets. Under three alternative carbon prices, the value of the carbon offsets are shown in Table 3.5. At a carbon price of $15 per ton, the potential value of the carbon offsets are $18.7 billion dollars under the moderate scenario when the sequestration from both biochar and fossil fuel substitution are included. It increases to $62.5 billion at a carbon price of $50 per ton. The economic impact of these carbon offsets would have a substantial impact on agriculture and rural communities around the world.

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Table 3.5: Estimated Annual Carbon Offset Values by Scenario under Alternative Carbon Prices (billion dollars)

Biochar Alone	**$15/ton**	**$30/ton**	**$50/ton**
Conservative	3.3	6.6	11.0
Moderate	7.8	15.6	26.0
Optimistic	11.7	23.4	39.0
Optimistic plus	16.2	32.4	54.0
Biochar plus Fossil Offsets			
Conservative	10.5	21.0	35.0
Moderate	18.7	37.5	62.5
Optimistic	28.5	57.0	95.0
Optimistic plus	33.0	66.0	110.

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CHAPTER THREE

Methodology

3.1. Description of the Study Area

Jimma town is found in South west Ethiopia. It is located at 7°, 33 N and 36°, 57' E at an altitude of 1710 meter above sea level**.** The mean annual temperature of the town ranges around 26.8^0c to 11.4^0c. The relative humidities are 91.4% and 39.92%, respectively. The mean annual rainfall of the study area is 1500mm and the soils of the study area are dominated by Nitisol.

(Source:-BPEDORS, 2000. Physical and Socio-Economical Profile of 180 District of Oromia Region, Ethiopia)

3.1.1 Methods

The method is to collect the organic solid waste (khat) to change in biochar production by using following steps:-

- Collected the khat
- Pretreatments (dried the kaht in solar and in oven)
- Cutted(reducing size approximately 10cm) of the dried khat
- Inserted or fillied the size reduced khat in the selected stoves
- Water boiling test
- Burned
- Measured the temperature difference
- Weighed fire wood and char

3.1.2 Materials

3.1.3 Raw Material

The raw material of khat which is used to biochar production, and the khat Waste was collected from different sites and distributing center like shops.

3.1.4 Chemical Analysis of Biochar

The biochar was crushed to pass through 1mm sieve to make it suitable for analysis. Analyses of the biochar include proximate analysis, elemental analysis, pH, bulk density, and surface area of biochar.

3.1.5 Proximate Analysis

The proximate analysis on biochar was done according to the ASTM Standard Method for Chemical Analysis of Wood Charcoal with some slight modification on the analysis temperature range (ASTM D1762-84, reapproved 2007), since biochar is not destined to be used as a fuel source (Noor et al., 2012; McLaughlin, 2010). Proximate analysis refers the quantification of the moisture, volatile matter, fixed carbon, and ash fractions of a material (Edmunds, 2012).

3.1.6 Moisture Content of solid khat in solar (open air drying) and in oven (home)

The moisture content (MC) was found by weighing 1kg of the solid khat which shows sample (E) and oven dried at 105 º C 3 hours, until the mass of the sample was constant. The change in weight (D) was then used to determine the sample‘s percentage moisture content using equation.

$$Mcdb = \frac{E - D}{D} x100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (1)$$

Where: $M_C db$ = Moisture content (dry basis)

E = Mass of sample before drying

D = Mass of sample after drying

$\mathrm{Mcdb} = \frac{1000\mathrm{gram} - 890\mathrm{gram}}{890\mathrm{gram}} \mathrm{x}100\%$ = 12.4% Also, most bio charring units work best using moisture content in the range of 10 – 20% (Cummer and Brown, 2002) and 1-10% (dapted from Brown, 2009; Antal and Gronli, 2003; Deenik and McClellan, 2011, Sukartono *et al.*, 2011)

Figure 3.1 measuring the moister content of the khat.

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3.1.7 Moisture Content of biochar

The moisture content (MC) was found by weighing 2 g of the biochar sample (E) and oven dried at 105 ºC 3 hour, until the mass of the sample was constant. The change in weight (D) was then used to determine the sample‘s percentage moisture content using equation.

$$\mathrm{Mcdb} = \frac{\mathrm{E} - \mathrm{D}}{\mathrm{D}} \mathrm{x}100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(2)$$

3.1.8 Ash Content

Ash was the fraction of the moisture-free (mf) biochar that was not organic (McLaughlin, 2009). For determination of weight percentage of ash, the proximate analysis temperature of the muffle furnace was lowered to 550ºC (McLaughlin, 2009; Noor et al., 2012). Ash content was measured by heating 2 g of moisture-free biochar, finely ground, in an open top ashing crucible in a furnace to 550 ºC in an atmosphere of air for 4 hours. It is weighed after cooling in a desiccator to obtain the weight of the ash (C). Ashed samples were typically pale gray powder and exhibited no black particles of residual.

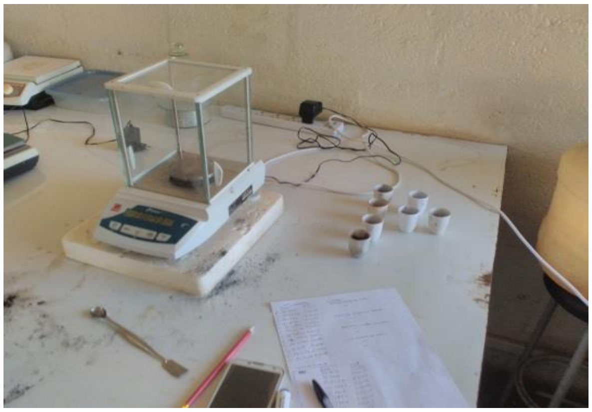

Figure 3.2 .measuring biochar to determine the ash content.

$$\text{Ash content(wt.\%)} = \left(\frac{\mathrm{C}}{\mathrm{A}}\right) \mathrm{x}100 \text{ (wt.\%)}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where C is weight of ash, and A weight of the biochar used for ashing.

3.1.9 Volatile Matter/ Mobile matter

Within moisture-free biochar there is a portion of organic matter that will not be permanent in the soil. This is the volatile matter, also termed ’’mobile matter’’. For fuels e.g coal, volatile matter is the gases released when coal is heated. However in biochar, it can be lost by leaching into the soil or by digestion by soil microbes, but it is not likely to be released as a gas. It is the portion of the moisture-free biochar that may easily migrate from the biochar into the soil, and serve as a source of organics for the soil microbes (McLaughlin, 2010). The volatile matter (VM) was determined by heating 2 g of moisture-free biochar sample in a in a furnace at a temperature of 450 °C for 30 minutes and weighed after cooling in a dessicator.

$$\text{volatile matter(wt.\%} = \left(\frac{F}{G}\right) x100 \text{ (wt.\%)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4)}$$

Where F - is the change in weight of the initial sample, and

G- is the weight of the moisture-free biochar sample.

A, Mass balance. B, heating biochar in furnace c, putting the heated char in desiccator

Figure 3.3 Temperature measurement of the volatile matter of the khat biochar

When heating the biochar in the furnace to determine volatile matter and after furnace putting in desiccator and weighing the weight of char after cooling desiccator.

3.1.9 Fixed Carbon

Fixed carbon is the portion of the moisture-free biochar that is not ash, but is expected to remain stable in the soil for a very long time. It is calculated by subtraction, being the portion of the moisture-free biochar that is not volatile matter and not ash. The weight percentage of fixed

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carbon (FC) content or ‘the recalcitrant matter’ of the biochar was calculated using Eqn. 4 (Noor et al., 2012

$$FC(wt.\% = [100\% - (\%AC + \%VM + \%MC)](wt.\%) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5).$$

3.2. Materials used for experimental test to produce Biochar

The experiments, was conducted in the field using to producing the biochar by using following materials likes:-

List of Materials for Experimental Test

- Cooking vessel
- Thermocouple
- Digital multi-meter
- thermometer
- Fuel (wood)
- Mass balance
- Watch and Water
- Match
- Stoves like Normal Anila stove and Continuous feeding Anila type Stove.
- Shaking machine
- Biomass (khat)
- Beakers, graduated Cylinders

- **Pretreatment (drying) of the kaht**

a. Khat drying in home (close drying)

b. khat drying in solar (open drying)

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Figure 3.5 measuring the moisture contents and filling the size reduced dried khat into the stove.

3.2.1 Water Boiling Test

The Water Boiling Test is a simplified simulation of the cooking process. It is intended to measure how efficiently a stove uses fuel to heat water in a cooking vessel (pan) and the making char. This lab-based test attempts to check or simulate the selected stove performances based on results as comparable as possible to decide the best one.

The following test consists of two phases, each of them representing a particular cooking situation processes:

(1) Bringing water to a boil with a cold stove (cold start).

This is a high power phase where the water is brought to the boiling point;

(2) Bringing water to a boil with a hot stove (hot start; and the results relate to four of the performance criteria: efficiency, fire power, time to boil and turn down ratio (the difference in fuel consumption per minute between high power and low power).

For each phase, water boiling test version 4.2.2 (Released 22 April 2013 was used which involves a series of measurements and calculations. For indirect stove biomass for char production is not inserted during water boiling test. The moisture content of the fuel, wood was measured using Standard test method for direct moisture content measurement of wood and wood-Base materials D4442-92(Reapproved 2003).

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Figure 3.6 Water boiling test in normal feeding Anila stove

3.2.2 The determination of Moisture content of the Fuel

When the Moisture content of the fuel wood was determined by using Drying oven to putting 1kg of fuel wood at 105^0c for three hours.

Moisture content (wet basis) of the wood was calculated as following

$$Mc = \frac{Mfw - Mfd}{Mfw} \dots\dots\dots\dots\dots\dots\dots\dots\dots.(1)$$

Where: - Mc- moisture content of fuel

$M_{fw:-}$Mass of fuel wet before drying

M_{fd}:- Mass of fuel wet after drying

3.2.3 Determination of the Calorific Value and moisture content of wood

Table 3.6 Ultimate analysis of eucalyptus wood. (13)

Ultimate Analysis	**Lower calorific value of wood**	**Higher calorific value of wood**
C	50	53
H	5.8	7
N	0	0.34
Cl	0.0001	0.1
O	3.8	44
S	0	0.1
Ash	0.1	

`

- Calculating the calorific value by using the Dulongs formula

$$HHV = \frac{1}{100} x \left[35000C + 143000x \left(H - \frac{O}{8} + 9160S\right] KJkg(3.1) \dots\dots\dots\dots\dots\dots (2)$$

$$LHV = \left(HHV - \frac{9H}{100} x2442\right) \frac{KJ}{Kg} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (3)$$

$$EHV = LHVx(1 - Mc) - Mcx\Delta hH2O$$

$$EHV = LHVx(1 - Mc) - Mcx((Tb - Ti)x4.2 + 2260$$

Where: - T_b is the local boiling point of water (local boiling temperature cannot be assumed to be 100^0C.)

$$Tb = (100 - \frac{h}{300})^0\text{C}\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (4)$$

T_i: - *is* the initial temperature

h: - is Jimma altitude in, 1763m

- Based on above the equation the higher and lower calorific value was determined by taking the higher and lower values of the ultimate analysis of wood respectively.

$$HHV = \frac{1}{100} x[35000x53 + 143000x \left(7 - \frac{44}{8} + 9160x0.1\right] KJkg(3.1)$$

$$HHV = \frac{20704KJ}{Kg}$$

$$LHV = (20704 - \frac{9x5.8}{100} x2442) \frac{KJ}{Kg}$$

LHV= $19165.7 \frac{KJ}{Kg}$

3.2.4 Time to boil (∆tc)

This is the time to boil water in the primary pot and it is simply taking the time difference and expressed as:

$$\Delta t = t_f - t_i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (5)$$

Where, ∆tc = is time to boil

t_f = final time (min)

t_i = Initially starting time (min)

3.2.5 Temperature corrected time to boil (ΔT)

This adjusts the time to boil to a standard 75°C temperature change (from 25°C to 100°C) to compensate different initial temperature and local boiling point.

$$\Delta T = \left(t_f - t_i\right) x \frac{75}{t_f - t_i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (6)$$

Where, T_f= Local boiling temperature of water (°C)

T_i= Initial temperature of water (°C)

3.2.6 Overall stove thermal efficiency (η)

This is a ratio of the work done by heating and evaporating water to the energy released by burning equivalent amount of dry wood and expressed as:

$$\eta = \frac{cp*(Pi-P)*(Tf-Ti)] + 2260*(Wv)}{fd*LHV} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. (7)$$

Where, Specific heat of water (cp) = 4.186 j/g °C

P = Weight of empty pot (gm)

Pi = Weight of pot with water before test (gm)

Ti = Water temperature before test (°C)

T_f = Water temperature after test (°C)

Fd = Equivalent dry fuel consumed (gm)

Wv = Amount of water vaporized (gm)

LHV = Lower heating value or net heating value of the fuel (kj/kg)

3.2.7 Burning rate (rb)

The burning rate was calculated from the recorded initial and final weight of the fuel and time taken for completing WBT. It was calculated by dividing the equivalent dry fuel consumed during test run by the time required for the test, which is expressed as:

$$rb = \frac{fd}{tf - ti} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (8)$$

Where, rb = burning rate (gm dry fuel/min)

fd = Equivalent dry fuel consumed (gm)

fd = fm× [1-(1.12 × mc)] – 1.5 × Δc

Δc = net change in char during test phase (gm)

fm = Moist fuel consumed (gm); fm= fi- ff

tf = Time at the end of test (min)

ti = Time at the start of test (min)

mc = moisture content (%, wet basis)

$$mc_{wet}\% = \frac{(mass\ of fuel)_{wet} - (mass\ of fuel)_{dry}}{(mass\ of fuel)_{wet}} x100 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots.. (9)$$

3.2.8 Specific fuel consumption (SC)

It was measured as the amount of equivalent dry wood required producing one liter or one kilo of boiling water and is expressed as:

$$SC = \frac{f_d}{(Pf-P)*(\frac{Tf-Ti}{Tb-Ti})} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. \dots\dots\dots\dots (10)$$

SC = Specific fuel consumption (gm fuel/gm water)

P = Weight of empty pot (gm)

Pf = Weight of pot with water after test (gm)

Ti = Water temperature at the beginning of the test (^{o}C)

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Tf = Water temperature after test (^{o}C)

Tb = Local boiling point of water (^{o}C)

3.2.9. Temperature corrected specific fuel consumption (SCT)

This corrects the specific fuel consumption to account for differences in initial water temperatures. This correction accounts for a standard temperature change of 75^{o}C (from 25 to 100^{o}C). It is calculated as following formula:

$$SC^{T} = SC * \left(\frac{75}{Tf - Ti}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (11)$$

3.3 Temperature corrected specific energy consumption (SET)

This was determined by multiplying SCT with the net calorific value of the fuel and the unit is kj/liter

$$SE^{T} = SC^{T} * LHV \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (12)$$

3.3.1 Firepower (FP)

This is a ratio of the equivalent dry fuel energy consumed by the stove per unit time and the unit of the firepower is Watt. This parameter is useful for high and low power phase since turndown ratio of a cook stove can be found from high and low power phase firepower and expressed as:

$$FP = fdx \frac{LHV}{60\ x\ \Delta t} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. (13)$$

Where, Fp = is fire power

fd= Equivalent dry fuel consumed (gm)

LHV = Lower heating value (j/gm)

∆t = Duration of test run (min)

3.3.2Useful/cooking power (FP useful)

The useful/cooking power is the average rate of energy released from fuel combustion that is transferred to the pot over the duration of the test and the unit of the useful/cooking power is Watt. Cooking power was calculated for the cold start and hot start, but not for the simmer,

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because cooking power cannot be accurately measured during the simmer phase of the WBT, as discussed in the article. Cooking power is expressed as:

FP_{useful}= FP x η………………………………………………………… (14)

3.3.3 Variables for high Power phase (Hot Start)

In this high power phase tests, the measurements and calculations are identical to the cold start test except that the char remaining is not extracted and weighed. Simply substitute the subscript *''h''* for the subscript *''c''* in each variable. Char remaining is assumed to be the same as the char remaining from the" cold start" phase.

3.3.4 Biochar preparation

Slow pyrolyzer was used for biochar production. When the char production of biomass (khat) is collected from different sites and distribution center like shops. Since to prepare the char two pretreatments a method was selected:-

- Drying on solar (open drying) for one weeks and
- In laboratory rooms (oven) that it takes to dry in one month and also, after drying the kaht the moisture contents was measured.

3.3.5 Biochar temperature measurement and characterization

Biochar temperature measurement and characterization, it was selected the Indirect type Stoves likes Normal anelia and Continuous feeding anelia feedstocks are selected for biochar production from khat.

Low temperature case (300-500^{o}c) and High temperature case (>500^{o}c) the charring time is 60 minutes.

To measure the temperature within the biomass bed two points is marked or selected on the outer surface of the two stoves and drilled to insert K- type thermocouple wire up to the center and sealed by using Epoxy. Then After this measuring device by selecting a similar region on each surface of the stoves per ten minute interval for all testing conditions was measured by using Digital Mulit-meter used to measure the biomass pyrolysis temperature.

Figure 3.7. Biochar produced in Normal Anila and Continuous feeding Anelia stoves

3.3.6 Biochar Testing

Biochar testing parameters are PH value, bulk density and biochar surface area was taken the based on their parameters in laboratory results. But Biochar made from khat was crushed to small size for measuring the following parameters.

3.3.7 Biochar pH

Biochar pH Standardized Product Definition and Product Testing Guidelines for Biochar that is used in Soil developed through International Biochar Initiatives was used for biochar testing. Each produced biochar was mixed and a sample was taken. Biochar pH values were obtained using a ratio of 1.0 gm of biochar in 20 mL deionized water with shaking for 1.5 h using shaker to ensure sufficient equilibration between solution and biochar surfaces (sources :- Shelby Rajkovich, Akio Enders, Kelly Hanley, Charles Hyland, Andrew R. Zimmerman, and Johannes Lehmann. Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. Biology and Fertility of Soils, 48(3):271–284, 2012.)

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Figure 3.8 PH value testing

3.3.8 Biochar Surface Area

Biochar Surface Area Surface area per gm of the biochar was obtained using Sears method, Sears 1956. 1.5 gm of biochar sample was mixed with 100 ml of water and 30gm NaCl. The mixture was stirred for five minutes. To this 0.1 N HCl was added to make final volume 150 ml and final pH = 4.0. It was then titrated against 0.1N NaOH. The volume (V ml) of 0.1N NaOH required to raise the pH from 4.0 to 9.0 was noted. The specific area (i.e. area per gm) was obtained using the formula. (Sources:-Sarita Yadav, D.K. Tyagi, and O.P. Yadav. Equilibrium and Kinetic Studies on Adsorption of Aniline Blue from Aqueous. International Journal of Chemistry Research, 2(3), 2011.)

$$\boldsymbol{A = 32V - 25}$$

Where:-

A = Surface area of carbon per gm (in m^2/gm);

V = volume of 0.1N NaOH required to raise the pH from 4.0 to 9.0

3.3.9 Biochar Bulk Density

Biochar Bulk Density The bulk density depends on both the density of Biochar particles and the spatial arrangement of particles in the bed. Putting the biochar to a known volume cylinder, the bulk density was measured using digital mass balance and subtracting the weight of the empty cylinder then dividing to the volume of the cylinder

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3.4 Experimental performance Testing and Evaluation of Biochar Production Using Pyrolysis Stove.

3.4.1 Anila Stove

The Anila stove is a simple technology for converting biomass to char at household level. The stove has been designed and built by Professor U.N. Ravi kumar of the Mysore University in India. The stove consists of two metal barrels. The outer barrel is filled up with biomass and the inner with firewood. After burning the fuel wood for 30-40 minutes, the pyrolysis of the biomass starts.

Figure 3.9 producing biochar in normal Anila stove

3.4.2 Continuous feeding Anila type Stove

Continuos feeding Anila stove was modified by Mr Teka Tesfaye in Jimma University to make the fuel (wood) Continuous, Reduced height and increased outer diameter with flange.

Figure.3.10 producing biochar in continuous feeding anila stove.

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CHAPTER FOUR

Result and Discussion

4. Water Boiling Test and the temperature results from two stoves.

- Normal anelia stoves
- Continuous feeding anelia stoves

4.1 Thermal efficiency of stoves

Thermal efficiency was performed on the two stoves using eucalyptus tree as a fuel. It was observed that the average thermal efficiency of normal anelia and continuous feeding anelia stove 18%, and 17% in the case of high power test (cold start) and 15.23% and 15.67% respectively for high power hot start.

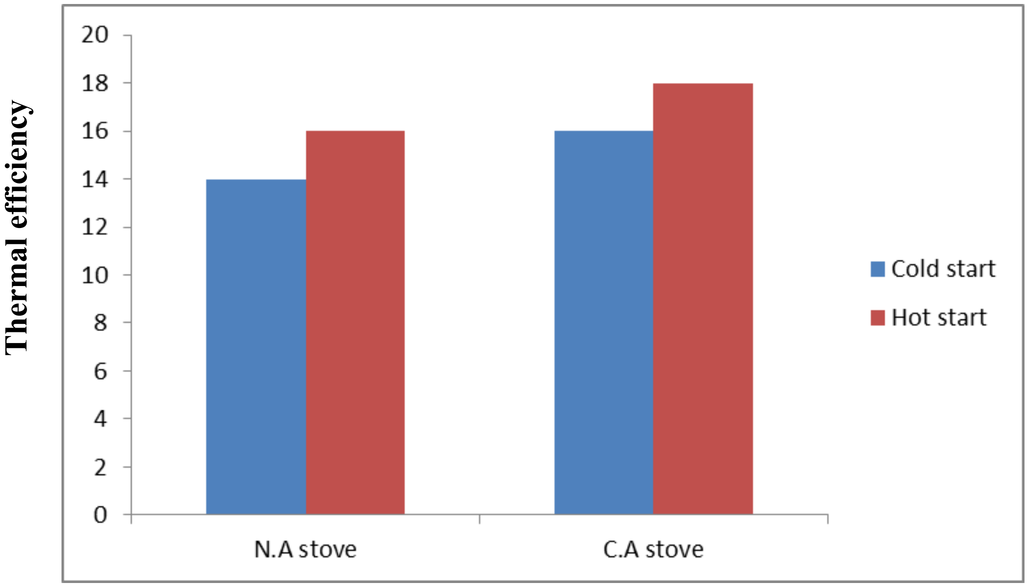

Figure 4.1 Thermal efficiency of the two stoves in the case of high power test and low power test

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4.1.2 Fire power

The firepower is a measure of the heat output of the stoves and the turn-down ratio is an indicator of the control range of fire the power. The higher the turn-down ratio, the greater the power control ranges of the stove. The Normal Anila stove had the highest turn-down ratio of 2.21 followed by the Continuous feeding Anila type stove with a turn-down ratio of 1.78. It had the lowest firepower during both the cold start and hot start phases.

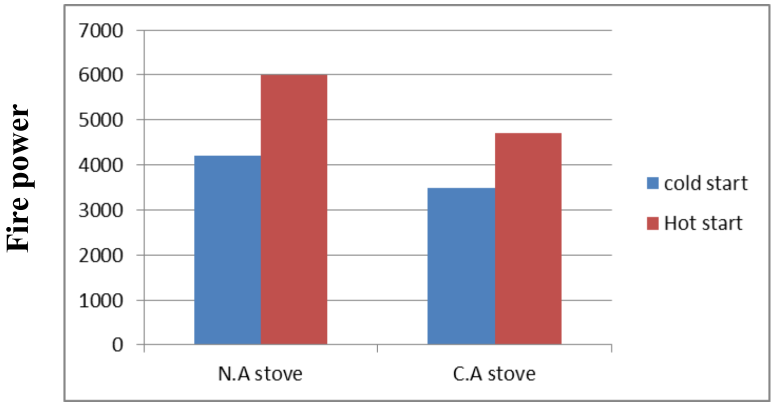

Figure 4.2 Comparison of the fire power for the each stove

4.1.3 Turn down ratio

Turndown ratio refers to the width of the operational range of a device, and is defined as the ratio of the maximum capacity to minimum capacity. (12)

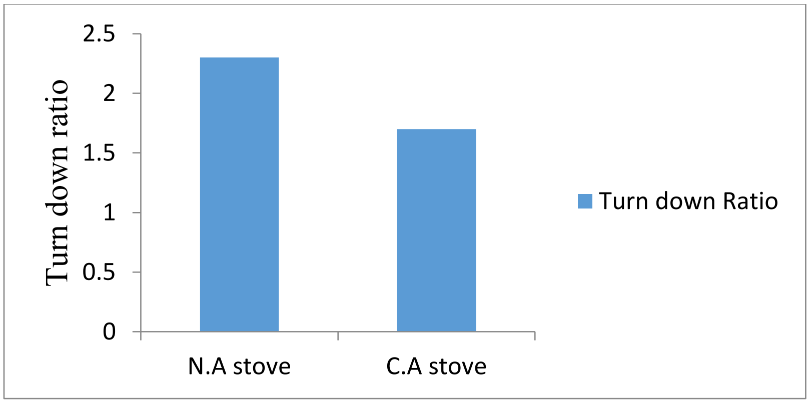

Figure 4.3 Comparison of turn down ratio of each stove

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4.1.4 Temperature and Biochar Yield

4.1.5 Influence of residence time on yield of biochar

The quantity of biochar produced at 60 minute was determined by weighing the biochar after the pyrolysis. Biochar yield was calculated using equation 1, and expressed in weight percentage (wt. %). When the sample was taken in two stoves based on their PH values are the same in the solar test as well as applicable in the most of the people used solar to drying and its capacity of the stove it holds the khat 3000gram of dried khat in solar (open drying) after the heating in 60 minute the the weight of biochar is 1775.31 gram was measured in mass balance, and the continuous stove was selected in CFD simulation because the N.A stove difficulty to decide the boundary condition that means fuel inlet and air inlet is the same. The yield of biochar from slow pyrolysis of biomass has been stated to be within the ranges of (24 % - 77% (Dutta, 2010; Stoyle, 2011**).**

$$Biochar\ yield = \frac{weight\ of\ biochar}{weight\ of\ khat} x100\% \ldots\ldots (1)$$

$$Biochar\ yield = \frac{1775gram}{3000gram} x100\% = 59.2\%$$

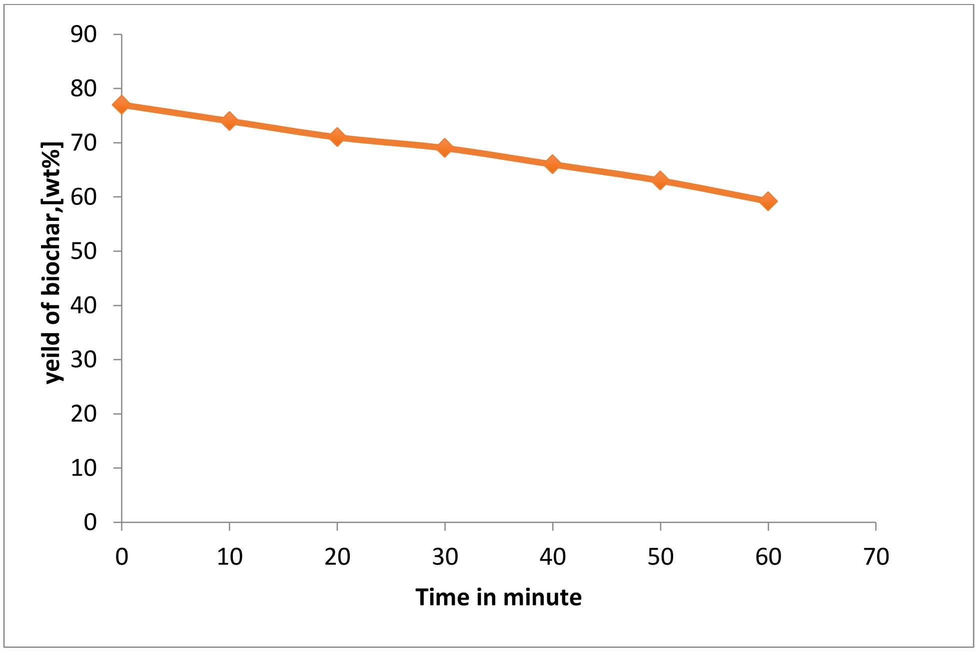

Figure 4.4 – The pyrolysis char yields versus residence time

- Since the above graphs indicated that the reaction time increases the yield of biochar was decrease that means the density of biochar decreases the PH value and surface area was increased.

4.1.6 The two stoves temperature measurement during biochar production.

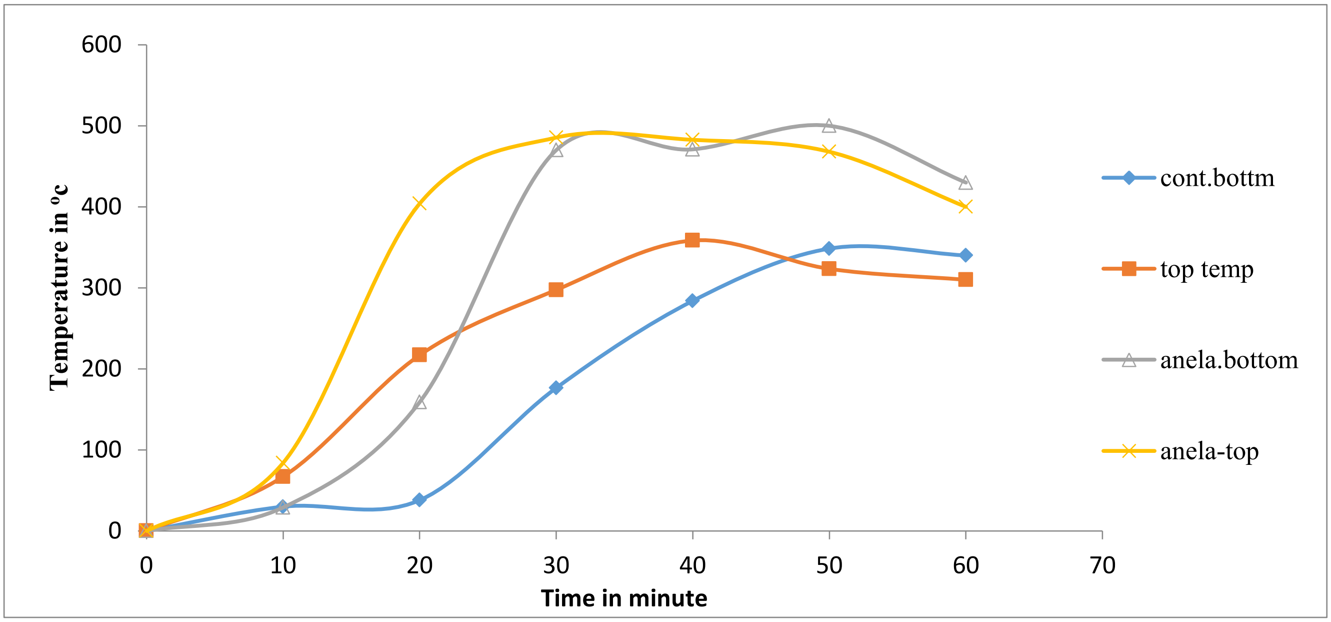

Figure 4.5 Normal Anelia stove temperature versus the charring time.

The figure shows the trend of temperature with time at different position of the stoves during the khat charring. In this case the inner surface temperature of the stoves was controlled at pyrolysis temperature ranges (300-550°c).When the max temperature is (539°c) during biochar production was recorded in 60 minutes. The heat transfer capability within the biomass from inner surface was seen at selected point between the two surfaces in the packed bed. The higher temperature on the inner surface of the stove gives higher temperature reading in the biomass bed.

4.1.7 The measuring temperature of Continuous feeding anelia stove by oven

- From the below graphs the two stoves of average inner surface temperature was recorded in below 500°C during the test. Since the trend of inner surface temperature and amount of biomass inserted to the two stoves is Normal anelia temperature is greater than continuous feeding anelia stove, the variation of the bed temperature effects due to geometry of the stove, the types of reading thermocouple and volatile gas residence time of pyrolysis temperature is high because to remove the bio-mass volatile gases.

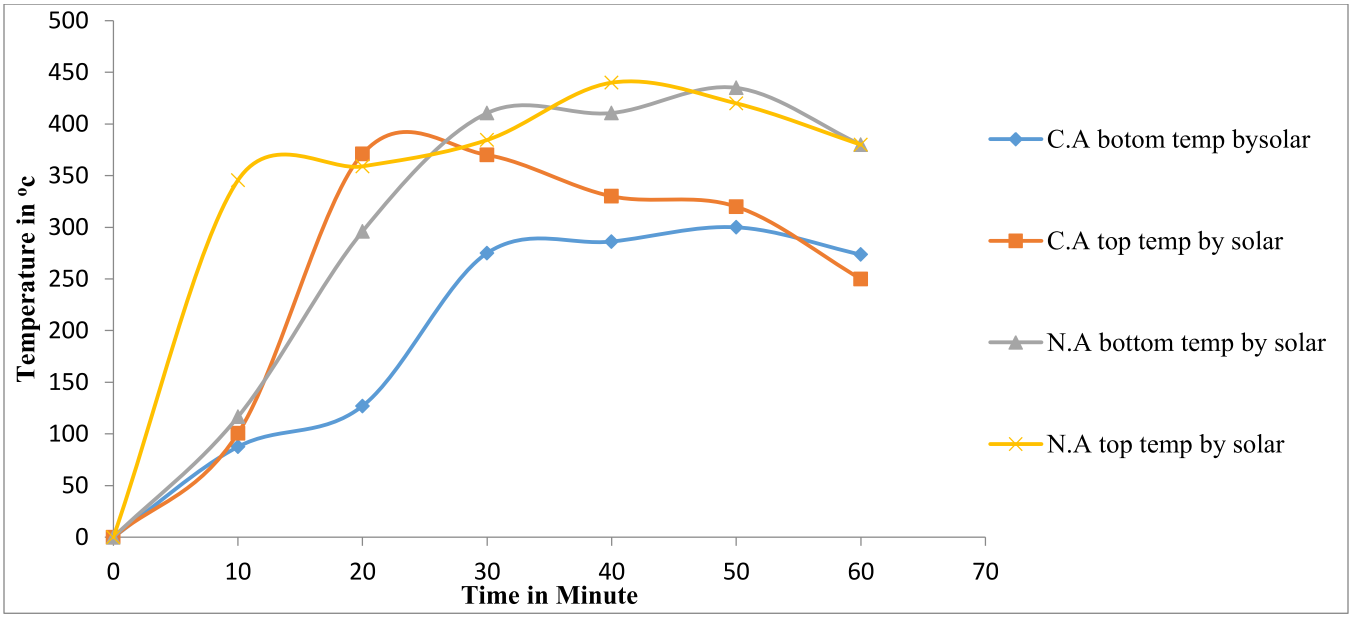

Figure 4.6 Biochar production in N.A and C.A stove in solar test.

4.1.8 The average of the two stoves temperature in both solar and oven bio-char

- When the temperature comparison of two stoves of average inner surface temperature was recorded from the solar in below 500°C during the test. Since the trend of inner surface temperature and amount of biomass inserted to the two stoves is Normal anelia temperature is greater than Continuous feeding anelia stove, because the variation of the bed temperature due to geometry of the stove and volatile gas residence time was lower so these described the pyrolysis of biomass (khat) reaction time was decreases.

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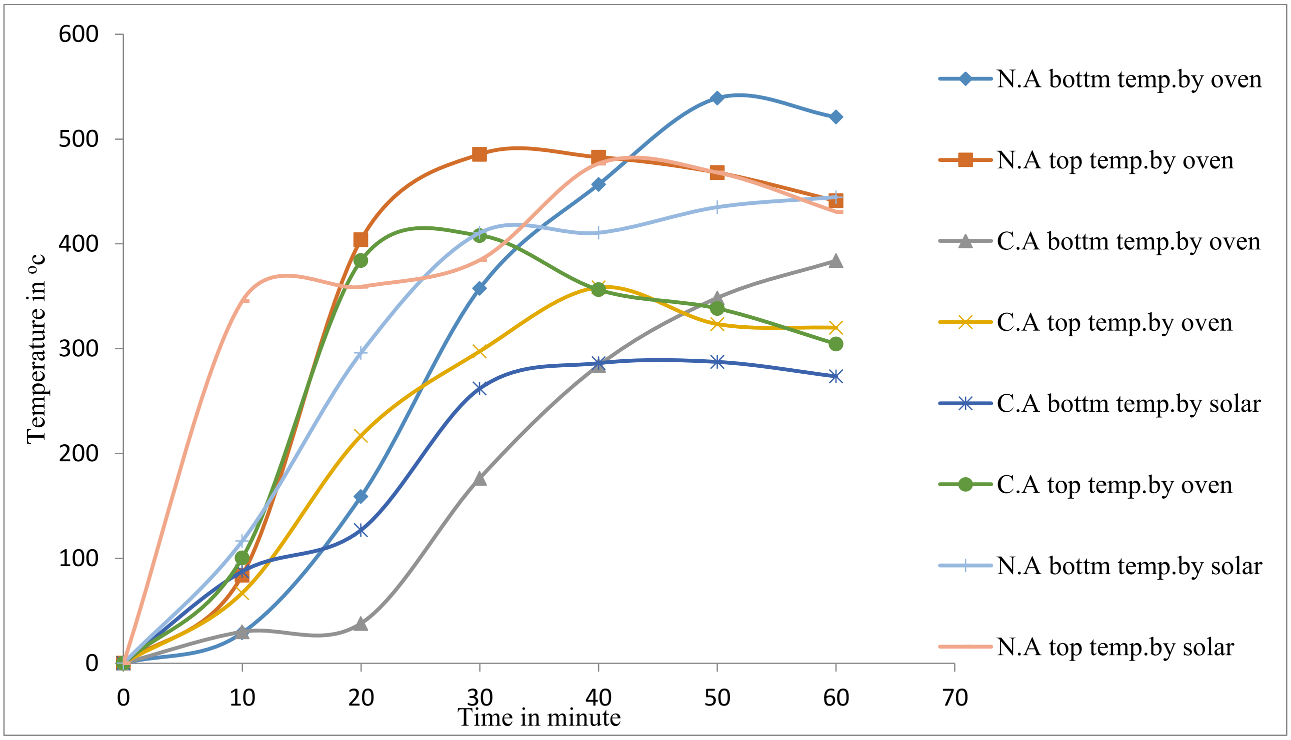

Figure 4.7 Temperature versus time

When the two stoves of average inner surface temperature was recorded in the range of 300-539°C during the test. Since the trend of inner surface temperature and amount of biomass inserted to the two stoves in normal anelia temperature is greater than continuous feeding anelia stove, the variation of the bed temperature due to geometry of the normal anelia stove smaller than continuous feeding anelia stove, due to this releases the volatile gas it increases residence time and the pyrolysis temperature.

4.1.9 Bulk density

Biochar have the lowest density among a wide range of solid materials applied to soil, therefore it will lower the soils bulk density, reduce soil compaction and increase plant available nutrients sufficiently to rehabilitate the soil and ensure native vegetation regrowth Improvement of pore space makes plants adsorption of the nutrients better and effective microorganisms' growth stronger. It is lead to reduce using chemical fertilizer and maintain the fertility of the soil.

The effects of biochar addition on soil properties may have a significant effect under field conditions, where bulk density are important factor influencing plant growth, germination, and

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grain production. ((Nathaniel Anderson, J.Greg Jones, Deborah Page-Dumroese, Daniel McCollum, Stephen Baker, Daniel Loeffler, and Woodam Chung. A Comparison of Producer Gas,Biochar, and Activated Carbon from Two Distributed Scale Thermochemical Conversion SystemsUsed to Process Forest Biomass. Energies, 6:164–183, 2013.))

Biochar bulk density the bulk density depends on both the density of Biochar particles and the spatial arrangement of particles in the bed. Putting the biochar to a known volume cylinder, the bulk density was measured using digital mass balance and subtracting the weight of the empty cylinder then dividing to the volume of the cylinder. (28)

$$\rho_{\boldsymbol{d}} = \frac{\boldsymbol{W2-W1}}{\boldsymbol{V}} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (1)$$

Where ρ_d is bulk density

W_1 **-**is empty cylinder weight (gm)

W_{2-} is cylinder of weight with char (gm)

Table 4.1 the average value of bulk density

Normal anelia stove by solar test		Continuous feeding anelia stove by solar	Normal anelia stove By oven	Continuous feeding By oven
	Average $\rho_{d=}$0.37gm/ml	Average ρ_d =0.36 gm/ml	Average ρ_d =0.38 gm/ml	Average ρ_d =0.35 gm/ml

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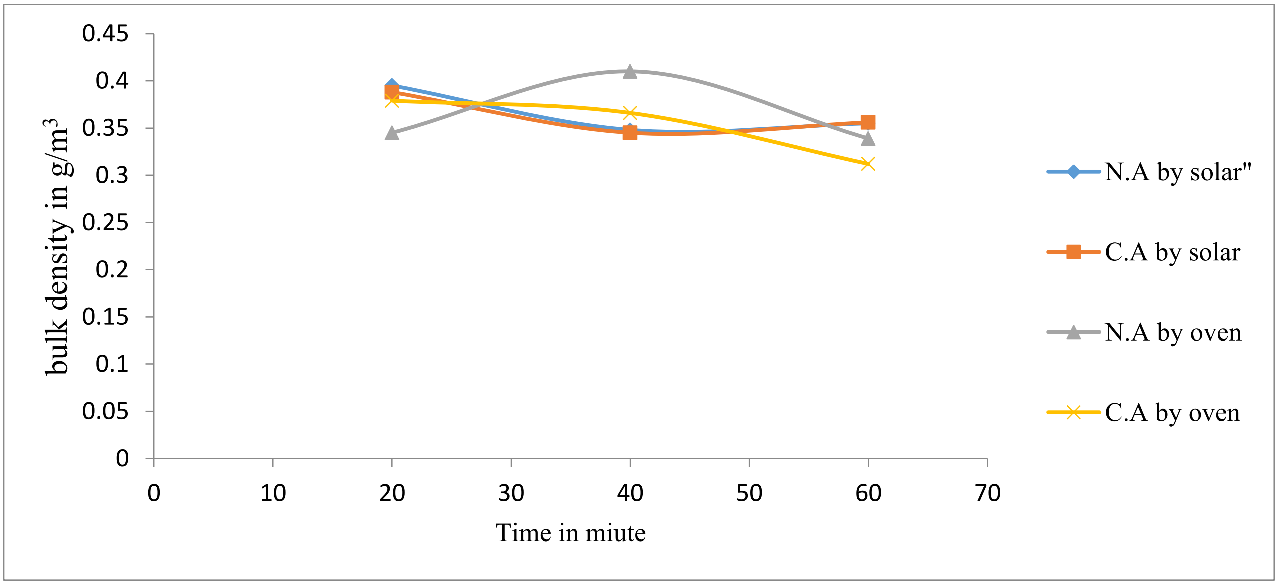

Figure 4.8 bulk density versus the time

In the above figure the change of bulk density with temperature, heating time and feedstock was observed and the bulk density of the biochar was decreasing with residence time was increased up to one hour.

4.10. Biochar PH

The pH of Biochar solution is depending on the pyrolysis condition and the type of feedstock ANOVA test shows all the parameters significantly affect pH. With respect to biomass, khat in the both normal and continuous feeding anelia stove pH 8.2 values are the same in solar test but significantly the continuous feeding anelia stove by oven test result pH 7.8 also it is the differ.

Table 4.8 measuring of pH value

Normal anelia stove by solar test		Continuous feeding anelia stove by solar	Normal anelia stove By oven	Continuous feeding By oven
	Average *pH=8.2*	Average *pH=8.2*	Average *pH=8.3*	Average *pH=7.8*

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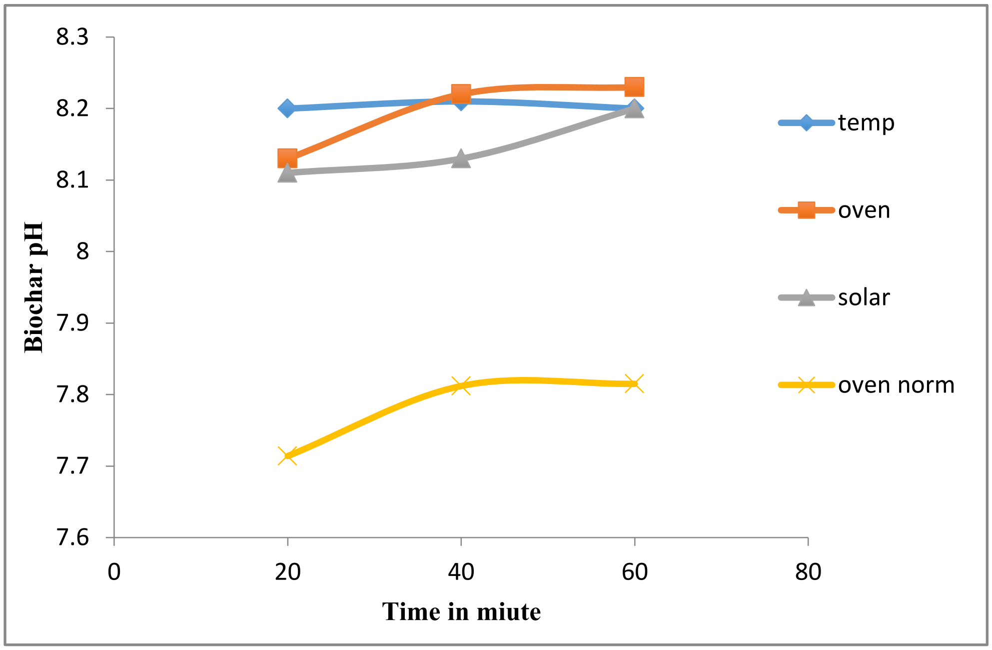

Figure 4.9 biochar PH versus the charring time

4.11 Biochar Surface Area

Increasing the surface area of a substance generally increases the rate of a chemical reaction the ensuing carbonization step at high temperature was detrimental to the development of a porous structure in the biochar. The Surface area of soil is an important physical parameter which controls essential functions of soil fertility such as water and nutrient holding capacity, aeration, and microbial activity. (29)

Biochar Surface Area Surface area per gm of the biochar was obtained using Sears method, (Sears 1956.) 1.5 gm of biochar sample was mixed with 100 ml of water and 30 gm NaCl. The mixture was stirred for five minutes. To this 0.1 N HCl was added to make final volume 150 ml and final pH = 4.0. It was then titrated against 0.1N NaOH. The volume (V ml) of 0.1N NaOH required to raise the pH from 4.0 to 9.0 was noted.

The specific area (i.e. area per gm) was obtained using the formula

$A = 32V - 25$………………………………………………………………………… (2)

Where:-

A = Surface area of carbon per gm (in m^2/gm);

V = volume of 0.1N NaOH required to raise the pH from 4.0 to 9.0

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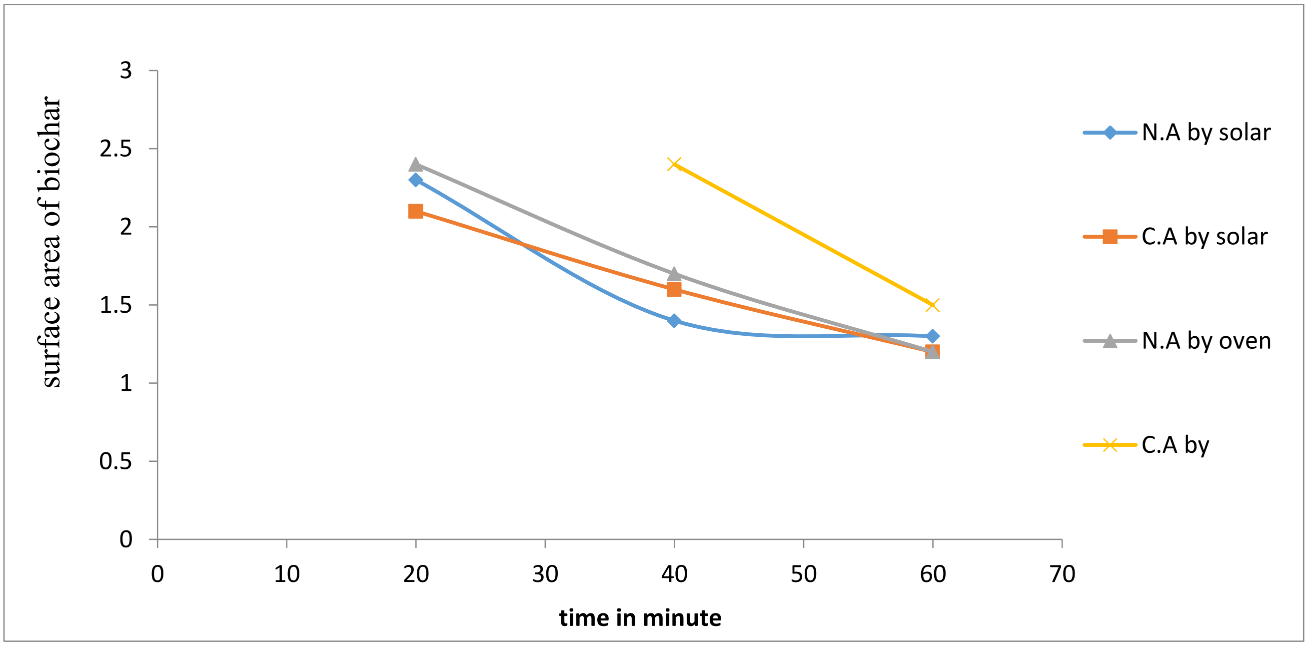

Figure 4.10 biochar surface area versus with time

A figure shows the experimental result of surface area of biochar at different condition. The result indicates surface area of biochar was decreasing with time for both temperature conditions on most of the stoves. Since until completion of the solidification stage within the bio-char before 40 minute. When the residence time or the temperature of biochar increases also the surface area was increased.

4.12. The effect of biochar on the yield of maize

a, Maize variation in one-two weeks

b, maize variation in three up to four weeks

Figure 4.11 maize variations in with biochar

a, Maize variation in one-two weeks b, maize variation in three up to four weeks

Figure 4.12 maize without biochar

Maize with biochar variation in one-two weeks

Maize without biochar variation in one-two weeks

A .Maize with biochar variation in three up to four weeks **b**. maize without biochar variation in three up to 4- weeks

Figure 4.13 maize profile variations with and without biochar

Figure 4.13 maize profile variations after one month and half days with biochar and without biochar.

When the above figure describes the effect of the yield of maize compression based on the results maize of without biochar effect is better than maize with biochar. Since the reason is the mixed ratio of biochar greater than the ratio of added soil due to this effect the biochar is by in nature the holding water capacity is very high. For this reason the soil and biochar completely compacted, then the maize with biochar growing duration is less.

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CFD validation of experimental results

4.2. Theory of Species Transport and Eddy- Dissipation model

Ansys Fluent was used to model the mixing and transport of chemical species by solving the conservation equations describing convection, diffusion, and reaction sources for each component species. Multiple simultaneous chemical reactions can be modeled, with reactions occurring in the bulk phase (volumetric reactions) and/or on wall or particle surfaces, and in the porous region.

4.2.1 Volumetric Reactions - Species Transport Equations

In order to solve the conservation equations for chemical species, Fluent predicts the local mass fraction of each species, Yi, through the solution of a convection-diffusion equation for the i_{th} species. This conservation equation takes the following general form (31).

$$\frac{\partial(\rho Y_i)}{\partial t} + \nabla.(\rho\bar{v}Y_i) = -\nabla.\overline{J_\iota} + R_i + S_i$$

Ri is the net rate of production of species i by chemical reaction, $\overline{J_\iota}$ is the diffusion flux of species i and *Si* is the rate of creation by addition from the dispersed phase plus any user defined sources. An equation of this form will be solved for $N-1$ species where N is the total number of fluid phase chemical species present in the system. Since the mass fraction of the species must sum to unity, the N^{th} mass fraction is determined as one minus the sum of the $N-1$ solved mass fractions. To minimize numerical error, the N^{th} species should be selected as that species with the overall largest mass fraction, such as $N2$ when the oxidizer is air.

4.2.2 The Eddy-Dissipation Model

The Eddy Dissipation model is best applied to turbulent flows when the chemical reaction rate is fast relative to the transport processes in the flow. There is no kinetic control of the reaction process. By default, for the Eddy Dissipation model it is sufficient that fuel and oxidant be available in the control volume for combustion to occur. If the product limiter is enabled, by setting the Eddy Dissipation Coefficient B parameter to positive, then products must also be available. Assuming the problem is one in which a stable flame may be established, initial

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specification of products within the domain should be sufficient to start and maintain combustion.

However, if the combustion is difficult to maintain, it may be necessary to introduce a small fraction of products at an inlet.

Most fuels are fast burning, and the overall rate of reaction is controlled by turbulent mixing. In non-premixed flames, turbulence slowly convects or mixes fuel and oxidizer into the reaction zones where they burn quickly. In premixed flames, the turbulence slowly convects or mixes cold reactants and hot products into the reaction zones, where reaction occurs rapidly. In such cases, the combustion is said to be mixing-limited, and the complex, and often unknown, chemical kinetic rates can be safely neglected.

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Simulation setup using Ansys fluent 17.2

Stove geometry

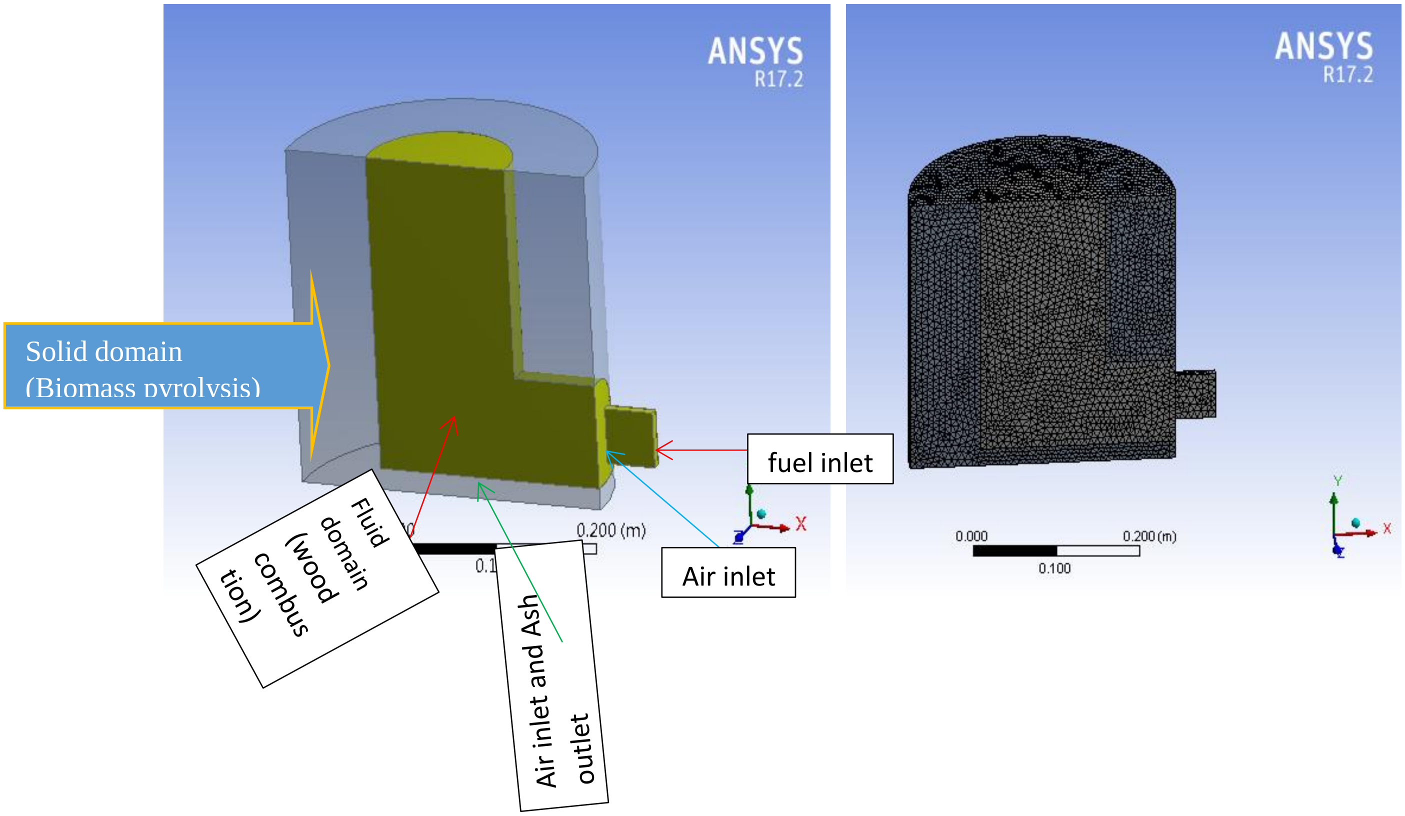

Figure 4.14. a, **Geometry** **b, Mesh of geometry**

Node value of mesh = 29175

Elemental value of mesh =152489

4.2.4 The geometry for the indirect type continuous feeding Anelia stove was done using CFD Ansys model.

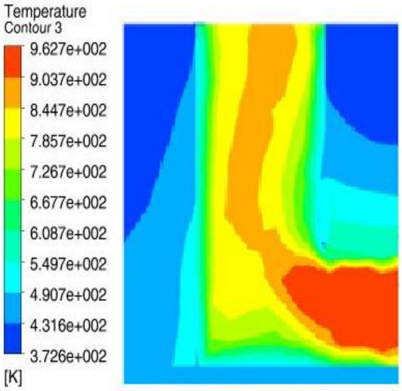

Figure: 4.15 only side direction of air inlet

- When in air inlet, in one direction the temperature distribution is it starts in right side, the inner temperature increases from bottom to top. Also from left side the temperature distribution increases in inner to outer in 372-903^{0}k.

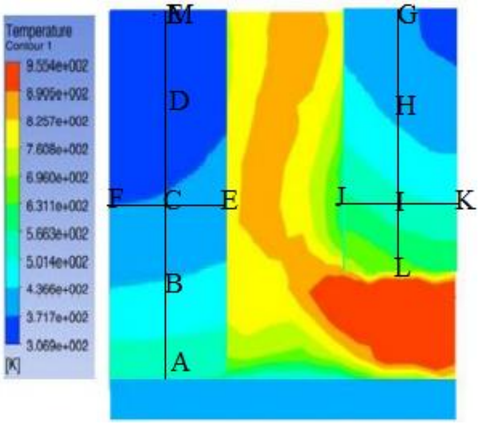

Figure 4.16 bottom and side direction of air inlet

Temperature distribution from left side				Temperature distribution from right side			
Bottom to top		Inner to outer		Bottom to top		Inner to outer	
Position(mm)	Temp(K)	Position	Temp(K)	Position	Temp(K)	Position	Temp(K)
A=0	517.13	*E*	402.42	L	523.09	J	502.51
B=95	452.35	C	387.12	I	478.83	I	478.83
C=190	387.12	F	326.28	H	392.63	K	451.89
D=285	343.18			G	384.73		
M=380	306.54						

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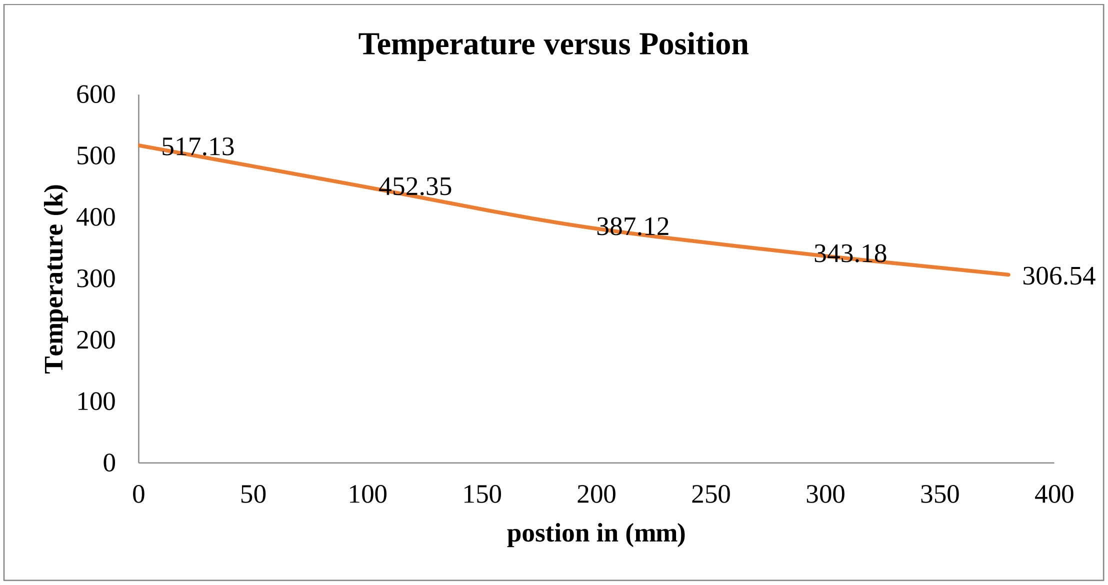

- When from these results air inlet, in two directions in bottom and side, the temperature distribution, then the temperature distribution position increases from bottom to top (A – M) in left hand side, and also the temperature distribution increases inner to outer (E, C and F). In right hand direction of air inlet temperature increases bottom to top from (L-G).and also inner to outer (J, I and K). Then in right side direction the temperature increases from bottom to top. Also from the left side the temperature distribution increases in inner to outer.

4.2.3 Comparison (validation) of experimental temperature and simulation temperature

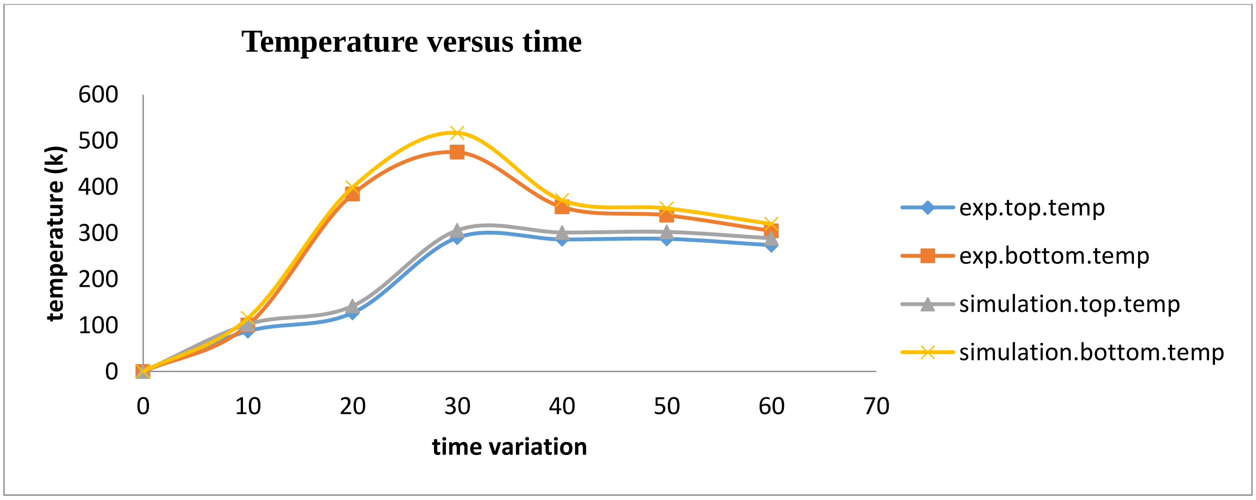

Figure4.14 Comparison (validation) of experimental temperature and simulation temperature

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From above graphs indicated that the both experimental and simulation of bottom temperature increased from interval of (0-30 minutes) and also in both cases top temperature gradually decreased up to (40-50 minutes).

The following graphs shows residual (iteration) temperature of ansys simulation graphs profile

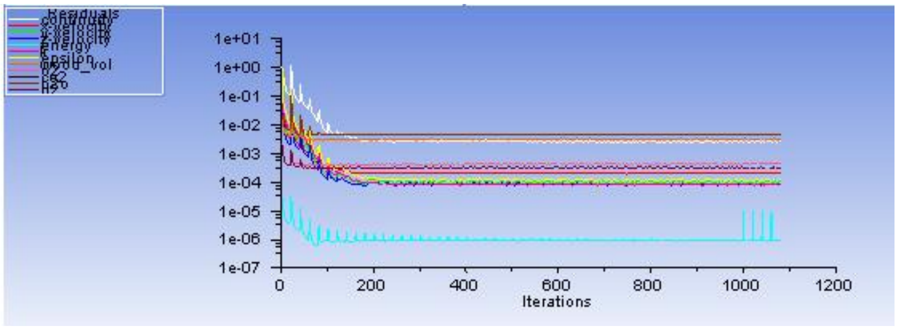

Figure residual (iteration) temperature of ansys simulation profile graphs.

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CONCLUSION AND RECOMMENDATIONS

CONCLUSION

This thesis was demonstrated a khat biochar production process using indirect type of stoves like Normal Anelia and Continuous feeding Anelia stoves. Biochar production temperature profiles for the both feedstock stoves biochar were dependent on the temperature profile and air direction of the combustion chamber. From the experimental test, the stove geometry is one the major effect that means when the geometry of stove increases, the volatile matter it is not easily released as well as biochar yield is decrease during reaction time is also increase. When the effect of biochar is depends on charring feed stock, temperature profile and air flow direction. The pH of biochar significantly affected by biomass (8.2 mean for khat both Normal Anelia and Continuous feeding Anelia by solar and 8.3 and 7.8 for normal anelia and continuous feeding type Anelia stoves mean for oven respectively in 60 minute, In fact the type of biomass significantly affects the bulk density and surface area of biochar and the moisture contents in both solar (open drying) and in home (oven) was determined. A maximum biochar yield of 59.2 wt. % was attained in the stoves in solar test, and the yield of biochar decreased as the residence time of the biochar in the temperature increased. These results suggest that biochar produced from organic solid wastes could be returned to soils to replenish soil nutrient stocks. Moreover, the sustainable biochar production for agricultural purposes could also be a long-term solution for the problems associated with organic solid waste management, enhancing the physical and chemical properties of the soil and increased crop productivity. In general biochar has significant potential as a tool for waste management, climate change mitigation because it can increase stable soil carbon stocks and increase soil carbon sequestration, while also decreasing atmospheric CO_2 concentrations. In addition to sequestering carbon in the soil, biochar has the potential to act as a fertilizer and as a soil improver. The temperature profile during pyrolysis was determined using a K-type thermocouple. After the experimental test results, the continuous anelia feeding type stove is modeled based on experimental temperature results to validate its temperature profile distribution differences by CFD simulation. When the CFD simulation temperature profile distribution is greater than the experimental, and generally it shows that the experimental temperature more accurate than the simulation temperature.

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RECOMMENDATIONS

Based on the experimental output result, the researcher found out that biochar production using thermal decomposition of biomass in the absence of oxygen called slow pyrolysis. When to reduce the organic solids waste like khat the thermochemical conversion of slow pyrolysis is becoming the best way to manage the waste treatment and changes into energy and biochar production.

It is recommended that:-

- The biochar production from solid waste it is the best way to reduces the environmental pollution.
- The function of recycling organic solid wastes it had to mutually benefit like energy and biochar production at the same time or simultaneously.
- It was used to reduce the mitigate greenhouse gas like co_2, nitrous oxide emission and methane from atmosphere.
- It is better to decrease transportation cost when it took to the disposal area.
- It reduces more energy wastes and time when collecting from disposed place.
- It is better to reduce the atmospheric carbon by sequestering underground.

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APPENDIX

Temperature and Biochar Yield

***Experimental tests, during the biochar production from khat waste (locally it's said to be khat Gereba), and Temperature Measurements*.**

The following tables it shows the trend of temperature with time at different position of the stoves during khat charring time and temperature. In this case the inner surface temperature of the stoves was controlled at pyrolysis temperature ranges (350-550 ^{o}c). When the max temperature is during biochar production, the temperature is recorded in decided time for 60 minutes.

The heat transfer capability within the biomass from inner surfaces two points (Top and bottom) was selected at packed bed to determine higher temperature in the inner surface by using K-type thermocouples for Normal anelia and continuous feeding anelia stove. When the K-type thermocouple was inserted in inner surface of biomass and the filled by Epoxy, then the biomass temperature was measured by the help of digital multi-meter in ten minute interval.

Biochar production and water boiling test

Experiment 1. Normal anelia stove Biochar production during in –oven, and starting time at 3:07-4:07pm- Especially the water boiled boiled at 3:37pm min during water boiling test.

Ambient Temp		Temp of biomass				Water temp	Initial Time
	Ambient temp 27 ^{o}c	Bottom temperature		Top temperature		Ambient temp 26 ^{o}c	3:07minute
1	26 ^{o}c	At 0.1mv	**29 ^{o}c**	At 2.3mv	**84 ^{o}c**	59 ^{o}c	3:07-3:17min
2	27 ^{o}c	5.4mv	**159^{o}c**	15.4mv	**404 ^{o}c**	88 ^{o}c	3:17-27min
3	25.5 ^{o}c	13.5mv	**357.5^{o}c**	18.9mv	**485.5 ^{o}c**	94 ^{o}c	3:27-37min
4	25.7 ^{o}c	17.7mv	**456.7^{o}c**	18.8mv	**482.7 ^{o}c**		3:37-47min
5	25 ^{o}c	21.2mv	**539 ^{o}c**	18.2mv	**468 ^{o}c**		3:47-57min
6	26 ^{o}c	20.4mv	**521 ^{o}c**	17.0mv	**441 ^{o}c**		3:57.40:07min

Experiment 1. Continuous feeding annelia stove by oven, at 4:08-5:08 pm especially water boiled at 4:28pm

Ambient Temp		Temp of biomass				Water temp	Initial Time
	Ambient temp 25.7 **^{o}c**	Bottom temperature		Top temperature		Ambient temp 25 ^{o}c	At 4:08
1	26 **^{o}c**	At 0.26mv	**30^{o}c**	At2.6m v	**67 ^{o}c**	59 ^{o}c	4:08-18 min
2	27 **^{o}c**	0.54mv	**38 ^{o}c**	10.2mv	**217 ^{o}c**	77 ^{o}c	4:18:4:28min
3	26.5 **^{o}c**	8.00mv	**176.5^{o}c**	14.7mv	**297.5 ^{o}c**	94 ^{o}c	4:28-4:38 min
4	26 **^{o}c**	13.9mv	**284 ^{o}c**	18.1mv	**358.5 ^{o}c**		4:38:48 min
5	25.5 **^{o}c**	17.6mv	**348.5^{o}c**	16.2mv	**323.5 ^{o}c**		4:48-58 min
6	28 **^{o}c**	19.4mv	**384 ^{o}c**	18.0mv	**320^{o}c**		4:58-5:08 min

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Solar experiment 2. Biochar in solar test starting @2:30-3:30 pm (Normal Aneila .stove)

Ambient Temp		Temp of biomass				Water temp	Time
	Ambient temp 24 °c	Bottom temp		Top tem 00:00		Ambient temp 24.5 °c	2:30 min
1	25.5 °c	At3.7mv	**116.5°c**	At13.0mv	**345.5°c**	56 °c	2:30-40
2	25 °c	11.0mv	**296 °c**	13.6mv	**359 °c**	77 °c	2:40-50
3	24.5 °c	15.8mv	**410.5°c**	14.7mv	**384.5°c**	91 °c	2:50-9:00
4	24.6 °c	15.8mv	**410.6°c**	18.6mv	**476.6°c**		3:00-10
5	25 °c	16.8mv	**435 °c**	18.2mv	**468 °c**		3:10-20
6	27.6 °c	17.1mv	**444.6°c**	16.5mv	**430.6°c**		3:20-30

Solar experiment 2. Biochar in solar test starting at 1:10-2:10pm (continuous feeding anelia stove)

Amben Temp		Temp of biomass				Water temp	Time
	Initial temp 25 °c	Bottom temp		Top tem		Intial temp 24 °c	1:10 minute
1	25.5 °c	@3.2mv	**87.5°c**	@3.91mv	**100.5°c**	78 °c	1:10-20min
2	26 °c	5.3mv	**127 °c**	19.5 mv	**384 °c**	83 °c	1:20-30min
3	27 °c	12.7mv	**262 °c**	20.8 mv	**408 °c**	94 °c	1:30-40min
4	27.2 °c	14.0mv	**286.2°c**	17.9 mv	**356.2°c**		1:40-50min
5	27.4 °c	14.1mv	**287.4°c**	16.9 mv	**338.4°c**		1:502:00min
6	27.6 °c	13.3mv	**273.6°c**	15.0 mv	**304.6°c**		200:2:10min

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Experiment 2. Moisture content by solar (open drying) drying and oven (home) drying

- ✓ When to dry the khat in solar it took only one weeks and in oven 1 month after to this the dried khat moisture contents is determined by staying in1kg khat at 105^{o}c 3hr in oven machine, and it's moisture contents is determined based on this formula.

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

  $$Mcdb = \frac{A - B}{B} x100\%$$

  Where: MCdb = Moisture content (dry basis)

  A = Mass of sample before drying

  B = Mass of sample after drying

Solar(open drying)		Oven (home) or closed drying	
Before drying	After drying	Before drying	After drying
1kg 0r 1000gm	890gm	1kg or (1000gm)	867gm

$Mcdb = \frac{1000gram - 890gram}{890gram} x100\%$ = 12.4% Also, most bio charring units work best using moisture content in the range of 10 – 20% (Cummer and Brown, 2002)

Experiment 3. Bulk density

Biochar Bulk Density The bulk density depends on both the density of Biochar particles and the spatial arrangement of particles in the bed. Putting the biochar to a known volume cylinder, the bulk density was measured using digital mass balance and subtracting the weight of the empty cylinder then dividing to the volume of the cylinder. (source:-Nathaniel Anderson, J.Greg Jones, Deborah Page-Dumroese, Daniel McCollum, Stephen Baker, Daniel Loeffler, and Woodam Chung. A Comparison of Producer Gas, Biochar, and Activated Carbon from Two Distributed Scale Thermochemical Conversion Systems Used to Process Forest Biomass. Energies, 6:164–183, 2013.)

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$\rho_{d} = \frac{W2-W1}{V}$

Where ρ_d $is\ bulk\ density$

W_1 -is empty cylinder weight (gm)

W_{2}- is cylinder of weight with biochar (gm)

Normal anelia stove by solar test		Continuous feeding anelia stove by solar	Normal anelia stove By oven	Continuous feeding By oven
R1	W1=186.33gm	W1=176.33gm	W1=201.10gm	W1=175.19gm
	W2=275.04gm	W2=262.49gm	W2=287.68gm	W2=269.83gm
	V=250ml	V=250ml	V=250ml	V=250ml
ρ_d =0.355g/ml		**ρ_d =0.345 g/ml**	**ρ_d =0.345 g/ml**	**ρ_d =0.379 g/ml**
R2	W1=187.97gm	W1=178.43gm	W1=186.33gm	W1=197.01gm
	W2=275.07gm	W2=275.52gm	W2=298.24gm	W2=288.50gm
	V=250ml	V=250ml	V=250ml	V=250ml
	ρ_d =0.348	**ρ_d =0.388**	**ρ_d =0.447**	**ρ_d =0.366**
R3	W1=176.39gm	W1=175.22gm	W1=201.33gm	W1=201.01gm
	W2=275.06gm	W2=264.22gm	W2=286.21gm	W2=276.05gm
	V=250ml	V=250ml	V=250ml	V=250ml
	ρ_d =0.395	**ρ_d =0.356**	**ρ_d =0.339**	**ρ_d =0.300**
	Average $\rho_{d=}$0.37gm/ml	**Average ρ_d =0.36 gm/ml**	**Average ρ_d =0.38 gm/ml**	**Average ρ_d =0.35 gm/ml**

Biochar Surface Area Surface area per gm of the biochar was obtained using Sears method, (Sears 1956.) 1.5 gm of biochar sample was mixed with 100 ml of water and 30 gm NaCl. The mixture was stirred for five minutes. To this 0.1 N HCl was added to make final volume 150 ml and final pH = 4.0. It was then titrated against 0.1N NaOH. The volume (V ml) of 0.1N NaOH required to raise the pH from 4.0 to 9.0 was noted. [Sarita Yadav, D.K. Tyagi, and O.P. Yadav. Equilibrium and Kinetic Studies on Adsorption of Aniline Blue from Aqueous. *International Journal of Chemistry Research*, 2(3), 2011.]

The specific area (i.e. area per gm) was obtained using the formula

$\boldsymbol{A = 32V - 25}$

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Where

A = Surface area of carbon per gm (in m^2/gm);

V = volume of 0.1N NaOH required to raise the pH from 4.0 to 9.0

- ✓ Surface area of biochar sample measured at three times in titration method by using the equipment's of burate. Since the given value are substitute in the above given formula

Normal anelia stove by solar test		Continuous feeding anelia stove by solar	Normal anelia stove By oven	Continuous feeding By oven
R1	V=2.3 ml	V=2.5 ml	V=2.4 ml	V=2.2ml
	V= 2.4 ml	V= 2.3 ml	V= 2.2 ml	V= 2.3 ml
	V=2.2 ml	V=2.4 ml	V=2.3 ml	V=2.1ml
Average(V) =2.3ml		***Average (V) =2.4ml***	***Average (V) =2.3ml***	***Average (V) =2.2ml***
Area =32V-25		Area =32V-25	Area =32V-25	Area =32V-25
Area=48.6 m^2 ***/gm***		***Area=51.8*** m^2 ***/gm***	***Area=48.6*** m^2 ***/gm***	***Area =45.4*** m^2 ***/gm***

Biochar pH Standardized Product Definition and Product Testing Guidelines for Biochar that is used in Soil developed through International Biochar Initiatives was used for biochar testing. Each produced biochar was mixed and a sample was taken. Biochar pH values were obtained using a ratio of 1.0 gm of biochar in 20 mL deionized water with shaking for 1.5 h using shaker to ensure sufficient equilibration between solution and biochar surfaces. [Shelby Rajkovich, Akio Enders, Kelly Hanley, Charles Hyland, Andrew R. Zimmerman, and Johannes Lehmann. Corn growth and nitrogen nutrition after additions of biochars with varying properties to a temperate soil. Biology and Fertility of Soils, 48(3):271–284, 2012.]

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PH value measured data

Normal anelia stove by solar test		Continuous feeding anelia stove by solar	Normal anelia stove By oven	Continuous feeding By oven
R1	PH=8.191	PH=8.182	PH=8.272	PH=7.714
	PH=8.160	PH=8.133	PH=8.281	PH=7.812
	PH=8.215	PH=8.181	PH=8.210	PH=7.815
Average pH=8.2		***Average pH=8.2***	***Average pH=8.3***	***Average pH=7.8***

Biochar yield

The quantity of biochar produced at 60 minute was determined by weighing the biochar after the pyrolysis. Biochar yield was calculated using the following formula, and expressed in weight percentage (wt. %). When the capacity of the C.A and N.A stoves it holds the khat 3000gram and 2800gm after the heating in 60 minute the the weight of biochar is respectively was measured in mass balance. The yield of biochar from slow pyrolysis of biomass has been stated to be within the ranges of 24 % - 77% (Dutta, 2010; Stoyle, 2011**)**

Weight of solid khat		Weight of biochar	Solar(open drying) wt.%	Oven (home) wt.%
C.A in solar	3000gm	*1775.31gm*	59.2	
C.A in oven	3000gm	*1836.27gm*		61.2
N.A in solar	2800gm	*1763.46gm*	62.9	
N.A in oven	2800gm	*1768.72gm*		63.2

$$Biochar\ yield\ in\ solar\ = \frac{weight\ of\ biochar}{weight\ of\ khat} x100\%$$

$$Biochar\ yield = \frac{1775.31gm}{3000gm} x100\% = 59.2\%$$

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Experiment 4. Proximate analysis of biochar

The proximate analysis on biochar was done according to the ASTM Standard Method for Chemical Analysis of Wood Charcoal with some slight modification on the analysis temperature range (ASTM D1762-84, reapproved 2007), since biochar is not destined to be used as a fuel source (Noor et al., 2012; McLaughlin, 2010). Proximate analysis refers the quantification of the moisture, volatile matter, fixed carbon, and ash fractions of a material (Edmunds, 2012).

- ➢ The moisture content (MC) was found by weighing 2 g of the biochar sample (E) and oven dried at 105 ºC for 3 hours, until the mass of the sample was constant. The change in weight (D) was then used to determine the sample‘s percentage moisture content using equation.

- ✓ calculate the percentage of moisture in the sample as follows:

$$Moisture, \% = [\left(\frac{E-D}{E}\right)]x100\%$$

Where:-

E = grams of air-dry sample used, and

D = grams of sample after drying at 105°C

Normal anelia stove by solar test			Continuous feeding anelia stove by solar		Normal anelia stove By oven		Continuous feeding By oven	
Round 1	At39.972gm	**37.284gm**	At38.776gm	**36.168gm**	At40.455gm	**37.734gm**	At38.726gm	**36.121gm**
Round2	39.106gm	**36.476gm**	38.890gm	**36.274gm**	37.568gm	**35.041gm**	37.656gm	**35.123gm**
Round3	38.804gm	**36.194gm**	37.763gm	**35.223gm**	38.218gm	**35.648gm**	35.711gm	**33.309gm**
Average	**39.294gm**	**36.651gm**	**38.476gm**	**33.473gm**	**38.747gm**	**33.709gm**	**37.364gm**	**32.506gm**
Moisture,	**6.73%**		**13.00%**		**12.38%**		**13.00%**	

- ✓ When to calculate the moisture content based on feed stock (Normal anelia stove by solar test).

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E=39.294gm (grams of air-dry sample used)

D=36.651gm (grams of sample after drying at 105°C)

$$Moisture, \% = [\left(\frac{A-B}{A}\right)]x100\%$$

$$Moisture, \% = [\left(\frac{\mathbf{39.294-36.651}}{39.294}\right)]x100\% = 6.73\%$$

Volatile Matter—Heat the muffle furnace to 450°C. Preheat the crucibles used for the moisture determination, with lids in place and containing the sample, as follows:

- The crucible along with the lid is placed empty in the oven at the temperature of 450 ˚C for 30 minutes. Afterwards it is removed, left to cool down to ambient temperature and then is weighted.
- A sample of 2g is placed in the crucible, while it's evenly and uniformly distributed on the bottom
- The crucible is then weighted again, and placed in the oven for at 450 ˚C for 30 minutes.
- Afterwards it is removed and left to cool down to ambient temperature
- Then it's weighted again and the volatile matter is calculated numerically.

Normal anelia stove by solar test			Continuous feeding anelia stove by solar		Normal anelia stove By oven		Continuous feeding By oven	
R	25.654gm	*21.571gm*	25.363gm	*21.943gm*	24.411gm	***21.845gm***	22.479gm	***18.970gm***
	25.425gm	*21.377gm*	23.800gm	*20.590gm*	25.608gm	***23.148gm***	20.987gm	***17.711gm***
	23.119gm	*19.438gm*	24.093gm	*20.844gm*	23.238gm	***19.611gm***	23.801gm	***20.086gm***
Average	**24.732gm**	**20.795gm**	**24.418gm**	**21.125gm**	**24.419gm**	**21.534gm**	**22.422gm**	**18.922gm**
Volitile %	**15.918%**		**13.485%**		**11.814%**		**15.609%**	

$$volitle\ matter, \% = [\left(\frac{B-c}{B}\right)]x100\%$$

$$volitle\ matter, \% = \left[\left(\frac{24.732-20.795}{24.732}\right)\right]x100\% = 15.918\%$$

Where:-

C = grams of sample after drying at 450°C

Ash—Place the lids and the uncovered crucible used for the volatile matter determination, and A sample of 2g is placed in the crucible, while it's evenly and uniformly distributed on the bottom containing the sample in the muffle furnace at 550°C for 4h. Cool the crucibles with lids in place in a desiccator for 1 h and weighed.

Normal anelia stove by solar test			Continuous feeding anelia stove by solar		Normal anelia stove By oven		Continuous feeding By oven	
Round1	38.060gm	26.092gm	37.772gm	30.083gm	37.161gm	26.384gm	39.397gm	27.114gm
Round2	38.026gm	27.263gm	38.250gm	28.001gm	38.229gm	28.446gm	38.923gm	30.145gm
Round3	38.092gm	28.092gm	37.513gm	27.046gm	37.879gm	27.095gm	38.613gm	28.829gm
Average	38.059gm	27.149	37.845gm	28.376gm	37.756gm	27.308gm	38.977gm	28.696gm
Ash %	**71.33%**		**74.98%**		**72.32%**		**73.62%**	

$$\text{Ash content(wt.\%)} = \left(\frac{\text{C}}{\text{A}}\right) \text{x100 (wt.\%)}$$

Where C is weight of ash, and A weight of the biochar used for ashing.

$$\text{Ash content(wt.\%)} = \left(\frac{27.149}{38.059}\right) \text{x100 (wt.\%)} = 71.33\%$$