



**ADDIS ABABA UNIVERSITY**

**ADDIS ABABA INSTITUTE OF TECHNOLOGY**

**CENTER OF ENERGY TECHNOLOGY**

**Design and Experimental Analysis of charcoal production from Maize  
Waste (Corncob)**

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**Advisor: Dr.Ing. Wondwossen Bogale**

**A thesis submitted to the school of graduate studies of Addis Ababa  
University Addis Ababa Institute of Technology in partial fulfillment for the  
degree of masters of Science in Energy technology**

**Addis Ababa, Ethiopia**

**October 2020**

**DECLARATION**

I hereby, affirm that this thesis is my original work. I, the undersigned, declare that this thesis entitled " Design and Experimental Analysis of charcoal production from maize waste (corncob) " is my original work under the center of the energy technology department, Addis Ababa institute of technology and has not been submitted by any other person for an award of a degree in this or any other University, and that all resources of materials used for this thesis have been duly acknowledged and a list of references is given

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### **ABSTRACT**

Maize is the second dominant crop that is used as a food next to Teff in Ethiopia. However, there is much left-over corncob after harvest and during processing. Some peoples need the waste of this corn for cooking purposes and baking Injera. Pyrolysis is the process at which charcoal is produced within low oxygen environmental conditions. Developing an innovative pyrolysis system for the production of charcoal from corncob that is economical, efficient, and environmentally friendly is very important. The main objective of this research work to design and experimental analysis of charcoal production from corncob by slow pyrolysis. The continuous pyrolysis system has been designed, manufactured, and tested. Data collection, characterization of corncob, and charcoal analysis were done. The physical characterizations of the corncobs have also been done by estimating the proximate analysis. Bomb calorimeter was used to measure the energy content of the corncobs and the produced charcoal. As the quality properties and chemical composition of plant material are one of the most important indicators of how much waste can be used in charcoal production the characterizes of moisture content, Volatile matter content, fixed carbon content, and an ash content of the corncob were found as 9.11%, 65.84%, 15.76%, 9.28% respectively. Based on the experimental result the corncobs charcoal was 1.55% of moisture, 13.65% of Volatile matter, 65.64% of fixed carbon and 18.26% of ash contents were observed. Based on the result, 2.1 kg of biochar is produced from 3kg of corncobs at rpm of 12.5 and 24°C/min of residence time at the temperature of 600°C. This implies a product yield of 70 % has been found. The parameters like temperature, rotation of the motor, and moisture contents of the waste have effects on the production of the charcoal from corncobs using this machine. Based on the experimental result, the lower heating values of the corncobs and its charcoal were found to be 16.97 MJ/kg and 27.43 MJ/kg respectively. Thus, by using this machine 743 kg of charcoal is produced daily which can earn 3194.9 Ethiopian birrs daily if it sells.

#### Keywords

Charcoal, Corncobs, Slow pyrolysis, Continuous screw reactor

## LIST OF ACRONYMS AND ABBREVIATIONS

### A. ACRNOMYS

MJ	Mega Joule
Kg	Kilogram
Min	Minute
°C	Degree centigrade
°F	Degree Fahrenheit
$T_S$	Torque transmission of power in $\omega$
P	Power on the shaft
$T_1$	Tension in the right side of the belt
$T_2$	Tension on the slack side of the belt
$R_P$	The radius of the pulley
$W_P$	Vertical load acting on the screw shaft
$K_i$	Transmission ratio factor
$D_1$	The outside diameter of the small pulley
$M_{MAX}$	Maximum bending moment acting on the shaft
M	Moisture contents
$M_{Char}$	Dry Mass of corncob charcoal
$M_{bio}$	The dry mass of corncob biomass
$Y_{Char}$	The charcoal yield of product
ASTM	American Society for Testing and Materials
$V_P$	Pitch velocity
$\dot{q}$	Heat transfer rate in (W/m <sup>2</sup> ),
A	Total area in (m <sup>2</sup> ),
R	Thermal resistance for heat transfer
Nu	Nusselt number
$CR_{aL}$	Rayleigh number
$T_S$	Temperature from the surface

## Design and Experimental Analysis of charcoal production from corncob

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W	watt
$r_i$	The inner radius of the reactor
$r_o$	The outer radius of the reactor
$r_1$	The radius of a small pulley
$r_2$	The radius of the long pulley
$\dot{m}_{in}$	Total rates of mass flow into the control volume
$\dot{m}_{out}$	Total rates of mass flow out of control volume
$M_{CC}$	The total mass of corncobs inserted in the reactor
$\Delta E_{system}$	The total energy of the system during a process
$E_{in}$	Total energy entering the system
$E_{out}$	Total energy leaving the system
$E_{generated}$	Total energy generated

### B. ABBREVIATIONS

CC	Corncob
CC BM	Corncob biomass
CC Char	Corncob charcoal
MC	Moisture content
VMC	Volatile matter contents
FC	Fixed Carbon
HHV	Higher heating value
LHV	Lower heating value
GHG	Greenhouse gas
$L_{react}$	Length of the reactor

### C. GREEK WORDS

$\rho$	Density(kg/m <sup>3</sup> )
$\beta$	Angle of groove
$\mu$	Coefficient of friction
$\varepsilon$	Emissivity
$\omega$	Angular velocity

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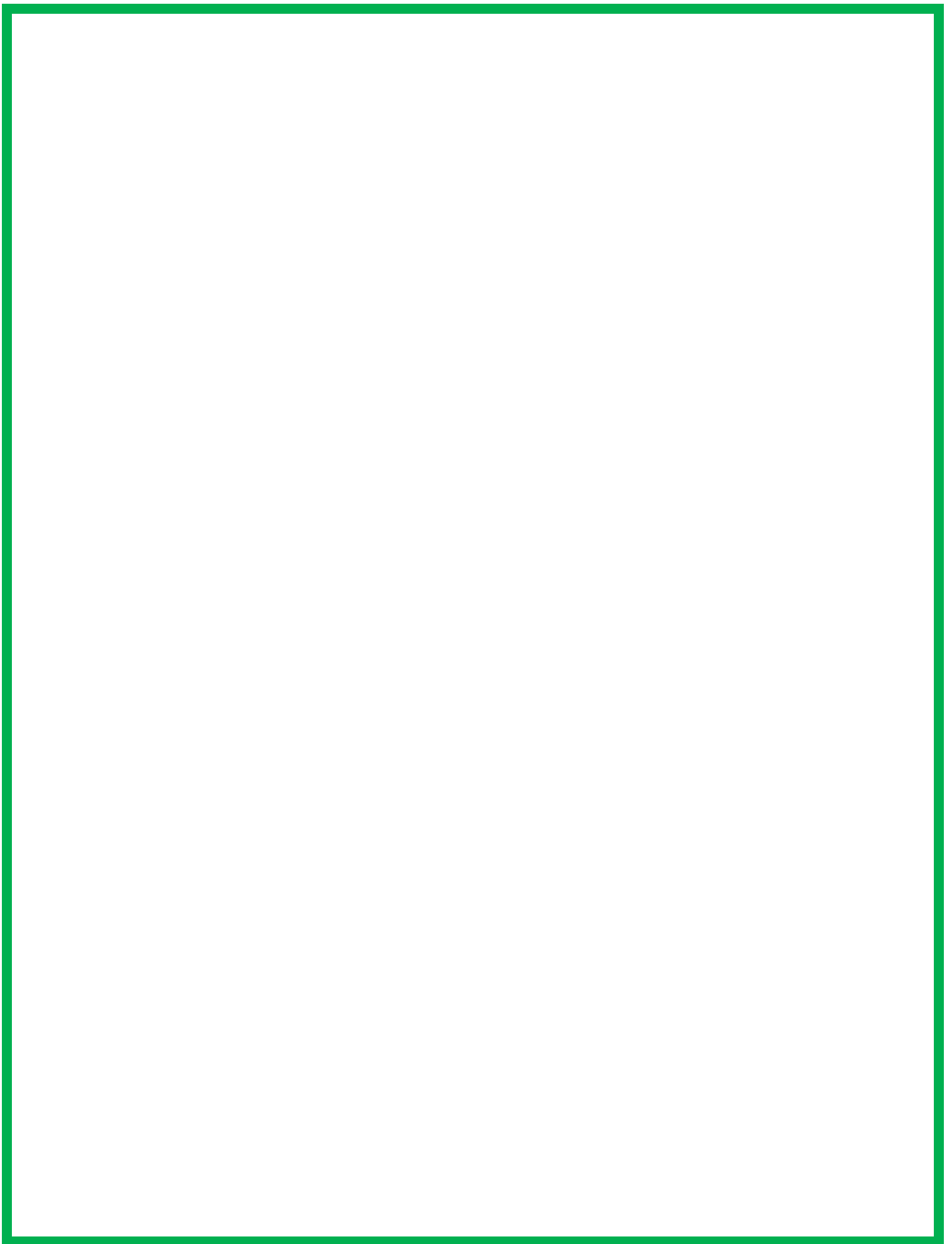
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## **CHAPTER ONE**

### **1. INTRODUCTION**

#### **1.1 Background**

As the world population increasing gradually their energy demand is rise with living standards. This energy is basically either from renewable or nonrenewable types of resources. Biomass and non-fossils energy resources are one of the types of renewable energy technology such are environmentally friendly resources which can be used by human beings mostly on this planet[1]. Biomass like corncobs is the material that originates from plants which is used as food or energy generation [2].

According to *A. M. Jones et.al.2019*, fuelwood and charcoal are important sources of energy for households and small industries in developing countries like Ethiopia. More than 2.4 billion people about one-third of the world's people still rely on the old-fashioned use of wood energy for food preparation, and many small enterprises use fuelwood and charcoal as the main energy carriers for purposes such as baking and tea processing[3].

Human beings can generate wastes in daily of their activities[4]. In current times, the degree and number of waste generation have been situated on the rise. As the capacity of wastes increases, the range of the waste also rises [5]. Currently is unlike in earlier history that wastes were needed to be disposed of. Making opportunities that enable low technical conversion of municipal biowaste streams into a valuable renewable energy carrier would combine several benefits, including[6]:

**Environmental benefits:** reduction of greenhouse gas emissions

**Socio-political benefits:** independence from nonrenewable resource and the fluctuating prices of fossil fuels

**Economic benefits:** the use of renewable and locally available energy sources made from waste substance will create business opportunities and generate employment easily.

Corn cob is one of the biomass residues, which is left-over and recycled in various countries like Ethiopia[7]. When using the seed for food, the corncobs are lefts and available for other uses

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without extra effort for the collection and conveyance. Through the slow pyrolysis procedure, corncobs have the probable to be transformed into biochar for both energy and soil upgrading [8]. Therefore, it is the main solution for the substitution of wood to waste materials to save our forests, environments, and increase our job opportunities. The technology which produces charcoal from this material was developed by different researchers. But they don't solve the problem basically because of the machine problems. The machines which are developed for the production of this charcoal are to save time and economically feasible. Thus, the corncob is finally converted into an opportunity.

### **1.2. Problems of the statement**

Using waste material is one of the challenges in Ethiopia, which is effects on environments and human health. Forests and wood charcoal are mainly used as the main source of energy in the country. By using different techniques, the waste materials are changed to useful energy since it is economically, socially, and environmentally feasible. Pyrolysis is one of the technologies developed to convert these waste materials into useful energy. It is the system used to change biomass remaining materials within a low energy situation. For the production of charcoal from corncobs slow pyrolysis is very suitable and the ability to support the achievement of alternative energy resource objectives[9].

Since raw charcoal (charcoal produced by traditional process from hardwood) is a type of charcoal that is being used in large amounts; it causes the environment and human health harm. The production process needs hardwood hence leads to deforestation. Additionally, the manufacture practice itself poses a danger to the environment by holding GHE and subdivisions to the atmosphere.

In Ethiopia, most peoples use maize for food. But after they need the parts of the corn for food, they leftover corncob parts as waste. Some peoples need the waste of this corn for the fire (for cooking and baking injera) as it is. Accordingly, they use a huge amount of corncob, to prepare a few foods when they use it as it is.

Traditionally charcoal was produced from wood forests by earth kiln and earth mount. This was harmful to the environment and the production yield was also low. To save time, minimize human efforts, and increase product development the technology is very important. Even though

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some machines are developed by many researchers previously it has the problem of assembling and disassembling which is difficult to maintain the machines. Not only the problems of assembling and disassembling, in Ethiopia most of the machines are done for the production of biochar from another waste rather than maize waste. To overcome the dependence on the wood charcoal and substitute charcoal obtained from maize waste (corncob), this study is aimed to develop continuous biochar producing machines which is saving our time and resources by the development of corncob waste charcoal manufacturing. It also offers crucial baseline facts about the feature of corncob for the production of biochar charcoal.

### **1.3. Objective**

#### **1.3.1. General objective**

The main objective of this study was to design an experimental analysis of charcoal production maize waste and characterizing of charcoal manufactured from corncob.

#### **1.3.2. Specific objectives**

1. To determine the proximate and caloric values of maize waste (corncocks) biomass
2. To produce charcoal from corncocks by preparing a machine
3. To determine the proximate, caloric values and analysis of charcoal produced from corncocks by pyrolysis
4. To increase the capacity of charcoal producing machine
5. To assess the properties of corncob charcoal and compare the yield and quality with other standards.

### **1.4. Significance of the study**

This study gives insight for corncob as alternative raw material for charcoal production and paves the way for further study as promising abundant agricultural waste biomass of our country for large scale charcoal production by slow pyrolysis with other materials by using this machine.

In general, it is aimed to provide the possibilities of:

- ❖ Using agricultural waste particularly corncob, as raw material for charcoal production.
- ❖ Reducing environmental load emissions by replacing forest wood with maize waste.
- ❖ Innovate the machines for charcoal production from biomass continuously
- ❖ Income and job opportunity for society

## **1.5. Scope of the study**

This study focuses on the development of continuous charcoal producing machines from corncob and quality characterization of the produced charcoal. It was including the modeling of the corncobs charcoal producing machine using the solid work software

The wastes of maize (corncobs) that are used for producing charcoal are taken from farmland. To develop the appropriate corncobs charcoal producing machine, a different material is used to increase the production of a machine better than the previous. Mild steel is used as raw material for the manufacturing of the machines. For the reason that the capability of heat conduction of this steel is well. The product from corncob is biochar charcoal. To increase the efficiency of this product modifying is also necessary to increase the capacity of the machines. Finally, the characterizations of the produced charcoal from corncobs are determined.

## **1.6. Delimitations**

This thesis concerns development of a charcoal producing machine and testing the quality of biochar produced from corncob waste through slow pyrolysis. To achieve improving quality characterizations of maize waste charcoal product from the selected material proximate analysis are needed. Additionally, this research cannot concern the ultimate analysis of corncob because of material limitations. Briquetting of the biochar charcoal produced from maize waste can also not determined because the experimental setup is not available in the university.

## **1.7. Thesis organization**

This research is a study about the development of continuous charcoal producing machines from maize waste. The study has generally six chapters. In part one contextual of the study, problems of the statement, goals of the study with importance, the scope and delimitations of the study are briefly discussed under the introduction part. Under Chapter two of the study the literature on previous work on charcoal production technologies, carbonization and pyrolysis of biomass, types of a reactor for pyrolysis, corncobs biochar pyrolysis, parameters which are effects on the production of biochar, mode of operation, and the research gap are discussed. Chapter three describes the methods of how the study was done and the materials and instrument uses to accomplish the objectives. Chapter four study design Concept development for the experimental

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setup. Under this chapter for production of biochar by slow pyrolysis the reactors types are listed with its dimensions, continuous Screw reactor is selected and developed with its suit parts. Under chapter five the characterization of charcoal from corncob is the study and the manufacturing of charcoal from corncob is experimentally investigate with a developed machine. Under this chapter, the governing equations, mass, and energy balance equations in the continuous screw reactor machine were also stated. In chapter six the study result is discussed and finally, the conclusion and recommendations of the thesis are explained under chapter seventh of the study.

## **CHAPTER TWO**

### **2. LITERATURE REVIEW**

#### **2.1 Historical Background of Biomass and Maize waste**

From the global bioenergy statistics, 2014 reported, biomass was the third main energy resource next to coal and oil. It is to non-fossil recyclable biological material which is mainly originated from plants, animals, and microbes. Some examples of biomass originate are trees, grasses, crops, agricultural wastes, wood waste and their derivatives, bagasse, urban solid waste, waste paper, waste from food handing out as well as water plants and algae animal wastes. Biomass is kinds of renewable resources since they are naturally occurring and when properly managed, that they are replaced easily without significant depletion of their sources[10].

According to Lanai. S .et. al (209) reported biomass contributes an interestingly large amount of the world's energy up to 10% of over-all worldwide main energy consumption. From this biomass, the energy is used as wood and charcoal for many household purposes. They are collected from forests or farmlands for this energy uses. Sustainable biofuel growth can use modern energy services for more people, especially for that can live in rural areas. It can also develop greater investment in agriculture, which employs 75% of the world's poor. It can generate new employment chances in rural parts and make available a key new foundation of income for farmers[11].

P. Ranum .et.al (2014) reported that the Maize (*Zea mays*), also called corn cob, is kinds of biomass which were originated from fundamental Mexico 7000 ages ago commencing rough grass and laterally changed to customs as a main basis of nutrition by Americans [12]. Predominately it is distributed to Africans and used as a food for over 70 million peoples in Africa and consumed directly by small scale holder families. Small scale holder farming operations in sub-Saharan encompasses over 25 million hectares. Ethiopia is categorized second in Africa with yearly maize manufacture which can estimate to 3.98 metric tons per hectare[13].

From the report of Ramirez. L et.al.(2017) Maize is a main nourishment home for the world and is a high-yield product yield, with an ordinary gathered part of 157 million hectares and

## **Design and Experimental Analysis of charcoal production from corncob**

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manufacture of 781 extra-large tones from 2000 to 2014; it is a energetic basis of diet refuge in various unindustrialized countries [14].



Figure 2-1 corncobs stock ([www.alamstock.com](http://www.alamstock.com))

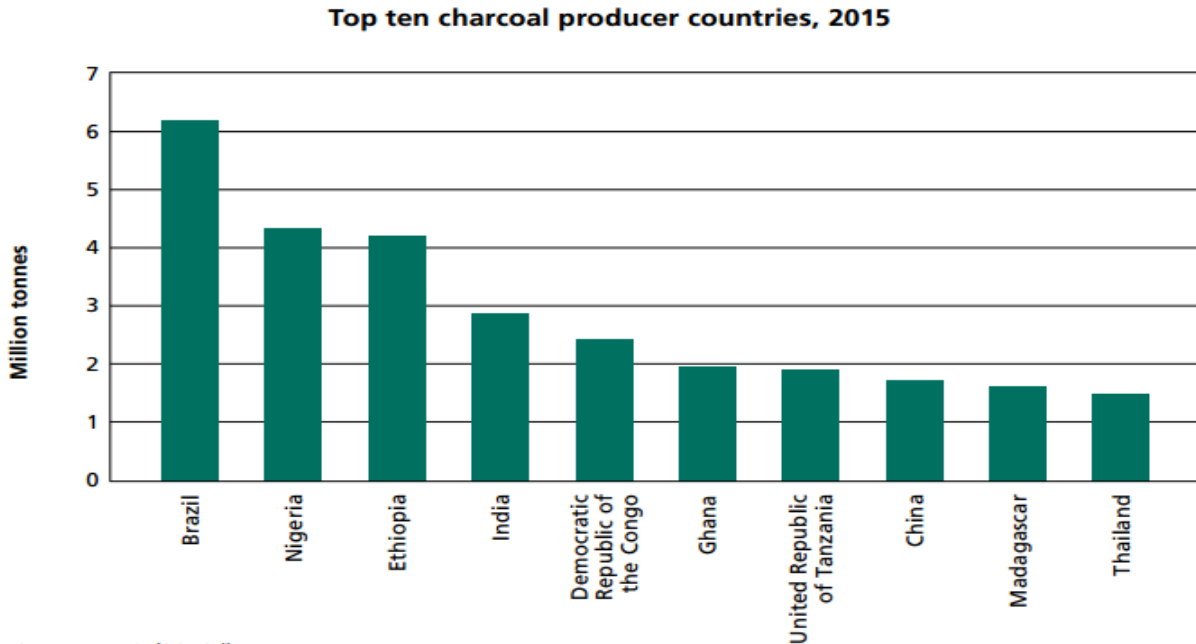


Figure 2-2 Worldwide top ten charcoal producer countries outlook 2015 [15]

From the above figure 1.1 reported by FAO, Ethiopia is the third charcoal producer country in the world next to Brazil and Nigeria. This indicates that in Ethiopia the demand for charcoal is very high. Consequently, we must to improve machinery for the manufacture of charcoal to rise production and achieve the supplies of household energy. The biomass that we need for the production of charcoal is also must be considered. Even though the demand for charcoal in Ethiopia is very high, most of the people use mainly forest plants for the manufacturing of this energy which has the problems of environmental pollution.

## 2.1. Literature reviews on Charcoal production technologies

Various revisions indication that charcoal can be manufactured by numerous systems for different commitments. In sub-Saharan African countries, many households use wood charcoal to cook energy, with the highest consumption being in urban areas[16].

Charcoal is the blackish remains that is transformed from biomass and comprising of contaminated carbon achieved by releasing moisture and other volatile essentials from animal and vegetation ingredients[17]. It is regularly made by slow pyrolysis, the heating of wood, bone char, or other agricultural constituents in the absence of oxygen environment at 450° - 510° C by using either in a kiln or a continuously-fed furnace called a retort[17]. High charcoals yields can

## Design and Experimental Analysis of charcoal production from corncob

be achieved through the use of efficient production kilns. There are three major factors influencing conversion yield [18].

- The moisture content of the wood at the time of carbonization
- Type of carbonizing equipment used
- Care with which the process is carried out

The available technologies for the manufacturing of charcoal from biomass are from the simple traditional furnaces for local manufacture to innovative equipment with increasing possible for developed manufacture[19].

Table 2-1 Summarization of comparison & characterizations between each technology types[19].

Technology types	Request for use	Benefit	Obstacle	Efficiency	Durability	Replicability
Traditional Earth Kiln Improved	Small scale	Easy mounted	Not easy to control	15-20%	Constructed once	High replicability
Improved/Casamance	Small scale	Controlled airflow	Stack management	26 – 30 %	Constructible	High
Drum kilns	Domestic	Easy to constructed	Charcoal contamination	20-30%	Drum usable 2 to 3 times	Easily replicable
Mekko kiln (Biochar)	Both small or large	Mobile/high recover	Costly	50-75%	Not yet established	Replicable
Portable metal kiln	Both small or large	Portability/ good recovery		26 – 30 %	Durable	Replicable
Ring Kilns	Small/Industrial	Mobile/ high recover	Costly	30-50%	Durable	Replicable
Brick kilns	Half orange	ligh recover	Costly	20-30%	Not durable	Replicable
	Dom shape	Uses small	Costly	50-60%	Not durable	Replicable

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Technology types	Request for use	Benefit	Obstacle	Efficiency	Durability	Replicability
		materials				
Rectangular	Small scale	Good recovery	Transportation of materials	28 – 30 %	Reparable	Replicable
Retort	Large scale	Mobile	Expensive	70– 80 %	Durable	Replicable

## 2.2. Literature reviews on the topic

Raymond S, 2013. Revisions illustration that; *Slow Pyrolysis of maize stover for production of biochar*. His key objective was to yield biochar from maize stover by using a regionalized biochar apparatus with detailed aims; 1) to define the temperature profile of the biochar reactor. 2) To examine the reasons of time residence on the product of biochar. 3) To quantify the element properties of the biochar. 4) To study the proximate impact on biochar yields. He gotten that the decentralized biochar reactor completed slow pyrolysis temperature within the range of 250 – 418 °C, with a residence time of nearly 6.8 °C/min. Proximate analysis of biochar gave a moisture content of 7.5 wt. %, ash content 15.2 wt. %, volatile matter 18.0 wt. % and fixed carbon 59.3 wt. %. He used the decentralized biochar reactor, for the production of biochar from maize stover by slow pyrolysis. He accomplishes that; a fixed carbon content of larger than 50 wt. % recommend that biochar from maize stover is good for carbon sequestration[20].

Wolf D. et al.; (2017): studied that *an open-source biomass pyrolysis reactor* in which the objective of their work was to design and production of a pyrolysis retort charcoal producing machine to convert feedstock with moisture content 30% at temperatures 450°C - 600°C. They identified that there is a perfect want in developing states for access to safe, cheap, and effective open-source designs and technology that can be manufactured locally. The design they described includes computational fluid modeling which established that the design demonstrations a steady flow and combustion design. A hazard and operability (HAZOP) study, mass and energy forming and estimate of all devices and fabrication were also revealed for a perfect kiln that will accept up to 250 kg biomass[21].

## **Design and Experimental Analysis of charcoal production from corncob**

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Tristan B et al. 2013, they studied that *estimating the profitability of developed biochar from corn Stover for two conditions*. They considered that slow pyrolysis was to yield biochar and pyrolysis gas and has the advantage of great profits of char with the disadvantage of making a comparatively low-value energy product. When the second condition is that fast pyrolysis to raise the yield of bio-oil with biochar and pyrolysis gas as lower-yielding co-products. The firm pyrolysis importance profits an widely larger rate energy produce than slow pyrolysis but at the price of higher stock. Their conclusion shows that slow pyrolysis is greatest for cost-saving with lower rate energy product and the fast pyrolysis has advantages instead of higher yield of energy than that of slow pyrolysis but has disadvantages of higher cost for manufacture[22].

Tippayawong N et al.(2018); studied the *Classification of Biochar from Pyrolysis of Corn Remains in a Semi-continuous Carbonizer*. Their paper aimed to review demonstrate a practical production of biochar from corn cobs in a modern semi-continuous carbonized and to evaluate its performance in terms of reaction temperatures attained, overall processing time, biochar yields, and properties. They were done the experiments in a retort typed, cylindrical drum mounted horizontally. Its dimension was 1.5 m long with an inside diameter of 1.05 m. The outer part of the machine was heated by the combustion of feedstock and pyrolysis gas in an irritated furnace. It was also manufactured with a slowly rotary paddle. For each test, about 90 up to 120 kg of feedstocks were inserted into the reactor. The temperatures distribution through the carbonization chamber were recorded and used as a characteristic for pyrolysis temperature. The reactor was then discharged and the causing biochar was left to calm down to room temperature in a locked container. Consequently, the solid char products were collected, weighed, and sent for analysis. A huge quantity of corn cobs was effectively changed to good quality biochar in a semi-continuous carbonization reactor system. They investigated that Corn cobs were successfully converted to biochar in an outside heated, retort typed and semi-continuous machine. Biochar yields of 23 – 33 % were gained. The biochar quality was similar to those produced from traditional charcoal kilns and other carbonizes. The conversion process took no more than 3 h at 120 kg loading, compared to 3 – 3.5 days for traditional charcoal kilns. The carbonization system was found to operate well [23].

Roegiers J, 2015. Study that, mass transfer and energy balance of auger reactors. He designed that Auger (or screw) apparatuses are tubular, continuous biochar producing reactors in which

feedstocks are elated using a revolving screw,, and high temperature is ecstatic along the tubular wall of the reactor. The bolt in that way realizes two determinations: main, it mixes the solid material, and then, it controls the dwelling time of the things in the reactor. Screw or auger reactors have been successfully applied in the gasification and/or pyrolysis of coal and are currently being considered for their use in biomass pyrolysis, torrefaction,, and gasification[24].

### **2.3. Thermochemical biowaste-to-energy conversion**

According to A. Demirbas, 2004 and K. Srirangan, 2012, thermochemical routes for the production of fuel are four main categories such as direct combustion, gasification, pyrolysis, and liquefaction. The study that, each differs in temperature, heating rate, and the oxygen level present during treatment[25][26].

**A. Direct combustion** is the oldest way of using biomass and accounts for over 97% of the world's bio-energy production. It involves the high-temperature conversion of biomass in air forming carbon dioxide and water vapor.

**B. Gasification** is performed at relatively high temperatures. The gas-making processes of pyrolysis and char-gasification are separated from the burning or storage of the gas[6].

**C. Liquefaction** is a low temperature, high-pressure thermochemical process, using a catalyst

**D. Pyrolysis** is a process by which a biomass feedstock is thermally changed into biochar or charcoal in the absence of oxygen/air. Pyrolysis is not only a self-governing process but the core reaction of all thermal processes, i.e., it is the first step in the gasification and combustion process[6].

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Table 2-2 Solid product yields, solid product carbon content, and carbon yield of different technologies [6]

Process type	Process temp.	Residence time	product yield on a dry wood [in mass%]	the carbon content of solid product [in mass%]	carbon yield mass carbon in a product
Slow pyrolysis	~400°C	min to days	~30%	95%	~0.58
Fast pyrolysis	~500°C	~1 s	12-26%	74%	0.2-0.26
Gasification	~800°C	~10 to 20 s	~10%		

In general, the desired product of slow pyrolysis is char, the solid residue remaining after volatile gases and vapors are released from the dry fuel material[27]. Vapour and gaseous products can also be desirable, although these are not always recovered. Old-style methods, by earthen pits, mounds, or kilns, largely include some shortest combustion of the biomass, usually wood, as a heat source[6].

### 2.4. Carbonization and pyrolysis of biomass

#### 2.4.1. Carbonization process

Slow pyrolysis or carbonization is the traditional method for the manufacture of charcoal that involves of wood-burning, consequential in the charcoal invention and both condensable and non-condensable vapors in the by-products, in accumulation to smoke, charcoal charges, and residue[28]. It is the method by which complex carbonaceous resources, such as fuel or cultivated leftovers, are damaged down into main carbon and biochemical materials by boiler[29]. Interrelated to charcoal building, carbonization (or whole pyrolysis) occurs when “firewood is feverish in a locked container of specific kind, absent from the oxygen of the air which if not would allow it to burn and hurt away to remains.” Wanting oxygen, the wood

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molders into a variability of materials, the central one being charcoal, which itself consists mostly of essential carbon.[29].

The simple processing of carbonization is done according to the following steps[17].

- ✓ Separate the biomass into different types of parts like stems, leaves, and fruits and cut them into short pieces. For carbonization, we use that each waste by separating.
- ✓ For carbonization, loosely pack the collected biomass into the kiln
- ✓ After loading the biomass into the kiln, close the top of the kiln with a metal lid attached to a conical chimney.
- ✓ Use a little amount of biomass in the firing portion to ignite in the kiln and close the doors tightly to start the pyrolysis process.

### **2.4.2. Pyrolysis process of biomass**

Pyrolysis contains fast heating system of biomass or other feed in the absence of air or oxygen at a supreme fever, recognized as the pyrolysis temperature, and stock it there for a quantified time to yield noncondensable vapors, solid char, and liquid product. The liquid product is of primary interest in pyrolysis. The nature of its product depends on several factors, including pyrolysis temperature and heating rate. [30].

Based on the heating rate, pyrolysis may be broadly classified as slow and fast. It is considered slow if the time of heating required to heat the fuel to the pyrolysis temperature is much longer than the characteristic pyrolysis reaction time,  $t_r$ , and vice versa. i.e.[30]

- Slow pyrolysis:  $t_{\text{heating}} \gg t_r$
- Fast pyrolysis:  $t_{\text{heating}} \ll t_r$ .

#### **2.4.2.1. Slow pyrolysis conversion process**

Slow pyrolysis refers to method conditions with slow heating rates (typically 5–80°C/min) coupled with moderate temperatures (typically 300–600°C), which maximize the char yield. Such method situations container be definitely attained in heaters with several balances and forms, such as static couches and rotary kilns, though achieving the theoretical limit of char yield requires a well-designed reactor to maximize the residence time for organic vapors[6].

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In slow pyrolysis, the home period of suspension in the pyrolysis sector (vapor residence time) is on the mandate of proceedings or elongated. This procedure is not used for traditional pyrolysis, where the production of liquid is the main goal. Slow pyrolysis is used primarily for char production and is broken down into two types: carbonization and torrefaction. Torrefaction takes place in a very low and narrow temperature (200-300°C), while carbonization takes place at a much higher and broad temperature [30]. Generally, the process of slow pyrolysis is the following [24]

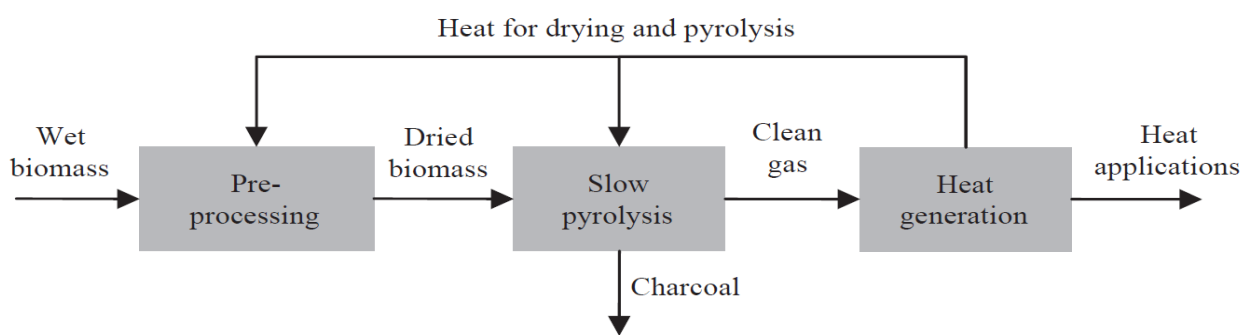


Figure 2-3 Process flow chart of slow pyrolysis (Rougier. J et al)

### **2.4.2.2. Fast pyrolysis conversion process**

The core objective of fast pyrolysis is to make the most of the production of liquid or bio-oil. The biomass is heated so rapidly that it reaches the top (pyrolysis) temperature earlier it molder. The heating rate can be as high as 1000-10,000°C/s, but the peak temperature should be below 650°C if bio-oil is the product of interest. However, the peak temperature can be up to 1000°C if the production of gas is of primary interest. Four important features of the fast pyrolysis process that help increase the liquid yield are; very high heating rate, reaction temperature within the range of 425-600°C, short residence time (,3 s) of vapor in the reactor, and rapid quenching of the product gas. Carbonization produces mainly charcoal; fast pyrolysis processes target the production of liquid or gas [6], [30].

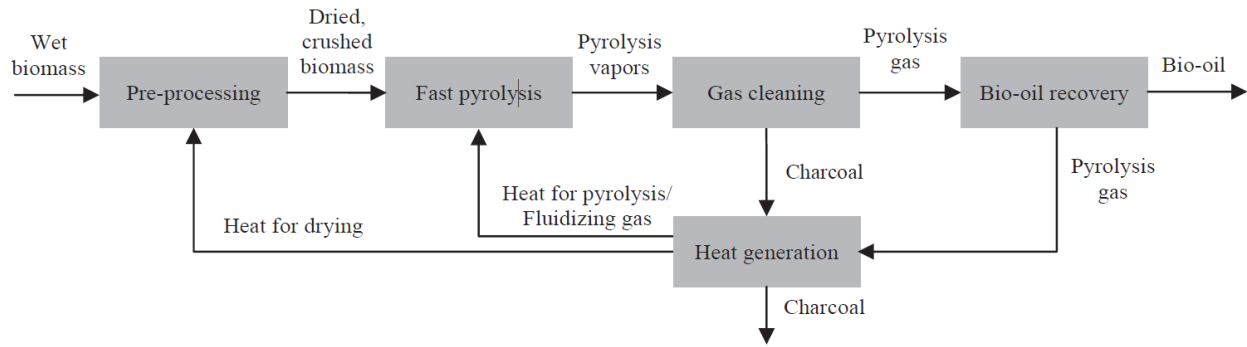


Figure 2-4 Process flow chart of fast pyrolysis[24]

### 2.4.3. Biochar process of biomass

Charcoal, also known as biochar, is a preferred product of slow pyrolysis at a moderate temperature[30]. Bio-char can be obtained from biomass pyrolysis. For a high biochar production from biomass pyrolysis, a low temperature and low heating rate process would be chosen[25]. The biochar can be used in the preparation of active carbon when its pore structure and surface area are appropriate. The starting materials used in commercial production of activated carbons are those with high carbon contents such as wood, lignite, peat, and coal of different ranks or low-cost and abundantly available agricultural by-products[25].

Biochar, a carbonaceous absorbent substantial created from the pyrolysis of agricultural residues and solid wastes has been widely used as a soil amendment. Current papers on biochar are mainly motivated on its use in climatic features, chemical control, soil change schemes, nutrient regaining, engineered material production, and waste-water treatment[31].

Biochar has a special appeal in greenhouse gas reduction as its production can greatly increase the amount of carbon retained in a ground instable form similar to that is done for carbon sequestration. The carbon in agricultural residues and forest residues when left on the ground is released over time to the atmosphere as CO<sub>2</sub> or CH<sub>4</sub>[30]. Biochar is influenced by; temperature, types of biomass, and residence time parameters.

**Influence of biomass types:** - The conformation of the biomass, specially its hydrogen-to-carbon (H/C) ratio, has an essential behavior on the pyrolysis produce.

**Influence of temperature:** - During pyrolysis, a fuel particle is heated at a defined rate from the ambient to a maximum temperature, known as the pyrolysis temperature. The fuel is held there

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until the completion of the process. The pyrolysis temperature affects both the composition and yield of the product.

**Influence of residence time:** - The rate of heating of the biomass particles has an important influence on the yield and composition of the product. Rapid heating to a moderate temperature (400-600°C) yields higher condensable volatiles and hence more liquid, while slower heating to that temperature produces more char.

### **2.4.4. Types of reactors for pyrolysis**

Pyrolysis feedback is the organic feedbacks happening in the pyrolysis apparatus, what wants this puts on the production of the plant and which purposes are built-in. Originally, the start-up of the pyrolysis process is described[30]. Pyrolysis reaction units are the division where the chemical feedbacks happening in the pyrolysis reactor, the portions of the apparatus wants for the construction of the plant, and which purposes are built in[32].

For the pyrolysis progression, the device is a very essential part that are used as hearts for the systems. This is where the reaction takes place, where biomass is pyrolyzed to pyrolysis gas and char. Reactors have been designed to satisfy specific conditions giving considerations to parameters such as heating temperature, vapor product residence time, and required pressure, for a high bio- oil yield [33].

Fixed bed reactor is a very simple equipment that gives significance to the manufacture of bio-oils, which are relatively unchanging in size with low fines content. It is made up of two basic mechanisms, that is, the gas cooling section and the washing organism by cleaning over a cyclone, wet scrubbers, and dry filters. During a reaction, the solid sample is allowed to pass through a vertical shaft where it encounters an upwardly moving counter-current gas stream product. This

## **2.5. Characterization of biomass for energy production**

### **2.5.1. Analysis of biomass**

Feedstock analysis is a energetic and essential portion of a progression. It gives the acute evidence on biomass that is desirable for a sensible scheme or enhanced kind of a method[34].

### **2.5.1.1. Proximate Analysis of biomass**

The proximate analysis gives the configuration of the biomass in expressions of its gross mechanisms such as moisture (M), Volatile matter (VM), ash, and fixed carbon (FC). It is comparatively simple and economical to quantity[35].

#### **A. Moisture**

High moisture is a main representative of biomass. The foundation of plant biomass engages moisture from the earth and drives it into the sapwood. The moisture movements to the trees over the capillary passages in the plant. Photosynthesis retorts in the leaves routine various of it, and the rest is out to the sky through transpiration. For this cause, there is extra moisture in the leaves than it is in the tree stem.

#### **B. Volatile matter (VM)**

The VM of a coal is the condensable and non-condensable vapor free when the coal is heated. Its quantity be contingent on the degree of heating and the temperature to which it is heated. For the determination of a volatile matter, the fuel is heated to a normal temperature and at a standard proportion in a measured situation.

#### **C. ASH**

Ash is the inorganic compacted remainder left when the fuel is totally burned. Its principal elements are silica, aluminum, iron, and calcium; small aggregates of magnesium, titanium, sodium, and potassium may also be existent.

#### **D.Fixed carbon (FC)**

FC is the solid carbon in the biomass that leftovers in the char in the pyrolysis progression afterwards devolatilization. The FC in coal includes elemental carbon in the original fuel plus any carbonaceous residue formed while heating, in the determination of VM (standard D-3175).

#### **E. Char**

Char, though a carbon residue of pyrolysis or devolatilization, is not a pure carbon; it is not the FC of the biomass either. Known as pyrolytic char, it contains some volatiles and ash in addition to FC. Biomass char is very reactive. It is highly porous and does not cake.

### 2.5.2. Proximate analysis of corncob

Corn cob (CC) is a biomass feedstock with direct possible as an energy source that can be used in gasification methods for energy creation. It has various rewards over other biomass feedstocks including its dense and uniform nature as well as its increased energy content and its low sulfur and nitrogen concentrations [36]. It is an cultivated residue that is produced from maize and leftovers portion of the ear on which the seed develop. In most recognized countries, CC is usually disposed of and destroyed by passion on the farmhouses to make for the succeeding future period.

From the previous study, the proximate standards of corncobs are dissimilar from the authors. The following tables generally show that the characterizations of corncobs obtained by different researchers.

Table 2-3 Proximate analysis of corncob from previous studies (wt. %)

Author (sources)	MC	VM	AC	FC
[36]	5.1	65.1	8.5	22.3
[37]	11.74	72.33	10.67	4.97
[38]	—	78.7	0.9	16.2

### 2.5.3 Ultimate Analysis of corncob

This analysis delivered evidence on the fundamental mechanisms of Corn cob both in qualitative and measurable positions. The percentage of carbon (C), hydrogen (H), sulfur (S), and nitrogen (N) could be resolute, while oxygen (O) will be gotten by means of difference. The energy rate (heating value) of corncob, will be intended from the form elements of the fundamental mechanisms found from CHNS analysis. Where the heating value is dignified in MJ/Kg, while CHNS are the carbon, hydrogen, Nitrogen, and Sulphur contents of corncob respectively[39].

**Table 2-4 Ultimate analysis of corncob from previous studies (wt. %)**

Author	C	H	N	S	O	HHV (MJ/kg)
[36]	44.4	5.6	0.43	1.3	48.8	17.88
[37]	46.2	5.42	0.92	0.24	47.22	18.36
[38]	45.5	6.2	1.3	—	47.0	18.19

### 2.5.3. Pyrolysis of corncob

Pyrolysis is the current corrosion of biomass to harvest a combination of condensable solutions (bio-oil), gases, and solid excess (biochar) in the absence of oxygen. The pyrolysis method can be categorized into three core lessons, namely slow pyrolysis, fast pyrolysis, and flash pyrolysis. Every class can be distinguished by their operational situations such as temperature, heating degree, and holding time. The return temperature range is concerning 300°C–700°C for slow pyrolysis, 400°C- 550°C for flash pyrolysis, and 550°C and beyond for fast[40]. According to this investigator, the corncob is appropriate to be recycled as the feedstock for slow pyrolysis for the reason that of its high volatile matter and little measurements of nitrogen and sulfur. The high fixed carbon makes it a possible feedstock

## 2.6. Mode of operation

Mode based on the mode of operation, pyrolysis apparatuses can be classified as a batch, semi-batch, and continuous[24].

### 2.6.1. Batch operation

This type of operation is the technology that was developed centuries ago to produce one of the first charcoal fuels. The production methods with different variations have mostly been used up until the present. The introduction of pyrolysis gas recirculation in the pyrolysis chamber, thus supplying the heat that is necessary for the pyrolysis process without using a part.

### **2.6.2. Semi-continuous operation**

The semi-batch operated system is portable and makes better use of hot ovens. Heat containing vapors are recycled between batch reactors. Some of these systems allow the recovery of liquid products, but most are typically used to produce Biochar. These semi-portable steel kilns have two advantages;

1. They can be moved easily (which may be useful for small-scale production) Shorter cycles result when biomass is dispersed.
2. Kilns cool quickly.

### **2.6.3. Continuous operation**

Continuous operation reactors are designed to run nearly continuously with occasional downtime for maintenance. Most continuous operation reactors are justified only if the flow rate is high. A typical continuous unit for the production of biochar has a capacity of over 2.75ton/hr. They are often more economical for large-scale production.

## **2.7. Research gap**

In this research, broad study is taken by considering more articles from different papers, those revised article accepted their revision by many researchers. Most of the articles reviewed make a conclusion based on the simulations rather than experimental. From the studied article only a few of them are done on the experimental model about pyrolysis of charcoal from corncobs

Generally, from a reviewed article some gaps are recognized. Consequently, for high support on the production of charcoal from maize waste (corncobs), continuous pyrolysis systems development suggested developing the machines in terms of feasibility and durability must have done experimentally rather than simulations. Therefore, in this study, the design, experimental analysis, and testing of continue charcoal production from corncob machine is additional reliable than the earlier done articles.

## CHAPTER THREE

### 3. Materials and Methods

The following materials and methods were used during the study period.

#### 3.1. Materials and Equipment's

The following materials were used to achieve the aim and objectives of this research.

**Raw material:** - Corncob (*Zea mays*, L) was used as raw material for producing charcoal.



Figure 3-1 Maize waste (corncob) collected from Tullubollo, Oromia, Ethiopia

**The equipment uses:** Furnace, crusher & oven were used for carbonizing, breaking and drying of the corncob respectively. The weight of the corncob was measured before and after processing by using a weighing balance. IR thermometer was also used for measuring the temperature at different conditions. Biochar producing machines were used for biochar production from corncob biomass. To manufacture the machine instruments like; screw conveyor, feed hopper, combustion chamber wheel, and gasket are used. A moisture analyzer was also used. Motor and blower were also used to generate power for the screw conveyor.

#### 3.2. Methodology

##### 3.2.1. Collection of corncob and sampling

To investigate the characterization of corncobs and biochar produced from corncobs, many experiments were done. The experimental procedures for biochar production of charcoal from corncobs by the developed machine are as follows:

- Collection of maize waste biomass and sampling

### ➤ Sample Analysis

Corncoobs were manually collected from the farmland of Tullubollo and taken to Addis Ababa institution and Technology University compound by transportation. To remove moisture content from corncoobs samples were sun-dried in 14 days. Then crushed the dried samples biomass into the appropriate size and kept in a bag until used for pyrolysis. The crushed corncoobs were sorted and re-dried to reduce the moisture content of the feedstock to ensure effective carbonization. The dried corncoobs were shredded to small sizes to provide more surface area for carbonization. The sample was tested and manufactured at Addis Ababa University Amist Kilo campus.

### **3.2.2. Sample analysis**

In this study, corncoobs was evaluated for its fuel quality by fuel quality determining parameter expressed in terms of proximate analysis and physical properties. Samples were collected from the farmland of Tullubollo, with appropriate safety using like a glove then crushed to fit the machine for carbonization. By comparing the standard properties of corncob charcoal the sample was analyzed.

### **3.2.3. Machines conversion yield**

The processing of changing biomass to char plays a small but crucial role in the biomass/bio waste-to-charcoal value chain. Machines or retort efficiency is also referred to as carbonization efficiency, conversion efficiency or char yield. The char yield provided by a machine was solved by equation 3.1 [41]:

$$Y_{\text{char}} = \frac{M_{ch}}{M_{bi}} \times 100 \dots\dots\dots 3.1$$

Where  $M_{ch}$  is the dry mass of corncob biochar processed in the machines and  $M_{bi}$  is the initial dry mass of the biomass feedstock interred into the machines.

The energy input to the machine was provided via blower and drive systems like screw, motor, pulley, and belt. Biomass, which is burned to provide direct heating, needs to be included in efficiency calculations.

### 3.2.4. 3D Modelling and Manufacturing developed machine

Biochar production from maize waste continuously was conducted using continuous biochar producing machine which was used a screw reactor. The unit of the machines consists of the following components main parts: Inlet (hopper), screw, outlet, gearbox, pulleys, V- belt, conveyor, blower, chimney, conveyer body, and supports (bricks). The 3D of this machine is modeled using solid work software and manufactured.

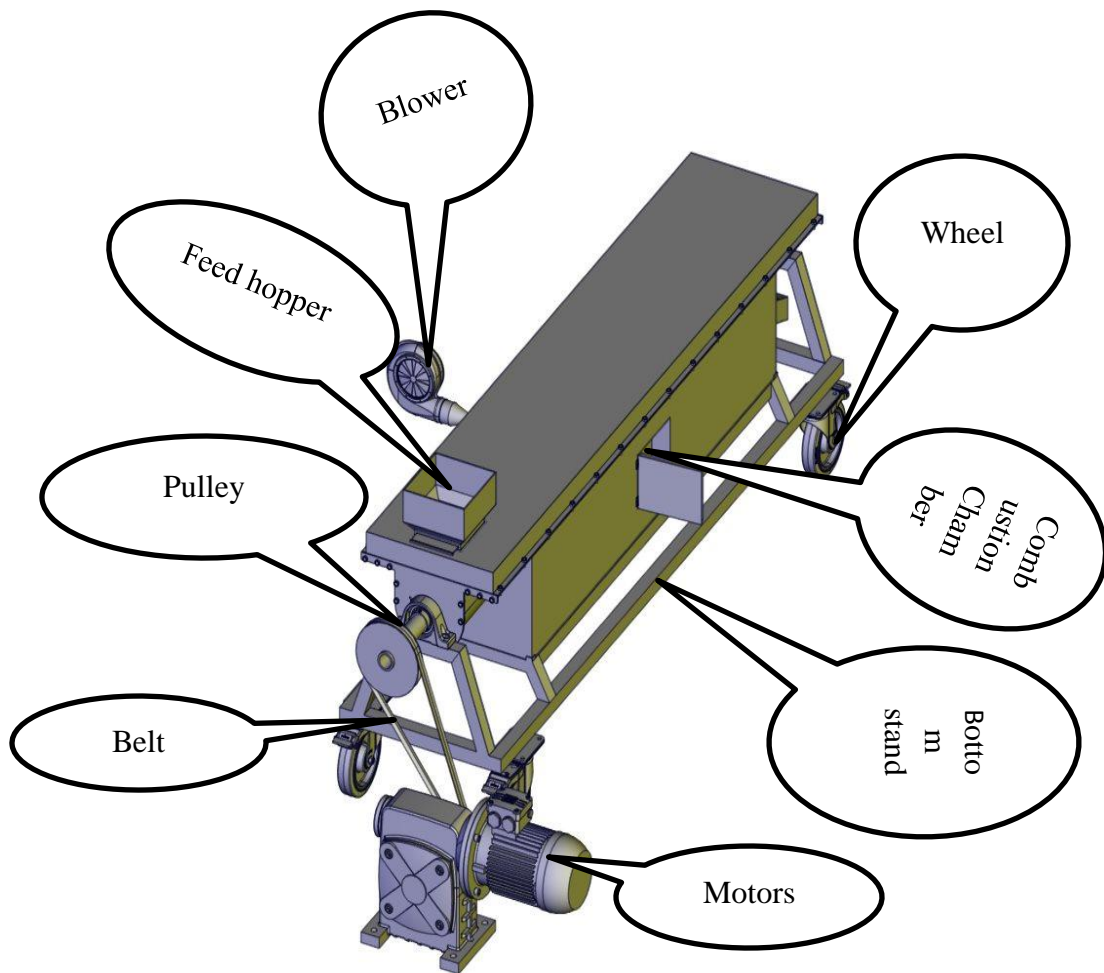


Figure 3-2 3D modeled of continuous screw reactor

The efficiency of the machine was also tested by using the above formula. The product yields can also calculate from the standard formula which is expressed in the literature. In the end the

## **Design and Experimental Analysis of charcoal production from corncob**

all activities were discussed based on the result investigations. Finally, depending on the result, the study was concluded, and recommending the all study were written. The general procedure for the production of charcoal from corncob by using the developed machines is described in the following diagram.

Generally, the following diagram shows the overall steps to design and experimental analysis of corncob charcoal production.

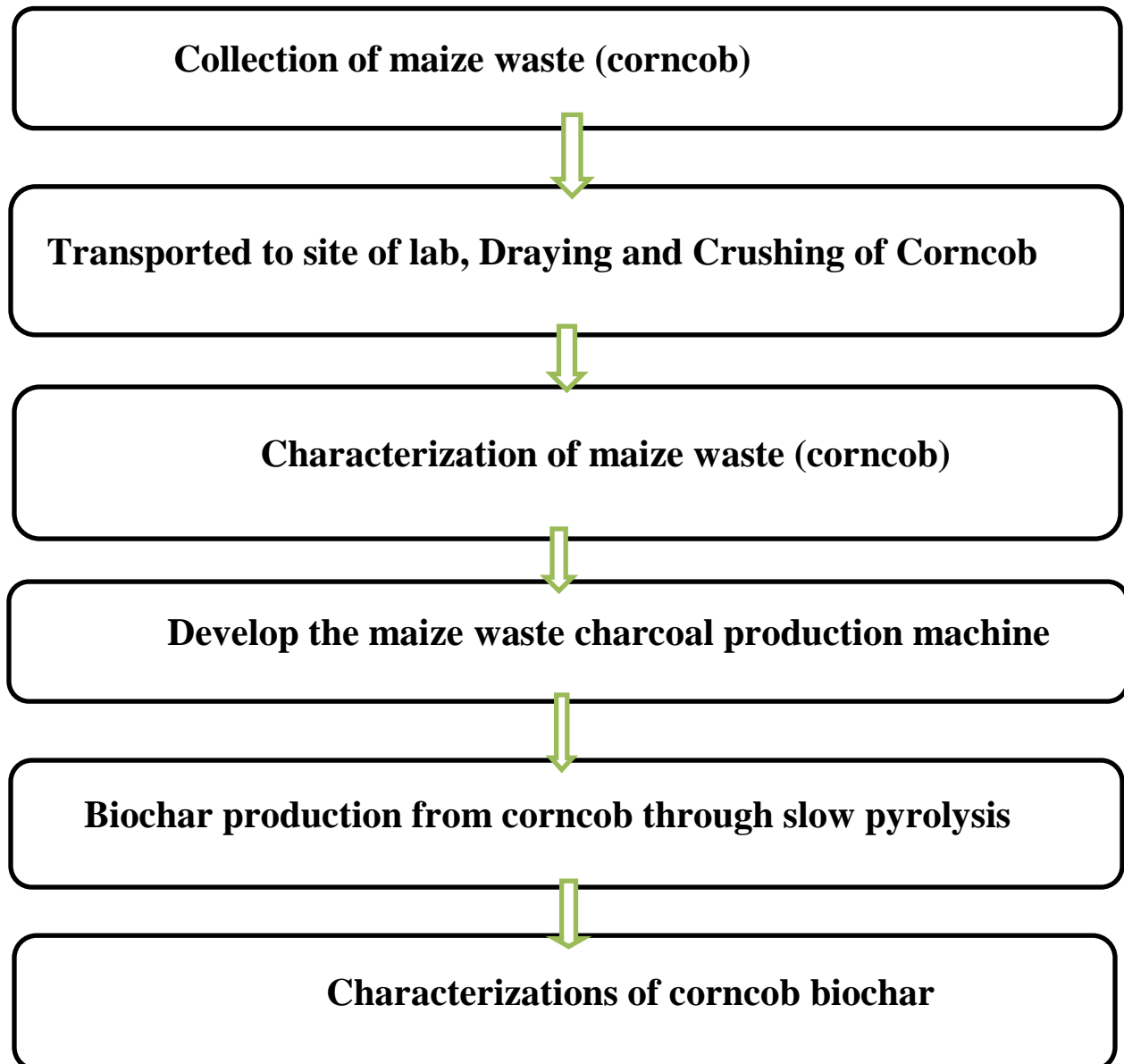


Figure 3-3 Flow chart process of manufacturing and testing the quality of biochar production from corncob

### **3.3. Characterization of maize waste (corncob) biomass**

The proximate exploration of the raw measurable (moisture content, ash content, volatile matter content, and fixed carbon content) was conducted following ASTM D-standards[41]. Characterization of maize waste biomass sample was important to identify its suitability to undergo the thermochemical conversion process. The proximate & calorific value of the corncob biomass samples shows in Table 3.1.

#### **3.3.1. Lower Heating Values of corncobs**

A dried corncob biomass sample is weighted and placed in a digital bomb calorimeter for calorific value or heating value determination. Then the digital bomb calorimeter is sealed and the corncob sample is ignited electrically. The whole ignition of this biomass reliefs heat. So that by using a digital sensor, of the water bath nearby the bomb calorimeter slow the change of temperature of biomass. The temperature of ignition can be considered from the resulting temperature rise. The lower heating (caloric) value of corncobs biomass was 16.97MJ/kg.

#### **3.3.2. Proximate Analysis of Corncob biomass**

##### **3.3.2.1. Moisture content of corncob biomass**

The moisture content of corncobs sample of biomass was determined by first weighing 1g of wet sample biomass then placed in an oven to dry at 105°C for one hour and weighted 0.9089g of a dried sample.

##### **3.3.2.2. Volatile matter content (VMC)**

The volatile matter content of corncob waste was determined by weighted 1g oven-dried of sample then placed in a furnace at a temperature of 950°C for six minutes and weighted 0.2504g after cooling in a desiccator. Then the percentage of the volatile content of the sample is computed as the difference between initial (Oven dry weight of charcoal specimen for moisture determination or weight after moisture removal) and final weight of the sample after removal of volatile matter and dividing the result by the total sample weight taken and multiplying the whole with hundred.

##### **3.3.2.3. Ash Content of corncob biomass**

The ash content (AC) was determined by heated of weighting 1g oven-dried samples biomass in an ash furnace at a temperature of 950°C for 4hrs and weighed 0.0928g after cooling. The ash

## **Design and Experimental Analysis of charcoal production from corncob**

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content of each sample was the mass-weighted after a temperature of 950°C for 4hrs in an ash furnace. Ash content was, computed as a proportion of the residue to the oven-dry weight of corncob waste. Then the percentage of ash content of the sample is computed as the difference between initial (Oven dry weight of corncob specimen for moisture determination or weight after moisture removal) and final weight of the sample after removal of ash and dividing the result by the total sample weight taken and multiplying the whole with hundred.

### **3.3.2.4. Fixed Carbon of corncob biomass**

The Fixed carbon (FC) weight content of the corncob biomass sample was determined by subtracting the sum of moisture content weight, volatile matter weight, and ash content weight from the weighted wet sample biomass.

## **3.4. Preparation and characterization of corncob biochar**

### **3.4.1. Preparation of biochar from corncobs**

The procedures of preparing biochar from maize waste follows as

1. Facilitate of the material needed like IR thermometer for measure temperature, moisture analyzer for measuring moisture contents and watch for a time keep



Figure 3-4 Infrared thermometer (A) and Moisture analyzer (B)

2. Feed 10kg of dry wood into the combustion chamber to generating energy used for pyrolysis



Figure 3-5 inserting the wood into the combustion chamber

3. Connect generator to rotate the screw within required RPM



Figure 3-6 generator

4. Connect blower for control heat transfer to reactor.



Figure 3-7 blower

5. Measure the temperature in the screw reactor before start-up heating measured. The Temperature measured is about 25 °C.

6. Startup heating dry wood in the combustion chamber and on the blower connected to for control heat transfer to the reactor.



Figure 3-8 starting the firing of wood in the chamber

6. Wait for 25 min until the inner reactor reaches desired or pyrolysis temperature and measured the increment of temperature by 5minute interval until the temperature is steady-state

7. Record the temperature on the length of the reactor noted as A, B, and C for all tests until the temperature reached pyrolysis temperature.

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9. The measured pyrolysis temperature distributions on the inner reactor before input corncob sample is 600°C after 20 minutes

10. Feed 3kg of corncob biomass into feeder hopper at a time.

11. Finally weighted 2.kg produced of biochar from 3kg of corncobs biomass within 1.25 minutes.

### **Test one**

The blower was used to the firing of the biomass in the chamber for the production of heat in this experiment. The temperature is recorded within five-minute intervals to know the temperature at which biomass of maize waste was must to started carbonization in the reactors. By taking three-point on the inner and outer reactors such as right (A), center (B), and left end (C) of the reactor. The pyrolysis temperature in the reactor stable (600°C) in 25-minute residence time by increasing 24°C/*minute* and the average the outer surface temperature of the reactor was 550°C

Table 3-1 Temperature distribution on the inner and outer surface reactor

Time	The temperature in the reactor (°C)				The surface temperature of the reactor (°C)			
	Right	Center	Left	Average	Right	Center	Left	Average
8:00(start time)	25	25	25	25	25	25	25	25
8:01-8:05	200	250	220.5	223.6	195	210	99.5	252.25
8:06-8:10	350	400	379	376.3	340	380	360	360
8:11-8:15	420	450	429.5	433.16	389	410	400	399.6
8:16-8:20	540	550	545	545	510	545	520	525
8:21-8:25	600	600	600	600	550	550	550	550
8:26-8:30	600	600	600	600	550	550	550	550

### **Test two**

## **Design and Experimental Analysis of charcoal production from corncob**

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After 25 minutes when the temperature comes to a steady state the 3kg of waste was inserted in the reactor through the hopper and after 1.25 minutes 2.1kg of biochar corncob was produced. When the waste was inserted in the reactor the following product at different rpm were observed.

Table 3-2 Rotational speed when the biochar charcoal was produced from corn cob

Rotational speed in rpm	Maize waste input in kg	Output product (charcoal) in kg	Time is taken to the product
1200	3	0	7 second
100	3	0.75	35 Second
25	3	1.25	1minute
12.5	3	2.1	1.25 minutes
10.5	3	1.7	2 Minute

---

By changing the rpm different biochar were observed. With the high rpm, the amount of biochar manufactured was very little or no. As the rpm is decreased the amount of corncob charcoal were increase. But with the rpm is less than 12.5 the amount of charcoal produced were also decrease gradually. Therefore 12.5 rpm is the point at which a high yield of biochar charcoal was observed for this machine. After the biochar was produced the measurement was taken by selecting the biochar from the output production. The experiment was done repeatably the same producers until getting high production of biochar from corncobs biomass.

### **3.4.2. Characterization of corncob charcoal**

After the charcoal was manufactured; the characterization of the corncob charcoal sample was important to identify its suitability to undergo the thermochemical conversion process. The proximate and calorific value of the maize waste corncob charcoal samples shows in Table 3.4

#### **3.4.2.1 Lower Heating Values of corncob biochar**

Corncoobs charcoal samples are weighed and placed in a digital bomb calorimeter for calorific value or heating value determination. Then the digital bomb calorimeter is sealed and the

## **Design and Experimental Analysis of charcoal production from corncob**

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corncob biochar sample is ignited electrically. The heat of combustion can be calculated from the resulting temperature rise. The heating values of corncob biochar was 27.42MJ/kg

### **3.3.2.2. Proximate Analysis of maize waste charcoal**

#### **A. Moisture content of corncob charcoal**

The moisture in the sample of corncobs charcoal was determined by first weighing 1g of sample charcoal then placed in an oven to dry at 105°C for one hour and weighted 0.9845g of a dried sample corncobs charcoal. The moisture content was a weight loss that occurs when the sample is dried in an oven at 105°C for one hour.

$$\text{Moisture content} = \left( \frac{[\text{WIM}] - [\text{WMR}]}{[\text{WIM}]} \right) \times 100 \dots\dots\dots 3.2$$

Where WIM is the weight of the initial mass of corncob charcoal and WMR weight of moisture removal of corncobs charcoal

#### **B. The volatile matter content (VMC)**

To determine VMC, 1 gm of charcoal is taken in a silica crucible with a porous silica cover were determined by weighted 1g oven-dried of the sample then placed in a furnace at a temperature of 950°C for six minutes and weighted 0.3191g after cooling in a desiccator.

$$\text{Volatile matter content} = \left( \frac{[\text{Moisture Mass}] - [\text{Volatile Mass}]}{[\text{Initial Mass}]} \right) \times 100 \dots\dots\dots 3.3$$

#### **C. Ash content**

The method to determine the ash content (AC) was by heated of initially weighing 1g oven-dried samples biomass at a temperature of 950°C in ash furnace for 4hrs and weighed 0.1365g after cooling.

$$\text{Ash content} = \left( \frac{\text{Ash mass}}{\text{Initial mass}} \right) \times 100 \dots\dots\dots 3.4$$

#### **D. Fixed carbon (FC)**

This value was determined by subtracting weighing the content of corncobs biochar sample (100%) the sum of moisture content weight, volatile matter weight, and ash content weight.

Fixed carbon%=100%– (ash%+ volatile matter%+ moisture %).

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Table 3-3 Compare Proximate & caloric value of maize waste (corncob) charcoal samples with international standard measurements[42]

Types of sample		Corncobs Measurements (wt. %) without briquette	biochar (wt. %) briquette	International Standard Measurement (wt. %) briquette
Proximate analysis	Moisture content	1.55		9.86
	Ah content	13.65		28.97
	Volatile content	66.54		14.5
	Fixed carbon	18.26		46.5
	Total	100		100
Heating Value	Lower heating value	27.42MJ/kg		27.2MJ/kg

---

### 3.5. Product yield

The carbonization efficiency can be affected by many factors like moisture content of the input sample or corncobs waste, several air holes in the machine that regulate the amount of air for the proper carbonization and cooling, and personal skill.

Weight-based carbonization efficiency (based on charcoal yield) is a percentage rate expressing the ratio between the weight of the charcoal output and the weight of the air-dry sample input. For instance, the typical yield of a biochar producing machine.

The machine was producing corncob charcoal depending on the rpm speed at a steady state of  $24^{\circ}\text{C}/\text{minute}$ . By taking the time at which, the charcoal was produced rpm speed the product yield was calculated. At this point, the input corncobs were measured 3kg and after 1.25 minutes 2.1<sub>kg</sub> of corncobs, corn cobs charcoal were produced

### 3.6. Governing equation in the machine

All of the phases in the systems are explained by the governing equation. By solving the equations in each cell at a certain time step, a state-space representation of the system can be

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generated. Cylindrical and spherical systems often experience temperature gradients in the radial direction only and may therefore be treated as one dimensional.

### 3.6.1. Heat transfer rate

From the concept of thermodynamics heat transfer is thermal energy that occurs when a temperature difference exists. Accordingly, there are three modes of energy transfer from one part to another[43]. These are:

- i. Conduction- occurs when a temperature gradient exists in a fixed average, which may be a solid or a fluid, we use the term conduction to refer to the heat transfer that will occur across the medium.
- ii. Convection- is the transmission of heat that occurs between a surface and a moving fluid when they are at different temperatures
- iii. Radiation- This type of heat transmission is occurring when all surfaces of finite temperature emit energy in the form of electromagnetic waves between two surfaces at different temperatures.

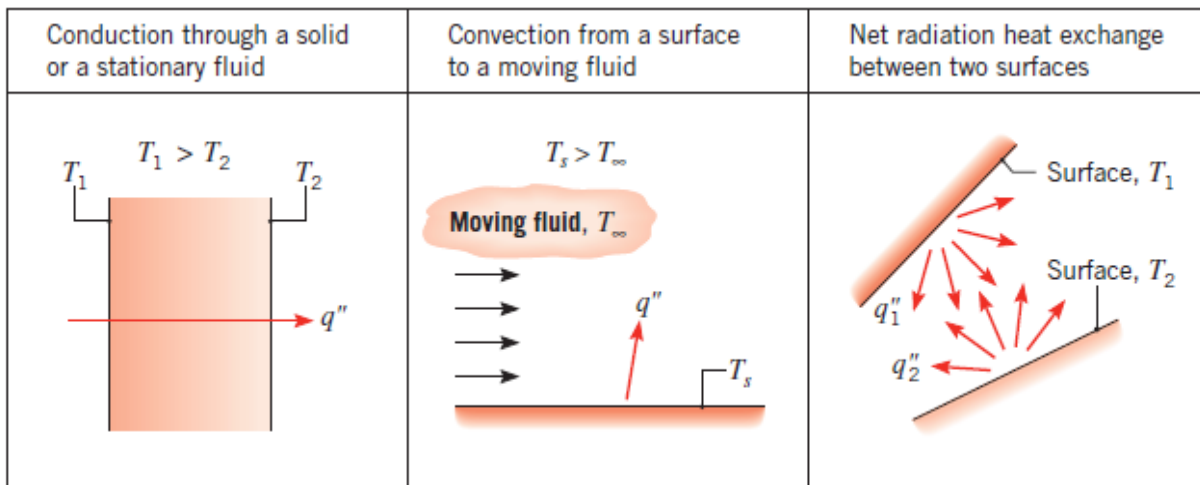


Figure 3-9 Conduction, convection, and radiation heat transfer modes [43].

In this research, the corncobs were entered the screw reactor at an ambient temperature and the flue gas from the afterburner/combustion chamber enters the outer reactor at 600°C. This implies that there was a temperature flow inside a screw reactor during the slow pyrolysis process due to conduction heat transfer. The temperature inside the reactor was gradually increased for the first

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few minutes after the experiment started and reaches pyrolysis temperature finally. From this, we observe that the temperature flows from higher temperature to lower temperature until it reaches a steady-state. The energy balance of the reactor contains several different parts that interact through different heat transfers. To simplify the calculations and attain the temperature profile of the reactor, a discretization is made.

From figure 3.7 the heat transfers in the systems for conduction are from Fourier's law is:

$$q_x'' = K \frac{T_1 - T_2}{L} = K \frac{\Delta T}{L} \dots \dots \dots 3.5$$

Where  $q_x''$ , is the heat transfer rate ( $W/m^2$ ),  $K$  is the thermal conductivity of the materials ( $W/m \cdot K$ ), and  $L$  is the total area ( $m^2$ ). The heat rate by conduction,  $qx$  ( $W$ ), through a plane wall of area  $A$  is then the product of the flux and the area,  $qx = q_x'' \cdot A$

Therefore, the heat transfers in the systems for conduction and convection from Fourier's law in equation 6.1 is given by the following formula:

$$\dot{Q} = \frac{\Delta T}{\Sigma R} \dots \dots \dots 3.6$$

Where  $Q$  is the heat transfer rate and  $R$  is Total thermal resistance for heat transfer

### 3.6.2. Transfer of heat from Combustion to the reactor during pyrolysis

The blower was used to raise the rate of heat for the combustion chamber. By conduction and convection method the reactor can get the heat from combustion hot combustion chamber. These processes are done until the temperature of the screw conveyor in the reactor reached pyrolysis temperature. Convection heat gains can occur to the outer surface of the inner reactor and gas in the inner reactor. Convection heat transfer coefficient  $h_c$  is calculated with the  $Nu$  is Nusselt number,  $k$  is heat conduction of reactor material and  $L_{react}$  is the length of the reactor expressed as[44]

$$NU = \frac{H_c * L_{react}}{K} \dots \dots \dots 3.7$$

### 3.6.3. Heat loss from different parts of the machines

#### 3.6.3.1. Heat loss from the combustion chamber

The reactor in which the pyrolysis takes place is to gain the heat from the combustion chamber either by conduction or convection. Due to several reasons, the heat can lose from this part. One of the reasons is due to different temperatures surrounding the combustion the heat can flow from higher temperature to lower temperature. In this process, the heat is lost. The combustion chamber has rectangular shapes with 14000mm length, 190mm diameter (height), and 60mm thickness. It was made from stainless steel with thermal properties such as thermal conductivity of  $21.5\text{W}/\text{K}_g\cdot\text{K}$ , the density  $7900\text{kg}/\text{m}^3$  and  $500\text{J}/\text{K}_g\cdot\text{K}$  specific heat and insulated by wood ash with  $0.02\text{W}/\text{m}\cdot\text{k}$  thermal conductivity. The temperature in the combustion chamber was  $600^\circ\text{C}$  and the surrounding temperature was  $25^\circ\text{C}$ . The rate of heat transfer to the surrounding due to temperature difference is

$$Q_{loss} = \frac{1T_{com} - T_{\infty}}{R_{tot}} \dots\dots\dots 3.8$$

#### 3.6.3.2. Heat loss from reactor

As we have seen above there three modes of heat transfer from one part to another if there is a temperature difference. Radiation can be a major form of heat loss. In this system, assume radiation losses negligible from the outer reactor surfaces i.e. on the whole sides of the reactor and combustion chamber. From the top, sides, surface, and wall of the reactor, the heat can losses due to convection heat losses. The losses due to convection losses can be calculated by using different techniques. Using the standard methods from the Nusselt number we can calculate the heat losses. The reactor can gain heat from the combustion chamber and the heat was continuously flowing until it reaches the steady-state. After the temperature of the reactor came to a steady-state the pyrolysis process was started. Then there is heat loss due to the temperature difference between the feedstocks in the reactor. By using an IR thermometer, the surface temperature of the reactor is measured and determined by the Rayleigh number and the Nusselt number. When the reactor was ready to manufacture the temperature of steady-state was measured as  $600^\circ\text{C}$ . Before starting the experiment, the ambient temperature was  $25^\circ\text{C}$ . The rate of radiation heat transfer between a surface of emissivity  $\epsilon$  and area  $A_s$  at the temperature  $T_{OS}$  the surrounding temperature can be expressed as:

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For a control volume, the conservation of mass principle can be expressed as The net mass transfer to or from a control volume during a time interval  $\Delta t$  is equal to the net change (increase or decrease) in the total mass within the control volume during  $\Delta t$  that is, [45]

$$\Delta M_{cv} = M_{in} - M_{out} \dots \dots \dots 3.9$$

Let  $\dot{m}_{in}$  and  $\dot{m}_{out}$  are the total rates of mass flow into and out of the control volume respectively, then the total amount of mass leaving control volume can be expressed as:

$$\Sigma \dot{m}_{in} - \Sigma \dot{m}_{out} = \frac{d}{dt} \int_{CV} \rho \, dv \dots \dots \dots 3.10$$

To balance chemical reaction equations, we use the conservation of mass principle for combustion (or the mass balance) principle. This principle can be stated as the total mass of each element is conserved during a chemical reaction. The total mass of each element on the right-hand side of the reaction equation (the products) must be equal to the total mass of that element on the left-hand side (the reactants) even though the elements exist in different chemical compounds in the reactants and products. From this equation, we observed that the total mass of corncobs inserted in the reactor is equal to the total mass of charcoal produced.

### 3.6.4. Energy balance in the screw reactor

From the first laws of thermodynamics, the net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy entering and the total energy leaving the system during that process.

$$\Delta E_{system} = E_{in} - E_{out} \dots \dots \dots 3.11$$

In this experiment, the energy used for pyrolysis is generated from the biomass wood which are fired in the combustion chamber. The dry wood was selected since it is the most appropriate in terms of cost and availability for the manufacturing in this experiment.

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Table 3-4 The standard types of combustion fuel with higher heating values [43]

Number	Fuel types	Higher heating values (MJ/kg)
1	Air-dried wood	16.2
2	Completely dry wood	18.5
3	Charcoal	29.6
4	Petroleum	42

From the above tables, the higher heating values of dry wood is 18.5MJ/Kg. The dry wood which was used to complete the combustion is 10kg. The energy generation in the combustion chamber is the product of the amount of mass input to the combustion chamber with HHV of dry wood.

$$E_{generated} = M_{wood} * HHV \dots \dots \dots 3.12$$

$$E_{Gen}=10kg*18.5=185KJ/Kg$$

### 3.7. Total cost of the machines

The costs of the machine are uses to determine the feasibility of study for feature works. By knowing the costs, we can determine either the machines are stable in terms of cost or not.

Table 3-5 Total costs of material for a machine prototype

No	Items	Quantity	Unit price	in	Total cost in birr
1	Screw with Shaft	1	1,400		1,400.0
2	Pulleys	2	700.0		1400.0
3	Belt	1	300.0		300.00
4	Sheet Metal	4	1,200		4,800.0
5	Bearing	2	150.0		300.00
6	Wheels	4	160.0		640.00
7	Samples Preparation	2	450.0		900.00
8	Gear and Motor	1	8,000		8,000.0
11	Total Cost				1,7740

Generally, the above tables show that the total costs for producing the prototypes

## **CHAPTER FOUR**

### **4. DESIGN CONCEPT DEVELOPMENT**

#### **4.1 Introduction to Design Concept Development**

Charcoal from corncob is a carbon element that remains when it is heated to a high temperature in a low-oxygen environment. In earlier many designers was made the carbonize in the form of a cylindrical oil drum with conical shapes made of sheet metals that are welded at the bottom and difficult to assembling or disassembling.

The machine which developed was, used for manufacturing charcoal from maize waste. This machine was first designed by solid work software and then developed. The performance of the machines was tested based on the ability of the machines to produce charcoal from corncob.

The previous design was selected had features similar to the development machines. The only difference was the absence of assembling and disassembling parts. The other difference is that the developed machines can be operated electrically and manually while the previous ones are operated with electrical only. During the testing of these machines, it was realized that it took a considerably shorter time than the previous for the burning process to complete. The guiding objective during this process was to successfully convert all of the corncob waste inserted into the machines into charcoal. The design of these machines was able to accomplish this objective.

#### **4.2. Types and selection of Reactor for production of biochar**

Pyrolysis is the process where biomass is heated in an environment with low oxygen levels forming pyrolysis gas and char. It is the thermal decomposition of carbonaceous material by the heat in the absence of oxygen. The reactor is the main part of the machines for the pyrolysis process. It is the heart of the pyrolysis process where the reaction is taking place. Modern and traditional reactors are common types of pyrolysis reactors.

##### **4.2.1. Traditional reactors**

As indicated in the literature review traditionally reactors are used to manufacture charcoal or biochar from biomass wood. Earth mount kiln and earth pit kiln are an example of traditional reactors. This kind of technology can take time to the processing and the efficiency of the

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materials is also low compared to traditional. It is lead to greenhouse gas emission since the burnt materials are simply released to the environment. But every person can do with this kind of technology and it is available everywhere. In my case, the modern reactor was chosen because for producing charcoal from corncob the modern reactor is the best to increase efficiency and time saving for producing the biochar.

### **4.2.2 Modern Reactors and its types**

Reactors are the device which is used to produce biochar with suitable temperature which has different units and types. The unit of the reactor body is made of mild steel. This unit is used to carbonize the corncob at different temperatures. It is a cylindrical shape in its inner parts and rectangular shape in its outer parts. Mild Steel is used as the main material due to its ability to withstand high temperatures. The melting point of mild steel is between 1350°C -1530°C (2462°F-2786°F). The temperature range for the pyrolysis is well below this value (300 - 700°C), hence making the material suitable. The unit of the machines consists of the following components main parts: Inlet, screw, outlet, blower, chimney, and supports (bricks). The different types of reactors are designed by many researchers to change agricultural wastes to useful energy. All over the world researchers have been revising the pyrolysis of agricultural residues(corncoobs, straw, husks, tea residues, sesame stalks, hazelnuts, sugarcane, sorghum, almond shells, rapeseeds, tobacco stalks and leaves, algae, cotton straw, sunflower bagasse, switchgrass, woods and forestry residues, and many others) by utilizing a variety of different reactors[33]. Based on the type of pyrolysis process such as slow and fast pyrolysis, the different types of designed reactors referred from researchers are the following:

**1. Fixed beds reactor:** In this type of reactor, the fixed bed of the reactor is heated in one side only because the reactor can't rotate since it is connected with other units. They are poor in heat transmission to the biomass because the bed of the reactor is intense in one direction only and there is no uniform mixing inside the reactor. These reactors have been used for the traditional production of charcoal

**2. Ablative Reactor:** In these reactors, biomass particles are moved at high speed on a hot surface of the reactor. Ablation of any char forming at a particle's surface maintains a high rate of heat transfer from the reactor.

## **Design and Experimental Analysis of charcoal production from corncob**

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**3. Fluidized Bed Reactor:** It is recommended that these reactors are more effective with gasification reactions because there are effective heat and mass transfer.

**4. Rotating Cone Reactor:** In this reactor, the pre-heated hot material such as sand and biomass particles are introduced into a rotating cone. Because of the rotation of the cone, the mixture of heat and biomass is transported across the cone surface by centrifugal force.

**5. Continuous Screw Reactor:** This reactor is the most suitable for the production of biochar through slow pyrolysis. In these reactor biomass particles are heated by the hot surface of a reactor which gains heat from the combustion chamber, conveyed and mixed biomass from inlet to outlet, and efficient for produce bio-oil, biochar, and syngas. Since the feedstock is not getting heat directly it is good to the conversion of biomass into charcoal with slow pyrolysis.

As we have seen from the above, among the all considered reactors, a continuous screw reactor is a top for my study because the corncobs waste is easily heated indirectly and simple to convert biochar with slow pyrolysis.

### **4.3. Continuous Screw reactor and its main parts**

In this reactor, biomass is not directly mixed with a dense heat carrier in the screw reactor. It is the main part of the machines which convert corncob to biochar by which heat is supplied to pyrolysis reactors. By using high thermal conductivity heat carriers, the energy required for slow pyrolysis is rapidly transferred to the biomass.

The continuous screw reactor was designed the same with components for biochar production previously. But some parts of the previous reactors such as screw feeder, length, and shapes of frames are modified. The continuous screw reactor used for this research is made up of an inner reactor, reactor cover, screw conveyor, combustion chamber, feeder hopper, chimney, and outer parts like wheels, bottom stand, generator, and blower. All dimensions of these reactors are given in the Table 4.1 below. Since it is made from mild steel it has generally the following properties:

- 43W/kg°C of thermal conductivity,
- 7801kg/m<sup>3</sup> of density and
- 473 J/ kg°C specific heat.

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Inside the main pipe, an assembled screw goes along all pipe length and an electric engine is connected to the gearbox by the main shaft. The screw conveyor rotates by the motion transfer from the output shaft into the screw shaft by a belt. The rotation of the screw carries the corncob biomass sample from the inlet reactor towards the heating (reaction) zone.

Table 4-1 Summary of all the dimensions in the screw reactors

Reactor body/ parts	Dimensions	Unit in mm
Inner reactor dimensions	Length	1400
	Diameter	100.0
	Thickness	3.000
Screw conveyor	Length	1990
	Pitch length	190.0
	Shaft diameter	50.00
	Screw diameter	40.00
	Flight thickness	3.000
Combustion chamber	Diameter	190.0
	Length	1400
	Thickness	3.000
Mouth of combustion chamber	Diameter	60.00
	Length	60.00
	Thickness	3.000
Outer cover reactor	Length	1520
	Diameter	313.0
	Thickness	3.000

### **4.3.1 Screw conveyor**

The screw conveyor is found in the inner reactor of the machine. Its function is to deliver necessary mixing and transport the biomass through the reactor as it is decomposed in a continuous process. It was a mechanism that was used to rotate a helical screw to transport the material into the process. This screw conveyor consists of a shaft and a helical blade which enclose the shaft. The shaft is coupled to driving and supported by bearing in the inner reactor at both ends. The function of the solid shaft screw conveyor is to convey horizontally the feed (maize waste) from the feed hopper to the heated zone where the slow pyrolysis reaction occurs in the reactor by different rotational speeds. For this research, 12.5 rpm rotational is selected.

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The screw conveyor is made of stainless with flights welded parts. Stainless steel conveyor screws and parts are manufactured to the same specifications as standard mild steel. The important dimensions such as screw diameter, clearance between screw and tube, the pitch of screw, shaft diameter, the thickness of screw flight, and length of shaft are 1998mm, 2mm, 100mm, 25mm, 3mm, and 1.748m respectively.

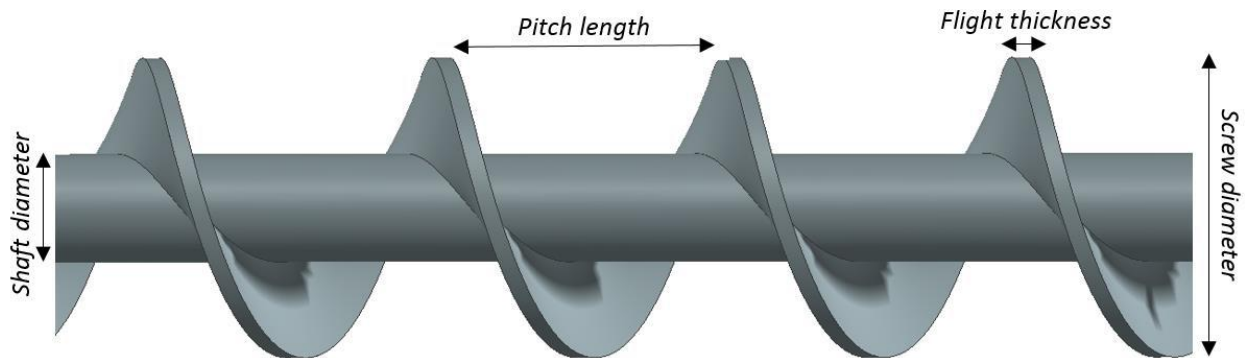


Figure 4-1 Screw conveyor and its competent parameters [24]

### 4.3.2. Combustion Chamber

The combustion chamber is rectangular shape made of stainless-steel having a length of 790mm, height 410mm and 600mm width with 3mm thickness. When the temperature of the reactor reaches pyrolysis temperature the corncob dry biomass is feed into a screw reactor continuously. The pyrolysis temperature was externally heated by heat generated from combustion at a heating rate of 50°C/min to the desired temperature.

### 4.3.3. Feed Hopper

The feedstock materials are transmitted to the screw conveyor through the feed hopper. The hopper is used to store and supply feed material to the screw feeder. In this part of the machines, the measured feedstock was inserted and transmitted to the screw by the means of screw rotation with the help of shafts which are fitted to outer parts of it. The shapes of the screw were a conical shape which is wide large at the upperparts and narrow at the bottom. The upper parts which are large are used to remains a large number of corncobs and the narrow is used to fit the screw parts.

### **4.3.4. Cyclone Separator**

Cyclone separator is used to remove biochar from a gas stream without the use of other force such as filters. It is consisting of an upper cylindrical part and a lower conical part. The mixture of solid biochar and gas flow enters the cyclone separator by screw conveyor. The gas stream enters tangentially at the upper cylindrical part and solid biochar travels downward into the conical part.

### **4.4. Design of shaft**

A shaft is a rotating member, usually of a circular cross-section which is used to transmit power or motion from one to another place. The machine elements such as flywheels gears and pulleys are mounted on shafts and used to transmitting power from the motor to the screw conveyor. Bending moment calculated due to reaction between the shaft and bearing and torque calculated due to power transmission to the shaft. There are three shafts used for power or motion transmission from the motor to the reactor as the following:

- Shaft with screw is used to convey corncob biomass.
- The main shaft is used to transmit torque from the motor to the gearbox.
- The output shaft (pulley mini) is used to transmit torque from the gearbox to the belt.

The shafts perform the function of transmitting power from one rotating member to another supported by it or to it. Thus, they are subjected to torque due to power transmission and bending moment due to reactions on the members that are supported by them.

Shafts could be made in mild steel, carbon steels, or alloy steels such as nickel, nickel-chromium or chrome-vanadium steels. Heavily loaded shafts are often made in alloy steels which because of their high strength would result in smaller diameters. The modulus of Elasticity for most steels is 200GPa. The following stresses are induced in the shafts;

- Shear stresses due to the transmission of torque
- Bending stresses (tensile or compressive) due to forces acting upon machine elements like gears, pulleys, etc. as well as due to the weight of the shaft itself.
- Stresses due to combined torsional and bending loads.

### **4.5. Selection of Bearing**

Rotating shafts with screws required to be supported at suitable places. The mechanical device which can take up the load and support the shaft is called a bearing. The bearing is so named because the surface of the support is subjected to a bearing load. A bearing is a machine element that supports another moving machine element. It permits a relative motion between the contact surfaces of the members while carrying the load. In the bearings, the relative motion between the two mating surfaces causes friction and generates heat. Any substance placed between the two surfaces which reduces friction, wear, and takes away heat, known as a lubricant. To reduce frictional resistance and wear in some cases to carry away the heat generated; a layered fluid (known as a lubricant) may be provided. The lubricant used to separate the journal and bearing is usually a mineral oil refined from petroleum, but vegetable oils, silicone oils, greases, etc. are may be used. Based on the direction of load bearing may be broadly classified into two categories:

- 1. Radial bearings;** radial bearings carry external load perpendicular to the axis of rotation of the shaft. Journal bearings and some types of ball and roller bearings belong to this category.
- 2. Thrust bearings;** in these bearings, the load acts along the axis of rotation, e.g. hydrostatic bearings and antifriction thrust bearings.

#### **4.5.1. Bearing Material**

The factors which lead the bearing to failure are; deflection, temperature distortion, surface roughness, and faulty selection of the bearing material. Therefore, the appropriate choice of bearing material is very significant. Since the progressing elements and the races are subjected to high local stresses of varying magnitude with each revolution of the bearing, therefore the material of the rolling element i.e. steel should be of high quality. The balls are mostly made of high carbon chromium steel. The material of both the balls and races are heat-treated to give extra hardness and toughness.

#### **4.5.2. Life of Bearing**

The lifetime of a specific ball (or roller) bearing can be well-defined as the number of revolutions which the bearing turns before the primary indication of fatigue progresses in the substantial of individual rings or any of the progressing elements. The rating life of a group of an

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alike ball or roller bearings is defined as the number of revolutions (or hours at some given constant speed) that 90 percent of a group of bearings will complete or exceed before the first evidence of fatigue develops (i.e. only 10 percent of group bearings fail due to fatigue). The term minimum life is also used to denote the rating life. We may say that the average life of a bearing is 5 times the rating life (or minimum life). It may be noted that the longest life of a single bearing is seldom longer than the 4 times the average life and the maximum life of a single bearing is about 30 to 50 times the minimum life[46].

For continuous biochar production reactor single row deep groove ball bearing selected based on radial load and known shaft with screw diameter ( $d=40\text{mm}$ ) which is equal to bore diameter (40mm) of bearing. Generally based on 40mm bore diameter selected single row deep groove ball bearing with 80 mm outside diameter and 17mm width from Table 4.2 [47]

Table 4-2 some standard of bearing dimensions

Bearing dimensions in mm		
Bore diameter (mm)	Outside diameter(mm)	Width of Bore (mm)
10	30	9
12	32	10
15	35	11
17	40	12
20	47	14
25	52	15
30	62	16
35	72	17
40	80	18
45	85	19
50	90	20
55	100	21
60	110	22
65	120	23

### **4.6. Design of Pulley**

Pulleys are wheels and axles with a groove around the outside which is used to transmit power from one shaft to another using chains, belts, or ropes around the groove. Since the velocity ratio

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is the inverse ratio of the diameters of driving and driven pulleys, therefore the pulley diameters should be carefully selected to have the desired velocity ratio. The pulleys may be made of cast iron, cast steel, or pressed steel and aluminum. For the continuous charcoal production machines, pulleys material is aluminum and V-grooved pulley is selected from the dimension of standard. Small pulley equivalent diameter is calculated by using the following formula:

$$D_e = K_i \cdot D_1 \dots \dots \dots 4.1$$

Where,  $K_i$  is the transmission ratio factor and  $D_1$  is the outside diameter of the small pulley.

### **4.7. Belt drive**

The v-belt is mostly used where a great amount of power is to be transmitted from the pulley mounted on the shaft of the gearbox to the pulley mounted on the shaft of the reactor. The following are the various important factors upon which the selection of a belt drive depends;

- Speed of the driving and driven shafts
- Speed reduction ratio
- Power to be transmitted
- Center distance between the shafts
- Space available and
- Service conditions.

For power transmission from the shaft of the gearbox, the rubber belt material has been selected because it is durable, flexible, and strong and it must have high coefficient friction. When the pulleys have a different angle of contact, then refer from the design of pulley which has smaller the values of angle of contact when the coefficient of friction between the belt and the pulley ( $\mu=0.3$ ) and angle of a groove ( $\beta=45^\circ$ ) of two pulleys are the same. Since the angle of the smaller pulley is small, therefore the design was based on a smaller pulley. The rotational speed of the larger pulley and the screw conveyor was 12.5rpm.

### **4.8. Motor and Gear Box**

#### **4.8.1. Selection of Motor**

An electric motor is an electrical mechanism that changes electrical energy to mechanical energy. For identifying appropriate type of motor and its applications; understanding the type of

## **Design and Experimental Analysis of charcoal production from corncob**

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motors, mounting and enclosures duty are important. The principles for motor selection include; operating conditions, driven equipment, electrical specifications, mounting requirements, and enclosure and bearing parameters. For continuous charcoal production from corncobs, the motor specification is 50/60rpm, 220V and 3kw obtained i.e. from the industrial guide book of motor selection. Thus, the motor is driving the gearbox by the shaft transmit torsion from motor to gearbox. From previous design and review literature at the maximum rotational speed of the screw conveyor; the produced product intended to be obtained becomes less or no product and the slow pyrolysis process operates at low rotational speed to produced charcoal. In this research, to reduce the rotational speed by used speed reduction driving units like gearbox and pulleys are adjusted which are mounted on the motor.

### **4.8.2. The power requirement for motor**

Depending on a uniform and regular feed rate to the conveyor the power is essential to run a horizontal screw conveyor. The power necessity is the overall power to overcome friction and the power to conveyance the material at the definite proportion multiplied by the completed load factor and divide by the total drive efficiency. For the capacity of screw conveyor, the required power

$$P = T_{\omega} = F_{Tn} \dots \dots \dots 4.2$$

### **4.8.3 Gear Box**

The gearbox is used to reduce the rotational speed and to increase torque. The nominal torque at the output shaft is obtained from observed torque at the driven machine, gearbox size, torque at the driven machine. This gearbox is made from the spur gear. Spur gears are used to transmit rotary motion between parallel shafts. They are cylindrical, and the teeth are straight and parallel to the axis of rotation. Thus, they are not subjected to axial thrust due to tooth load. The pinion is the smaller of two meeting gears; the larger is called the gear. To calculate nominal torque, the following three important points are observed[48]:

1. The unit is sized on the brake torque If a brake is positioned anywhere before the gearbox output shaft, (assuming this torque is greater than the motor torque). This is because any external loads back driving the gearbox will be sustained by the unit until the brake slips. The above is also true of any form of backstopping (anti-reversing) device. A check should also be made on

## **Design and Experimental Analysis of charcoal production from corncob**

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the kinetic energy that would have to be sustained by the unit if the brake is to be applied in an emergency.

2. That some prime movers, namely electric motors, can develop two or more times full load torque (FLT) on startup. If stop/start is a frequent occurrence then the gearbox must be sized accordingly.

3. Those rigid type couplings can transmit shock more easily to the gearbox than can flexible or gear type couplings, and the application factor selected accordingly. At the time of engagement of the two gears, the contact exceeds across the entire width on a line parallel to the axis of rotation.

Fundamentals for spur gears Pitch line velocity is given as follows

$$V_p = |r_1\omega_1| = |r_2\omega_2| \quad \text{Or} \quad \left| \frac{\omega_1}{\omega_2} \right| = \frac{r_1}{r_2} = \frac{d_1}{d_2} \dots\dots\dots 4.3$$

$$V_p = \frac{N_g}{d_g} = \frac{N_p}{d_p} \dots\dots\dots 4.4$$

$$\text{The velocity ratio } VR = \frac{\omega_p}{\omega_g} = \frac{d_g}{d_p} = \frac{N_g}{N_p} \dots\dots\dots 4.5$$

### **4.9. Selection of Wheel**

There are many types of wheels based on their capacities and specifications. Based on a load of screw reactor rotating swivel wheels with brake, roller bearing, covered by Zink plated, black rubber and 250kg maximum load capacity is selected from the swivel Europe type industrial 8'' rubber caster wheels specification. These types of swivel caster wheels allow for movement in all directions. The wheels are fixed on the frame and carry all parts of the screw reactor. In this experiment, the screw reactor moves by four wheels and its lock when it to start pyrolysis.

### **4.10. Manufacturing Prototype corncob biochar producing machines**

To suitable for the manufacturing of corncobs charcoal from waste maize the machines were developed by selecting the materials and determine the required dimensions. The prototype of a continuous biochar reactor was manufactured in the AAiT workshop. Based on the 3D modeled,

## Design and Experimental Analysis of charcoal production from corncob

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the required materials for all the components were bought from the shop and taken to the workshop for manufactured by lab technicians.



Figure 4-2 Prototype of the developed continuous biochar producing machine

### 4.11. Compare the developed machine with Previous

Even though many technologies were developed for the production of biochar from biomass waste, they have the problems of assembling or disassembling the machines is very difficult since they were welded. Bolts and gasket makers are extra parts. The bolts and nuts are used to assembling and disassembling the machines easily if the machines happened any problem. In

## Design and Experimental Analysis of charcoal production from corncob

previous machines for the production of biochar from different waste materials, the manufactured machines were welded and difficult to assembling or disassembling if they could have been any problems. In the previous screw reactor type, biochar production takes a longer time compared to this continuous charcoal production because the rpm at which the charcoal produced in this machine is higher than that of the previous one. As the rpm increases the amount of production also increases. In the previous one, the rpm at which they got biochar were 11.75 and 10.5rpm while 12.5rpm in this study. From the experimental result, the production capacity of continuous biochar production is about 743kg/day while the previous type of biochar production was about 470kg/day and 656.6kg/day from Nigussie and Tamirus respectively if the machines work 8hr/day. In this study, the machines could produce 743kg/day which is different from the previous one.



Figure 4-3 comparing the developed machines with previous ones

**CHAPTER FIVE**

**5. RESULT AND DISCUSSION**

**5.1 Physical Characteristics and heating values of corncobs**

The physical properties of the corncobs are one of the major factors that affect the efficiency of the corncob charcoal which is used to identify its suitability to undergo the thermochemical conversion process [23]. Figure 5.1 shows the physical characterization of corncob, which was obtained from the study done in the geological survey of Ethiopia laboratory by ASTM standard method calculation from the sample. The feedstock which has high volatile matter content is suitable for the thermochemical conversion process such as pyrolysis [35].

Table 5-1 Proximate & caloric value of corncobs biomass taken from the sample samples[49]

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Compare Characterization of corncob with standard measurements (wt. %)

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Types of sample		Corncob Measurements of this study (wt. %)	International Standard Measurement (wt. %)
Proximate analysis	Moisture content	9.11	9.27
	Ah content	9.82	2.42
	Volatile content	65.85	74.39
	Fixed carbon	15.76	13.92
	Total	100	100
Heating Value	Heating value	16.97MJ/kg	16.3MJ/kg

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From the above table, we observed that the physical properties of the sample taken for this study is good as compared to the previously standard measurement. The raw materials of this study have a higher heating value than the previous studies.

### **5.1.1 Moisture contents of the corncob's biomass**

From table 5.1, the moisture content of the corncob of this study was measured as 9.11%, which is relatively different when related to the values testified in the previous studies. It is higher than the value of 5.1% reported by A. I. Anukam et al., 2017 [36], and lower than the value of 9.27% reported by S. Y. Kpalo, et al,2020[49], in Table above. The difference in these results may have come from the source of the corncob and handling conditions. This result (9.11%) for moisture content is good. For charcoal production desirable to take place as materials with moisture content beyond 20% would create technical difficulties linked to poor combustion conditions within the gasification system and will inhibit immediate combustion of the material at the same time increasing its smoking propensity with a consequent reduction in gasification process efficiency.

### **5.1.2. Ash contents of the corncob biomass**

From the table above the ash content of the corncob biomass in this study was 9.28wt% which is relatively medium when compared with the previous studies in the literature[49]. The low ash content in the biomass feedstock could reduce slagging and fouling in the furnace for the thermochemical conversion process caused by the alkali content in the high-ash biomass.

According to *N. Tippayawong. et. 2018*, biomass ash content greater than 6% is not desirable for gasification because it creates technical issues related to agglomeration, fouling, and sintering as well as slagging that may together reduce gasification efficiency; however, ash may exert some catalytic effect that may allow for cracking of higher molecular weight compounds such as[23]

### **5.1.3. Volatile matter contents of corncobs biomass**

For this thesis, the corncob used was categorized by comparatively low volatile matter content with related to international volatile contents of corncobs measurements because of the organic nature of the maize waste that was selected for sample study. The contents of volatile matter in biomass materials are usually high due to the organic nature of the biomass, which indicates the biomass potential to create huge amounts of inorganic vapors when used as feedstock in a gasification process; the higher the volatile matter content of biomass, the better its combustion and gasification rates because of the biomass yield upon carbonization.

### **5.1.4. Fixed carbon contents of the corncobs**

The fixed carbon content of the corncobs biomass in this study also differed significantly between corncobs biomass from different studies. When the fixed carbon content is high the values of caloric values also increase. The biomass with high fixed carbon contents can produce high fixed carbon contents of charcoal which are used to obtain a high amount of caloric values. The materials with high caloric values can be used to get high heating values which are involved in the heating efficiency of the materials. From the sample taken, 15.7 % of fixed carbon contents of corncob biomass were observed.

### **5.1.5. Heating values of corncobs biomass**

The heating value of biomass is the amount of energy biomass releases when it is completely burnt with inadequate oxygen. It is one of the most important properties of biomass as far as energy conversion is concerned. In this study, the heating value of the feedstock was studied at the Ethiopian geological survey laboratory and found 16.97MJ/kg. This value is acceptable as compared to previous studies. The higher heating values of feedstock give high heating values of the product.

## **5.2. Physical Characteristics and heating values of corncob charcoal**

The parameters like moisture content (MC), volatile matter (VM), ash content (AC), fixed carbon content (FC), calorific value (CV), and Sulphur content (SC) are used for assessing the quality of solid fuel material. These quality determining parameters are used for determining the characterizations of corncob charcoal.

### **5.2.1. Moisture content of corncobs charcoal**

The moisture content of the corncobs charcoal is used to identify the characterizations and physical properties of the charcoal made from corncob by the developed machine. In this research, the moisture contents of the materials were studied to know as it was good for the production of charcoal from corncobs or not. The moisture contents of corncobs biomass were decreased from 9.11% to that 1.5% of biochar corncobs. This indicates that the moisture content of the feedstock is decreasing due to the temperature in the reactors.

### **5.2.2. Ash content of corncob charcoal**

During the pyrolysis process, the moisture contents of the feedstock were released from corncobs biomass which was obtained to decrease moisture contents of corncobs charcoal. The ash contents of corncobs charcoal were increased because of decreasing the moisture contents of the biochar corncobs.

### **5.2.3. Volatile matter content of corncob Charcoal**

The volatile matter content of corncob biomass was released during the pyrolysis process which was the reason for decreasing the volatile contents of corncob charcoal. The volatile carbon content of produced biochar from corncob biomass decreases from 65.85% to 13.65 %.

### **5.2.4. Heating values of corncobs charcoal**

The heating value of the fuel is the measure of the heat released during the complete combustion of the unit weight of fuel. Energy content in an organic matter (Calorific Value) can be measured by burning it and measuring the heat released. This is done by placing a sample of known mass in a bomb calorimeter, a device that is completely sealed and insulated to prevent heat loss. A thermometer is placed inside (but it can be read from the outside) and the increase in temperature after the sample is burnt completely is measured. The heating value of corncobs charcoal in this study was obtained 27.42 KJ/kg

From this data, the energy content in the organic matter can be found out. Here is the graph of the relation between my investigation and the author's done on the characterization of corncobs.

Generally, the following graph can show that the overall results of the characterization and heating values of this study and previous studies.

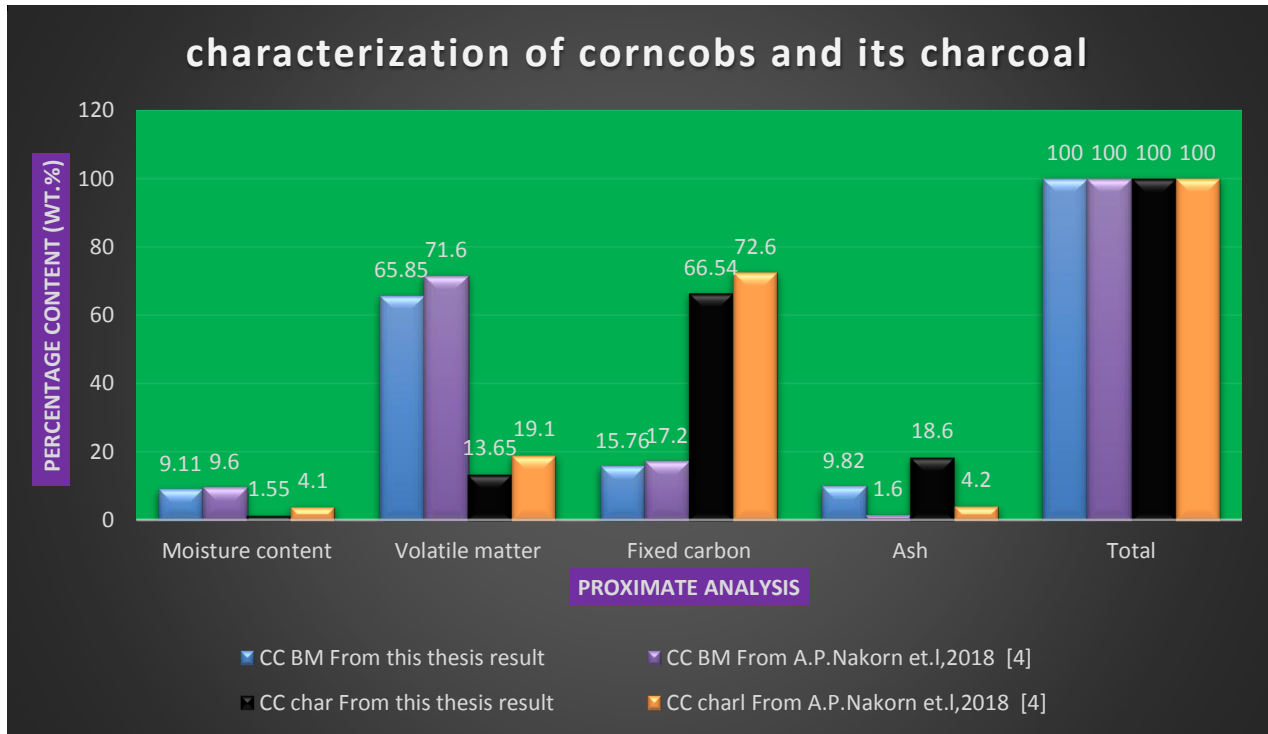


Figure 5-1 Characterizations of corncobs and its charcoal from this thesis and another study by the graph

From the above graph, different characterizations of corncobs biomass and its charcoal were observed. This study was compared with previous studies. The values of corncobs biochar indications that it contains about 9.11 % moisture content, comparable to the 9.6% reported by *A.P. Nakorn.ETL,2018* [23]. The values of moisture contents of corncobs biomass and corncob biochar obtained from this study were less value than that of *A.P.Nakorn.et. Studied*. This indicates that the Corncobs biomass and its charcoal of this study have better moisture contents than that of the previous one.

Generally, from the characterization of corncobs and it charcoal, the following points were observed

- High moisture content high smoking for biomass
- low ash content in the biomass feedstock could reduce slagging and fouling
- Higher the VM of biomass, the better its combustion
- Biomass with high FC can produce high FC of charcoal to obtain a high amount of caloric values
- Moisture contents of charcoal were decreased concerning feedstock

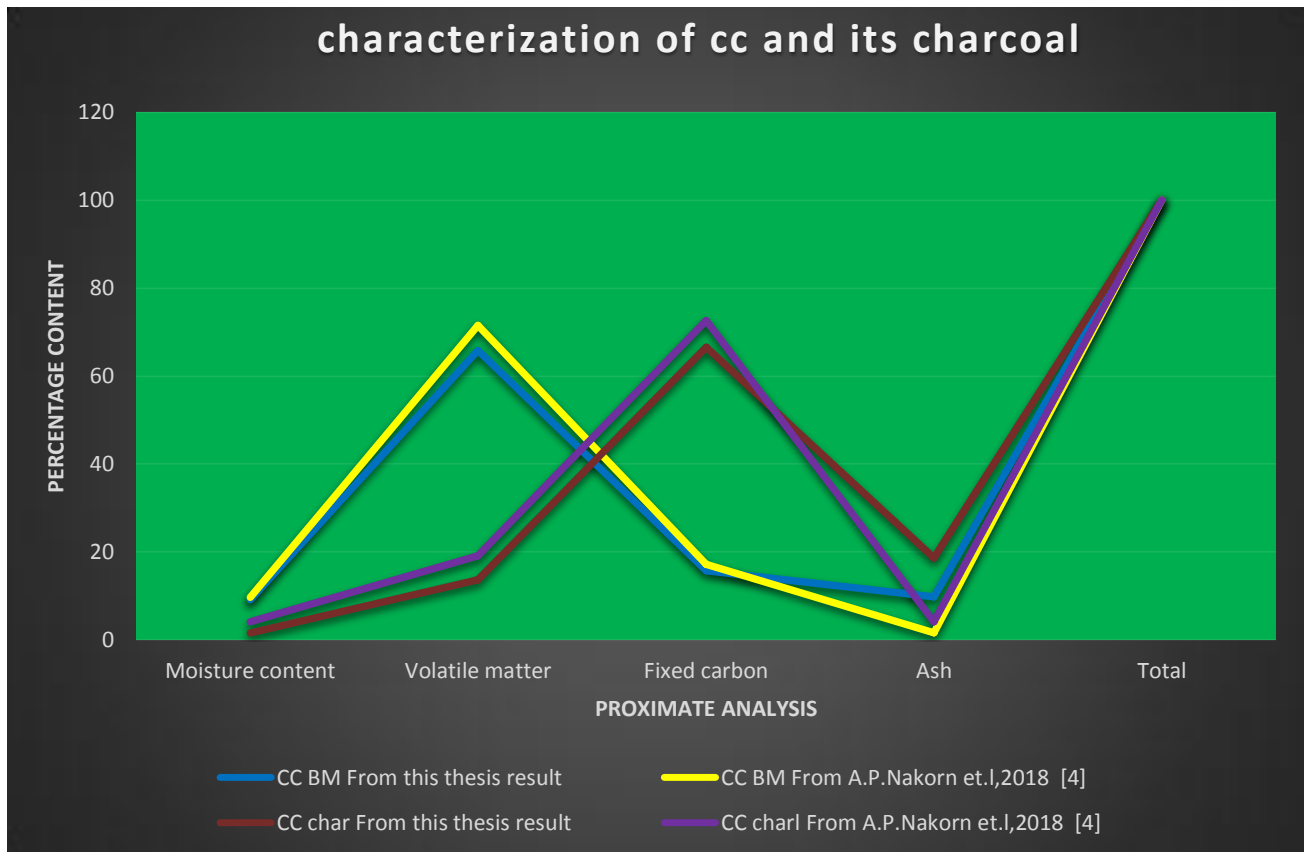


Figure 5-2 Comparing the proximate analysis of corncobs and its biochar between these investigations with other researchers.

Where CC BM is corncob biomass and cc char is corncob charcoal.

From this graph, we observed that the moisture contents, Volatile matter, and fixed carbon contents of corncobs and its charcoal of this study are lower than the previous one. Ash contents of both corncobs its charcoal of this study is higher than the previous one. Generally, the proximate analysis of this study charcoal has good moisture content and the Fixed carbon of both charcoal is decreased than the feedstock.

### 5.3. Product yield

In this thesis, the corncobs were inter into the reactor to produce corncobs charcoal. Mass yield of biochar was calculated based on the amount of corncob biomass weighting input to the reactor and the amount of weighting corncobs charcoal produced after pyrolysis.

From the experimental results, 2.1Kg of charcoal was obtained from 3kg of corncobs biomass. Using equation 3.1 we have that:

$$\text{Biochar yield} = \frac{\text{Mass of charcoal produced}}{\text{mass of corncobs biomass}} \times 100\%$$

$$\text{Biochar yield} = \frac{2.1\text{kg}}{3\text{kg}} \times 100\% = 70\%$$

Therefore 70% of charcoal yield was obtained by the developed machine at the rpm of 12.5 within 1.25 minutes. The developed machine can manufacture 743kg per day for eight working hours. The measured heating value of produced biochar was 27.42MJ/kg. This value is acceptable as compared with a standard measurement of corncob charcoal which were greater than 27kg/kg

### **5.5. Compression of the developed machines with previous ones**

The biochar producing machines from different feedstock were manufactured by different researchers with different dimensions, efficiency, and shapes. The capacity of the machines to produce biochars were also actually not the same from the study to another study. This difference has come from either the types of feedstock or types of the machine selected for production. The main objective of this thesis is to develop continuously corncob charcoal producing machines and modification of the machines in terms of efficiency, economics, feasibility, and durability.

Some researchers were developing biochar producing machines. From this experimental result, the production capacity of continuous biochar production is 720kg/day. *W.Bogale, 2017* was studied the *preparation of charcoal from flower waste under the objective of using pyrolysis production of biochar from flower waste materials*. For the study, the machine he was used for pyrolysis production was a batch type reactor. The capacity of the machine was 310.8kg/day charcoal production if the machine works eight hours [50].

*G. Nigussie, 2018* was also, studied that *Simulation and Experimental continuous biochar production from flower waste* under his thesis for awards of master's degree. Under his study practically he observed that the machine he used for the production of charcoal from flower waste were a capacity of 470Kg/day[51]. From this, we observed that the capacity of the developed machine in this study has a high production capacity than that of the previous one.

We observed from this study the machines have the capacity to generate high income than the two machines due to the model of the machines is modified and waste selection type.

### **5.6. Parameters affecting the production of corncob charcoal**

M. Tripathi et.al.2016, were studied the “*Effect of process parameters on production of biochar from biomass waste through pyrolysis*” and they concluded that the parameters like temperature, moisture, residence time, and composition of biomass are the main factors affecting the biochar yield. According to their investigation by shifting the operational parameters the distribution of pyrolysis products can be changed[52]. Generally, the biochar product from maize waste can be affected by the following parameters in this study.

#### **5.6.1. Effect of Temperature**

The temperature is one of the parameters that influence the pyrolysis product distribution. Different types of biochar were observed with different temperature profiles. From Zhang et al, the corncobs have been changed to biochar under the temperature range of 400°C to 700°C[53]. In this study 3Kg of corncobs were inserted into the reactor at different temperature profiles of the machine. Before the machines can reach steady-state temperature (for this study) some corncobs biochar were observed. As the pyrolysis temperature increase from 500°C to 600°C the corncob biochar content of the product decreased. At 600 °C 2.1Kg of corncob, biochar was observed from 3Kg of corncob biomass. Finally, 24°C/minute residence time was observed.

By using an infrared thermometer, the temperature profile of the reactor during pyrolysis was taken. From figure 5.3 we observed that the temperature increases with residence time. When the temperature can come to a steady-state the manufacturing of biochar was started. From figure 5.5 the temperature readings were taken at five-minute intervals. After 25 minutes the pyrolysis temperature distribution has become constant which is the time at which the production was started. The middle temperature of the machines was higher than the temperature distribution on the left and right of the reactor until the temperature has come to a steady-state. This is indicating that the middle parts of the reactor were gained the heat from the combustion chamber for the first time. Based on this experiment result, 600°C suitable for biochar production from corncob biomass. 600°C was selected because it is the temperature at which a high product is observed within a short period. If we can see 500°C it is the temperature at which high yield was observed but to produce this the time taken was higher than that of 600°C product.

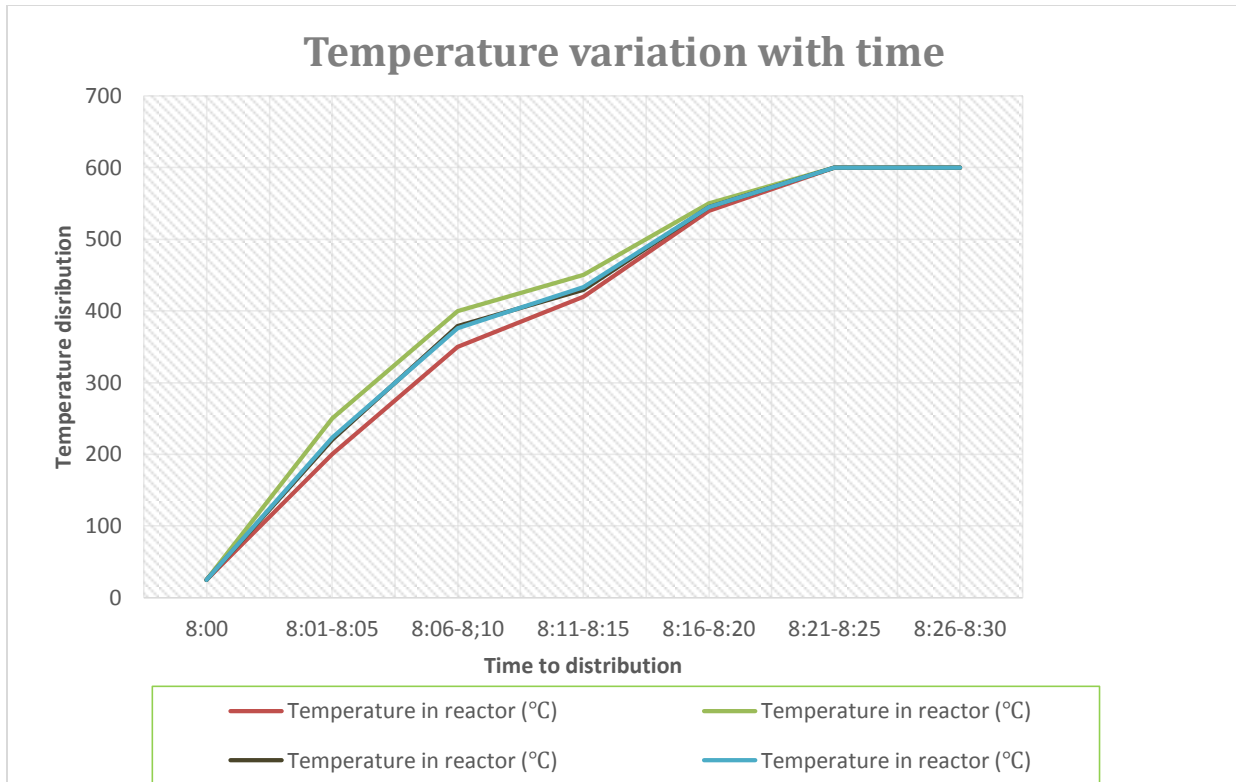


Figure 5-3 the temperature distribution versus time

From the above figure 5-3 it is observed that the temperature is rising with time increase at all of the machine bodies until it reaches an optimum point. This shows that the optimum temperature at which the machine started manufacturing charcoal from corncob was 600°C.

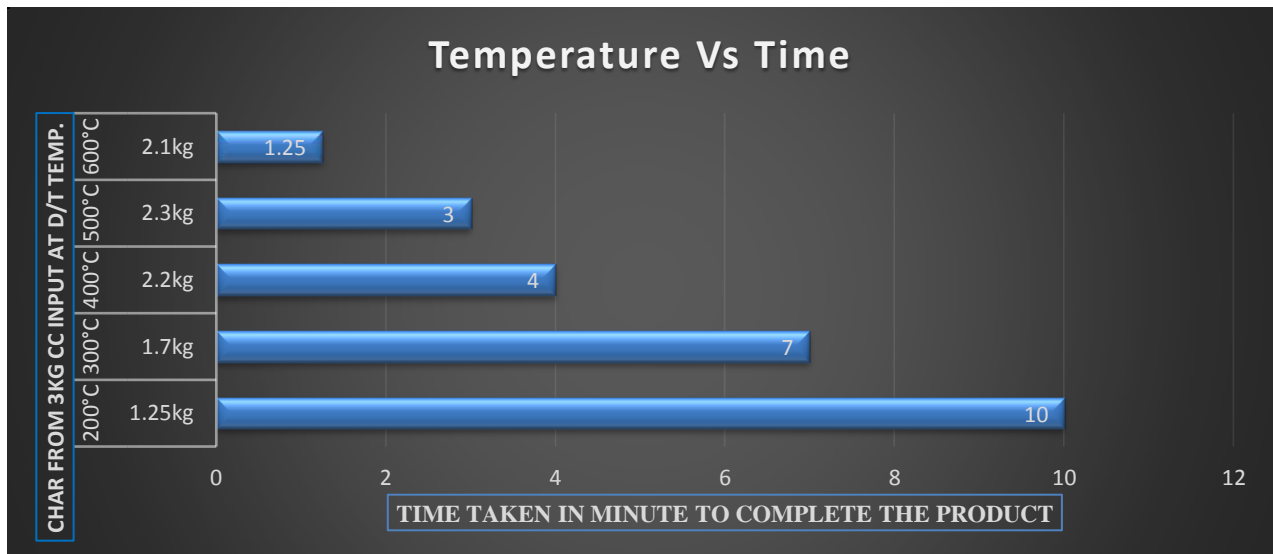


Figure 5-4 Product observed at different temperatures

## **Design and Experimental Analysis of charcoal production from corncob**










In the experiment test result shown in figure 6-4, at pyrolysis temperature increases from 400°C to 600°C the yield of charcoal produced from corncobs were increased. But the time at which the product was observed decreased. At the temperature of 400°C to obtain 2.2kg the time taken was 4 minutes. When the temperature rises to 500°C the time to complete the product yields was 3 minutes. After the temperature was reached 600°C the products were decreased from 2.2kg to 2.1kg with a residence time of 1.25 minutes which is the shortest time to complete corncobs to charcoal by the machine developed. Generally, depending on this experiment result, 600°C is suitable for the production of charcoal from corncobs because it is a temperature at which high yields were observed within a short of a minute.

### **5.6.2. Effects of a rotation speed of the motor**

The rotational speed is another parameter that affects the production of corncobs biochar. At different rpm different amounts of corncob, charcoal was produced. The amount of feedstock to be conveyed is influenced by the rotational speed of motors. From figure 5.6 we observed that at high rpm the biochar was less or not produced. If the rotational speed is low slow pyrolysis was observed. Pulley and gearboxes were used to change the rotational speed of the motor. As the rotational speed of the motor increases the rotation of screw reactor increase which fast the products which feed to the conveyor. By changing the speed of the motors with the mechanism of the gearbox different amounts of biochar were observed. By measuring the contents output of the biochar different rotations at which suitable for the production of biochar were observed. Accordingly, as the rpm increases the amount of biochar is decreases. The slow pyrolysis process operates at a low rotational speed.

## Design and Experimental Analysis of charcoal production from corncob

Table 5-2 the general output of charcoal contents from maize waste input

rpm	Input (corncob waste) 3kg	Output corncob charcoal contents in kg
120		There was no any charcoal produced at this speed
100		 0.5kg
25		 0.75kg
12.5		 2.1kg
10.5		 1.7kg

From the above tables, the high biochar contents of the product were observed at 12.5 rpm.

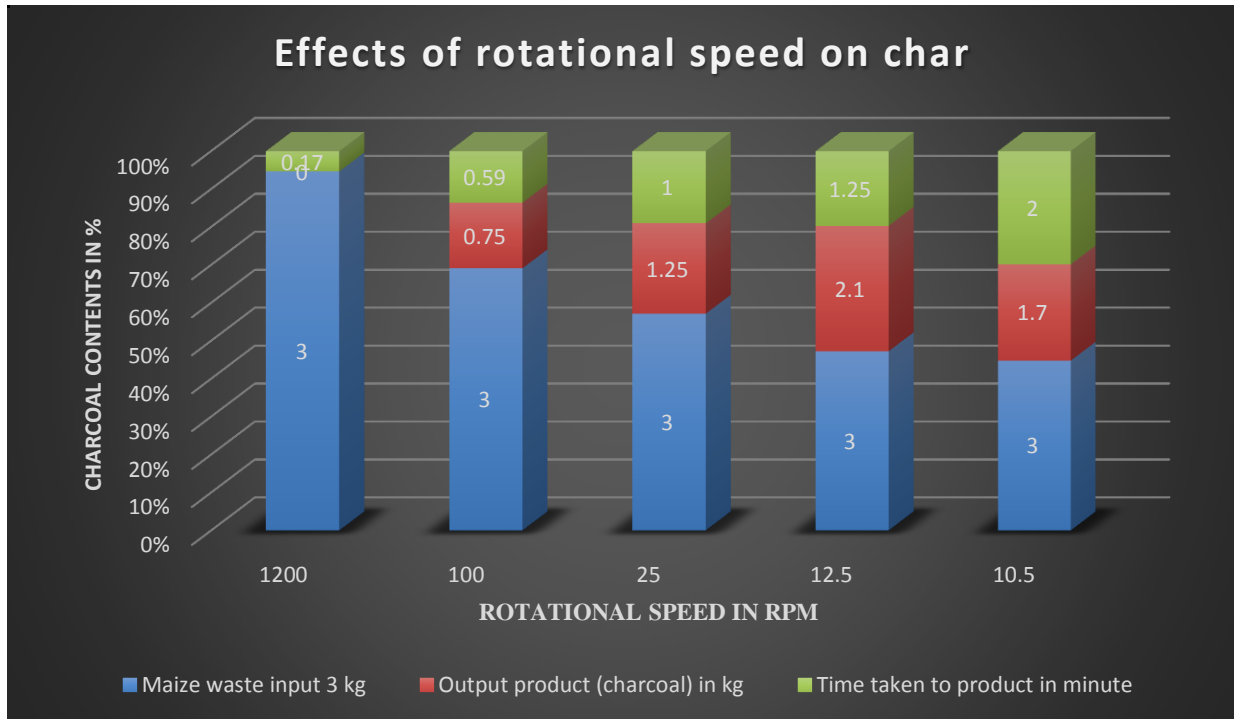


Figure 5-5 Effects of the rotational speed of the motors on the biochar production

From the above chart, we observed that 0% of biochar was produced at 1200 rpm of the motor from 3kg of maize waste. When the rpm was changed to 100 rpm 0.75kg of biochar was produced and the time taken to the process was more than the biochar at 1200 rpm produced. At 25 rpm 1.25kg of biochar was observed. When the rpm was adjusted to 12.5 more biochar was produced (2.1kg) from all of adjusting rotational speed. At this point, 70% of biochar is manufactured under 10.5 the amount of biochar observed was becoming to decrease 60% of biochar production.

Generally, the graph shows that as the rotational decrease the time of production rises. As the speed raised starting from 10.5, 12.5, 25, 100 and 1200rpm the 1.7kg, 2.1kg, 1.25kg, 0.7kg and 0kg amount of biochar produced respectively. The longer time observed was at 10.5rpm. For this thesis, the machine is working efficiently at 12.5 rpm. With increasing rpm, the time to produce biochar is decreasing while the charcoal content of the product is high with low rotational speed. Below 12.5 rpm of the motor, the biochar yield of the product becomes decreases gradually from 70% to 60%. Therefore the 12.5 rpm is the optimum for the production of corncob charcoal production of the machine for this study.

### **5.6.3. Moisture contents of the raw materials**

Moisture contents of the raw materials are a major factor affecting biomass quality and a functioning quality for the production of biochar. The moisture content in corncob biomass can have different effects on the production of biochar. To remove or reduce the moisture contents of the corncob's biomass, the feedstock was dry over the sun for ten days. According to *L. Fialho. et.al 2020*, the woods with high rates of moisture contents have negative impacts on the pyrolysis which causes high emission. This means the materials with higher moisture contents can be the high consumption of energy to remove water from pyrolysis systems. They investigated that moisture contents are the parameters that highly affect the quality and production of charcoal. They concluded that biomass wood which has less than 20% moisture content is good to improve the quality and production of charcoal [54].

In this thesis, the corncobs biomass has measured 9.11% of moisture contents which is best for the production of charcoal. It is under standard conditions for the production of charcoal since it is less than 20%. The feedstocks which have high moisture contents cause fouling and slagging of the machine. Moisture contents can affect both the machine and product yield.

## **CHAPTER SIX**

### **6. CONCLUSIONS AND RECOMMENDATIONS**

#### **6.1. Conclusions**

In this study, a continuous screw reactor machine was developed to produce biochar from corncobs waste and experimentally the designed machine was tested. The characterization of the corncob has also been done by estimating the proximate analysis for either the materials are necessarily using for charcoal production or not. From the result, the biochar yield has been obtained 70%. The heating value of corncobs in this experiment was increased from 16.72 MJ/Kg to 27.42 MJ/Kg of corncob charcoal. The parameters like temperature, moisture, and rotational speed are the main factors that affect the production of corncob biochar. The machine can work efficiently for high biochar production at 12.5 rotational speed. At a pyrolysis temperature of 600°C, the experiment was taken. The measurement was taken by IR thermometer instruments. This temperature is the point at which a high yield was observed in a short period. 743kg/day of charcoal can be generated daily if the machine has been working eight hours per day. Now a day in Ethiopia, 100 kg (sack) of wood charcoal can be sold approximately 430 Ethiopian Birr. Therefore, by selling 743kg of corncob charcoal, 3194.9 Ethiopian Birr can be gained daily which can source of income generation and create work opportunities. In this study, the developed machine is unique from the previous since it is possibly assembled and disassembled easily while it is difficult to do so in the previous since it is sealed. The shape and capacity of producing the machine are also different from the previous one. Due to adopting this continuous pyrolysis technology, the amount of maize waste which is easily left after uses can be reduced from going to the landfill, the energy is simply improved from corncob waste, the energy options for the society is approved and finally the environmental effect of the maize waste is decreased.

### **6.2. Recommendations**

Even though, Ethiopia has so many resources regarding renewable and sustainable energy they use forest plants for the production of charcoals which leads to deforestation. By using waste materials like maize waste could be considered as the options for the production of charcoal.

### **6.3. Future work**

The following points are recommended for the feature works:

- Briquetting machines for increasing the heating values of the charcoals must be designed and done
- Manually working machines is the best for rural areas and it must change manually from electrical rotating of the screw reactors.

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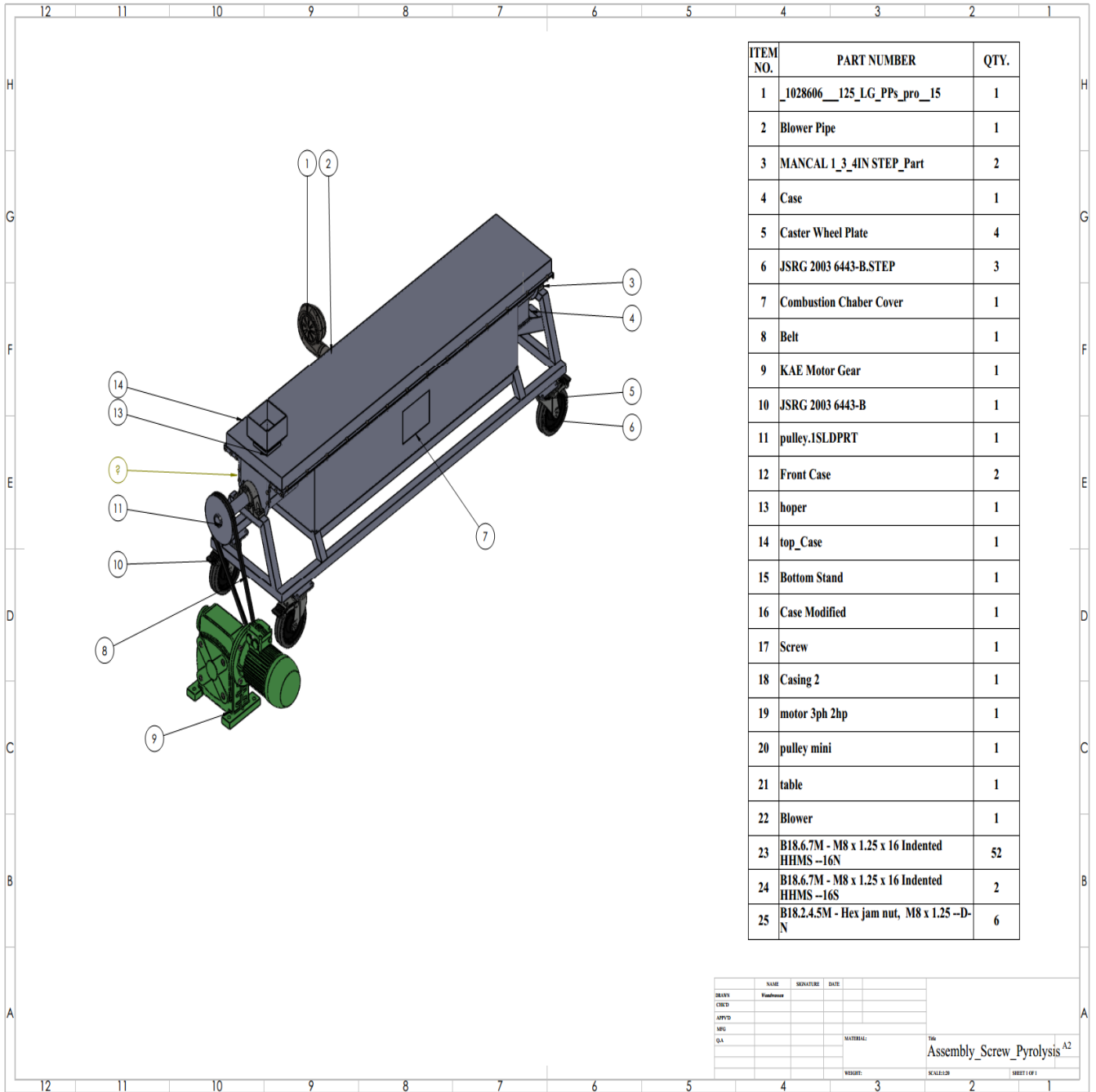
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### **APPENDIXES.**

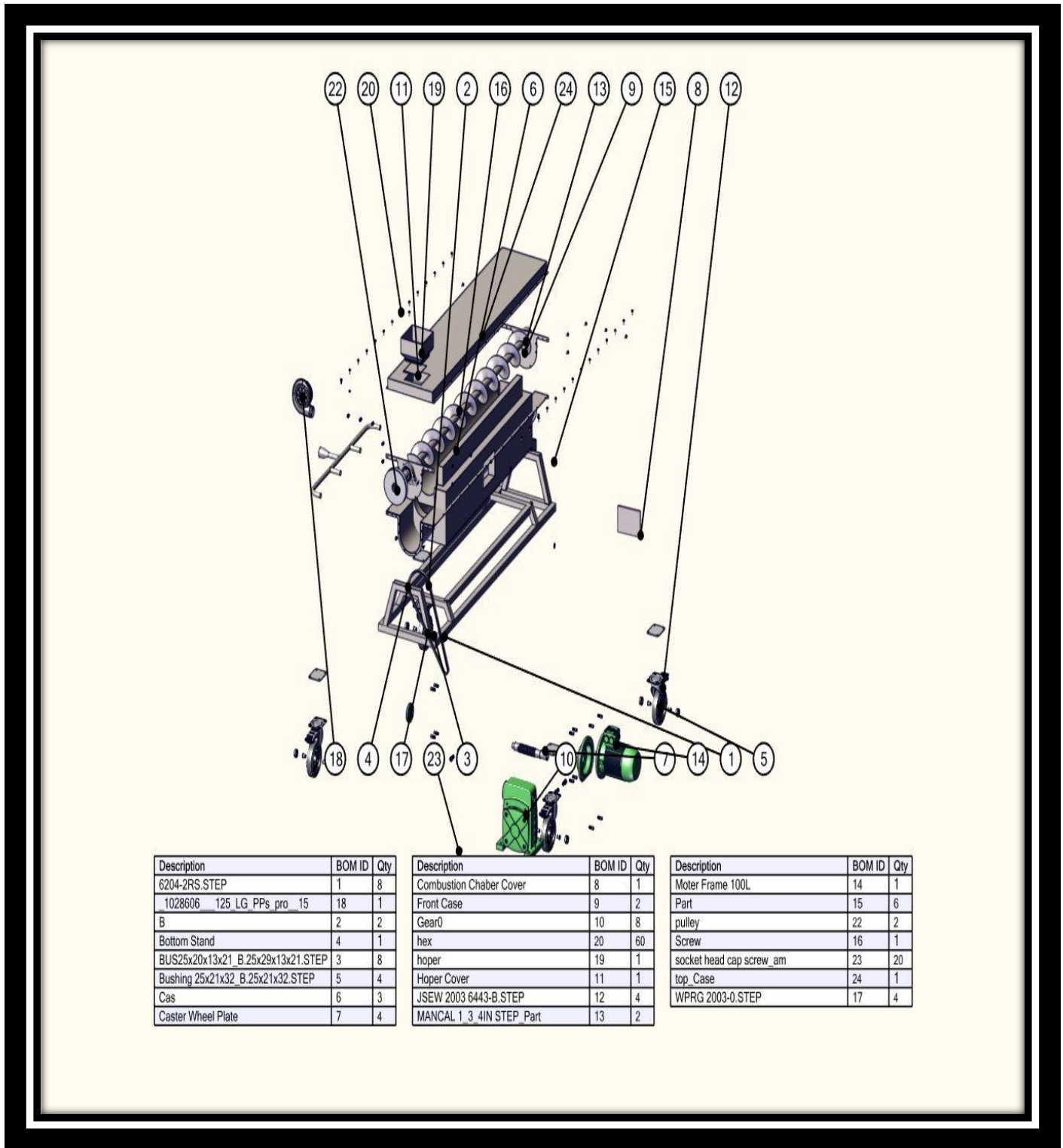
**Annex A: main component of the machines design by using solid work of 2018 software**

**Annex (A-1): The dimensions and components of Screw Reactor**

# Design and Experimental Analysis of charcoal production from corncob



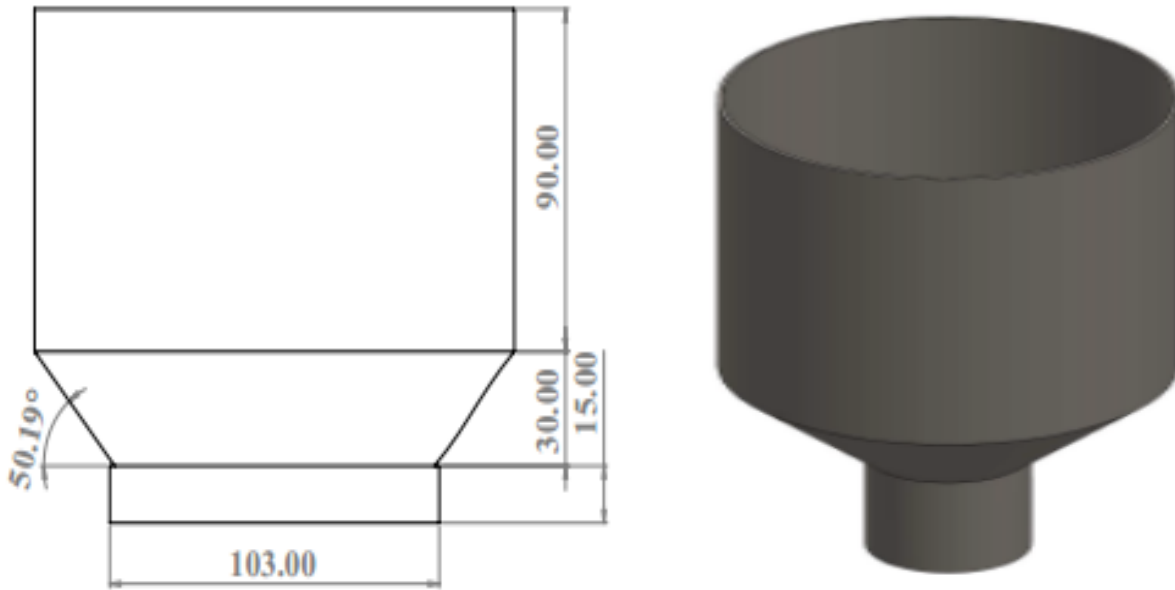
Annex (A-2): Cross section views of all screw reactor components parts



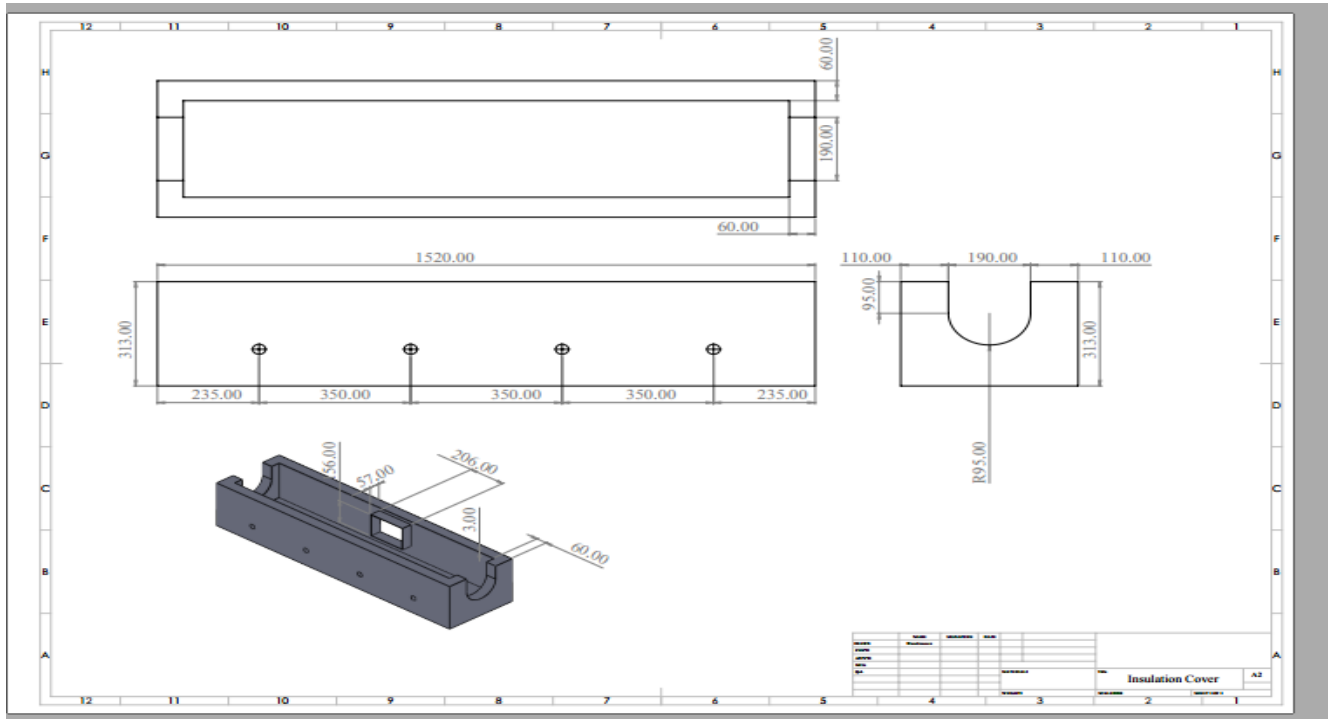
**Annex (A-3): Combustion chamber**



# Design and Experimental Analysis of charcoal production from corncob



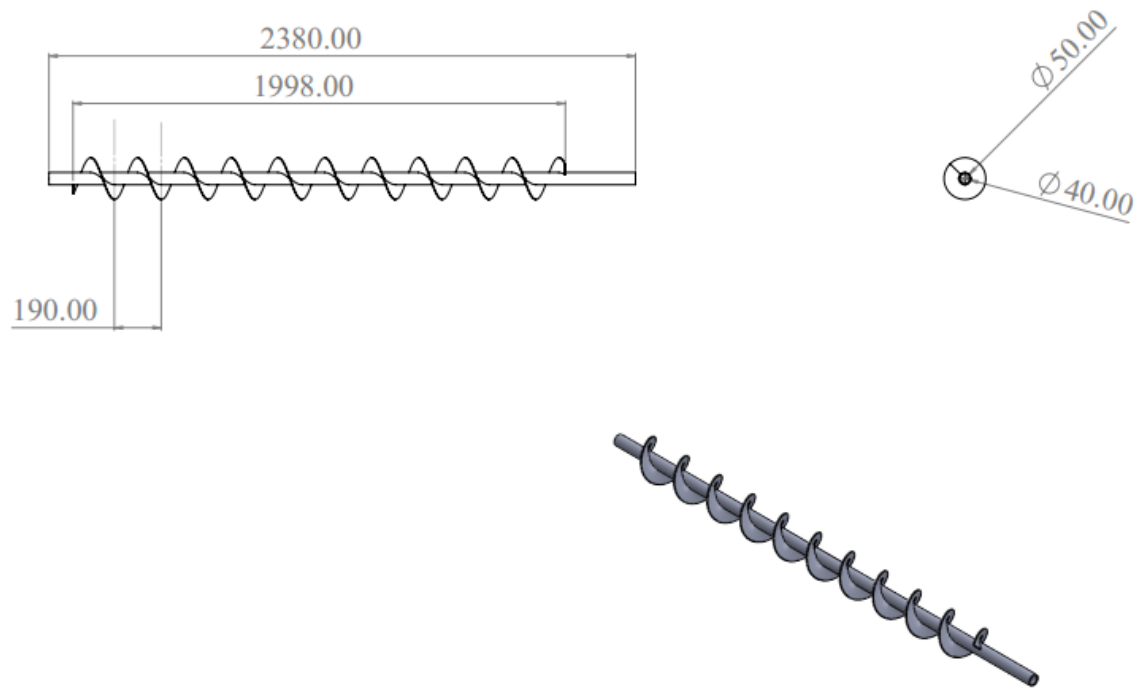
Annex (A-4): Insulation cover



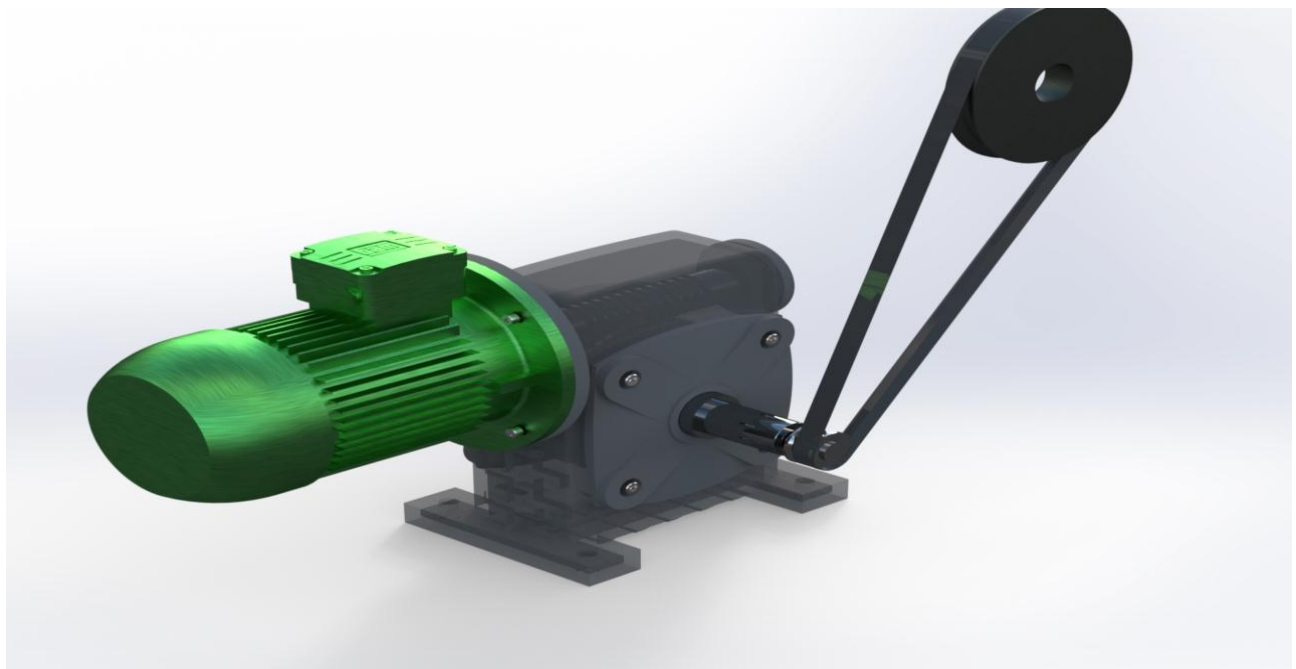
# Design and Experimental Analysis of charcoal production from corncob

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## Annex (A-5): Screw



## Annex (A-7): Generator and shaft



## **Design and Experimental Analysis of charcoal production from corncob**

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### **Annex (B): Measured data from experimental test**

#### **Annex (B-1): Temperature distribution inner and outer surface reactor for test 1**

Time	Temperature in reactor (°C)				Surface temperature of reactor (°C)			
	Right	Center	Left	Average	Right	Center	Left	Average
8:00(PM)	25	25	25	25	25	25	25	25
8:01-8:05	200	250	220.5	223.6	195	210	99.5	252.25
8:06-8:10	350	400	379	376.3	340	380	360	360
8:11-8:15	420	450	429.5	433.16	389	410	400	399.6
8:16-8:20	540	550	545	545	510	545	520	525
8:21-8:25	600	600	600	600	550	550	550	550
8:26-8:30	600	600	600	600	550	550	550	550
8:31-8:35	600	600	600	600	550	550	550	550

## **Design and Experimental Analysis of charcoal production from corncob**

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### **Annex (B-2): Temperature distribution inner and outer surface reactor for test 2**

Time	Temperature in reactor (°C)				Surface temperature of reactor (°C)			
	Right	Center	Left	Average	Right	Center	Left	Average
3:00(AM)	25	25	25	25	25	25	25	25
3:01-3:10	250	300	270.5	273.5	230	270	250	250
3:11-3:20	400	450	420	423.3	370.25	400	390	393.3
3:21-3:30	480.15	500	490	490.5	470	490	495	485
3:31-3:40	550	600	590	565	545	550	548	547.7
3:41-3:50	600	600	600	600	550	550	550	550
3:51-4:00	600	600	600	600	550	550	550	550
4:01-4:10	600	600	600	600	550	550	550	550

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# Design and Experimental Analysis of charcoal production from corncob

## Annex (C): Proximate analysis maize waste (corncoobs) biomass lab test result

	<b>GEOLOGICAL SURVEY OF ETHIOPIA</b>	Doc.Number: GSE/F 5.10-2	Version No: 1
	<b>GEOCHEMICAL LABORATORY DIRECTORATE</b>		Page 1 of 1
Document Title:	<b>Hydrocarbon Laboratory Analysis Report</b>	Effective date:	May, 2017

Customer Name: -Geda Feyera

Sample type: -Corn Cob.

Date Submitted: - 17/07/2020

Elements to be determined: (Moisture, Volatile matter, Fixed carbon and Ash), Calorie & Sulfur.

Method of analysis: Proximate Analysis, Adiabatic Calorie Metter and Gravimetric method

Issue Date: - 27/07/2020

Request No: - GLD/RN/20/20

Report No: - GLD/TR/465A/20

Sample Preparation : - 60 Mesh

Number of Sample: - One (1)

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value Cal/gm.	Sulfur%
G1C	9.11	65.85	15.76	9.28	4055.34	< 0.02

Note: - This result represent only for the sample submitted to the laboratory.

Analysts

Haimanot Bayeh

Kidist Bekele

Shashe Haile


Approved By

  
Alemnesh Abate



# Design and Experimental Analysis of charcoal production from corncob

## Annex (D): Proximate analysis of maize waste (corncob) charcoal lab test result

	<b><u>GEOLOGICAL SURVEY OF ETHIOPIA</u></b>	Doc.Number: GSE/F 5.10-2	Version No: 1
	<b><u>GEOCHEMICAL LABORATORY DIRECTORATE</u></b>		Page 1 of 1
Document Title:	<b>Hydrocarbon Laboratory Analysis Report</b>	Effective date:	May, 2017

Customer Name: -Geda Feyera

Sample type: - Charcoal.

Date Submitted: - 17/07/2020

Elements to be determined: (Moisture, Volatile matter, Fixed carbon and Ash), Calorie & Sulfur.

Method of analysis: Proximate Analysis, Adiabatic Calorie Metter and Gravimetric method

Issue Date: - 27/07/2020

Request No: - GLD/RN/20/20

Report No: - GLD/TR/465B/20

Sample Preparation : - 60 Mesh

Number of Sample: -One (1)

Collectors' Code	Moisture %	Volatile Matter %	Fixed carbon %	Ash %	Calorific Value Cal/gm.	Sulfur%
G2h	1.55	13.65	66.54	18.26	6544.67	< 0.02

Note: - This result represent only for the sample submitted to the laboratory.

Analysts

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Kidist Bekele

Shashe Haile

Approved By



Alemnesh Abate

Quality Control



Negash Worku