DESIGN AND DEVELOPMENT OF SMALL SCALE BIOCHAR KILN

Thesis

Submitted to the K. K. Wagh College of Agril. Engg. and Technology, Nashik
Affiliated to Mahatma Phule Krishi Vidyapeeth, Rahuri
in partial fulfillment of the requirements
for the degree of

BACHELOR OF TECHNOLOGY
in
AGRICULTURAL ENGINEERING

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Submitted To

DEPARTMENT OF RENEWABLE ENERGY ENGINEERING
K. K. Wagh College of Agricultural Engineering and Technology,
NASHIK-422003

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CERTIFICATE – I

This is to certify that the thesis entitled, **"Design and Development of Small Scale Biochar Kiln"** submitted for the degree of **B. Tech.(Agricultural Engineering)** in the department of **Renewable Energy Engineering,** K. K. Wagh College of Agricultural Engineering and Technology, Nashik affiliated to Mahatma Phule Krishi Vidyapeeth, Rahuri is a bonafide research work carried out by **Dhum Shailesh Kanti (EN-2018/17), Gavit Sagar Bajirao (EN-2018/23), Patil Deep Pramod (EN-2018/55), Patil Rushikesh Vijay (2018/60)** under my supervision and that no part of this thesis has been submitted for any other degree.

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CERTIFICATE – II

This is to certify that the thesis entitled, **"Design and Development of Small Scale Biochar Kiln"** submitted by **Dhum Shailesh Kanti (EN-2018/17), Gavit Sagar Bajirao (EN-2018/23), Patil Deep Pramod (EN-2018/55), Patil Rushikesh Vijay (2018/60)** to the K. K. Wagh College of Agricultural Engineering and Technology, Nashik-03 affiliated to Mahatma Phule Krishi Vidyapeeth, Rahuri, in partial fulfillment of the requirements for the degree **B. Tech. (Agricultural Engineering)** in the department of **Renewable Energy Engineering** has been approved.

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There are times when silence speaks so much more loudly than words of praise to only as good as belittle a person, whose words do not express, but only put a veneer over true feelings, which are gratitude at this point of time.

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Indeed the words at our command are not adequate either in form or spirit to convey the depth of graduate to our advisory committee member, ***Prof. S. S. Gawande, Prof. A. N. Shinde, Department of Farm Machinery & Power Engineering and Prof. G. D. Patil, Department of Process & Food Engineering, K.K.Wagh College of Agril. Engg. & Technology, Nashik*** *for their valuable guidance during Project, without which the work would have not been completed.*

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LIST OF ABBREVIATIONS

Abbreviation	Description
agril.	Agricultural
A.C	Ash content
cm	Centimeter
engg.	Engineering
etc.	Et cetera
et.al	And others
fig.	Figure
gm	Gram
GHG	Green house gasses
hr.	Hour
hrs	Hours
i.e	That is
IARI	Indian Agricultural Research Institute
kg	Kilogram
lit.	Liter
min.	Minute
MW	Mega watt
Mt	Million tonne
M.C	Moisture Content
MSL	Mean Sea Level
REE	Renewable energy engineering
Rs.	Rupees
V.M	Volatile Matter
wt.	Weight
%	Percentage
η	Efficiency
^{o}C	Degree celcius

ABSTRACT

"DESIGN AND DEVELOPMENT OF SMALL SCALE BIOCHAR KILN"

By

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Biochar is a product of pyrolysis of agricultural biomass under limited oxygen condition and the fire is lit at the top of the biomass. There was a variety of method or technique to produce biochar. A simple, practical and affordable unit of pyrolysis kiln was designed and fabricated to ease the small farmer to produce the biochar efficiently at low cost. Biochar samples were prepared from the pyrolysis process by using waste wood from the harvest site. Furthermore, pH level, surface area and other biochar characterization had been studies through laboratory test. Surface area of biochar observed through Scanning Electron Microscope (SEM). Gas emission was observed during the trial run of the pyrolysis kiln. The portable biochar kiln can be constructed easily by the small farmer by using available metal. This is one of the methods which utilises the biomass efficiently and use it as soil nutrient supplement. This approach is more environmental friendly compare to open burning of waste wood at the harvest site. The general performance of the portable biochar kiln is satisfactory and is suitable for burning the waste biomass to produce biochar.

Keywords: Pyrolysis, Biochar, Biomass, Kiln, Characteristic, Soil.

CHAPTER I

INTRODUCTION

Agriculture is the back bone of our country. Indian people largely depends on the agriculture sector and agriculture is the primary source of livelihood for about 58% of India's population. India is the second-largest producer of agricultural products in the world, produces more than 280 million tonnes, contributing to more than 15% of India’s GDP. India generates about 350 million tonnes of agricultural waste every year. As per the estimates given by the ministry of new and renewable energy, this waste can generate more than 18,000 MW of power every year. The use of biomass in agricultural activities had continued to get global attention over this few decades.

Biomass burning is significant air pollution source with global, regional and local impacts on air and climate change. According to Indian Agricultural Research Institute (IARI) approximately 14 million tons (Mt) biomass generated each year in India set to fire in Haryana and Punjab. Burning of biomass in open field adversely affects soil fertility. It destroys the soil nutrient and making it less fertile. This is because heat generated during the burning kills the bacteria and fungal population which are crucial for fertile soil. To prevent pollution, to retain soil condition this biomass can be utilize to produce other valuable products.

The waste can be processed into biochar through pyrolysis for soil enrichment by using biochar kiln. Waste management plays a significant role in sustaining the global cleanliness. Offering the small farmers an option to utilize the waste by providing a biochar kiln will help them to avoid the waste generation and air pollution. Through this project, the agricultural residue will be utilized for production of biochar to improves the quality of the soil and also reduce the quantity of fertilizer used by the small farmers.

1.1 BIOCHAR:

Biochar is a type of predominantly stable carbon rich product which is obtained through biomass pyrolysis. The source materials of biochar are feedstock such as woodchips, wheat residue, crop residues, maize straw pellets and animal manure. Pyrolysis is the thermal decomposition of biomass under low oxygen concentration conditions at relatively low temperatures below 700 ^{O}C.

Plate No. 1.1: Agroforestry residue 1. Eucalyptus twigs 2. Eucalyptus barks 3. Pongamia shells

Plate No. 1.2: Crop residue 1. Pigeonpea stalk 2. Cotton stalk 3. Castor stalk 4. Maize stalk

When the pyrolysis temperature increases, the total surface area of biochar also increases. This will facilitate the higher sorption of chemicals, for example pesticides. Bio-char consists of ash, carbon (C), oxygen (O), hydrogen (H), nitrogen (N) and sulphur (S) in different proportions which strongly correlates with the heating rate, temperature and time maintained during production. Therefore, it contributes in locking the amount of carbon present in the plant biomass through carbon sequestration. Biochar is a highly porous substance which can improve the water holding capacity of the soil by increasing total surface area of the soil for soil amendment.

In recent years, bio-char is very important in improving the soil nutrient content through a more concentrated carbon content, high calorific value, absorption capability and good porosity due to its high specific surface area and structure.

1.2 HISTORY OF BIOCHAR:

Biochar is one of the key components of soil properties found in the Amazon Basin, known as Terra Preta di indio (black earth) to describe the black soil that had been found. It had been discovered that the soil's depth is up to two meters throughout the terra preta region in the Amazon Basin. Mostly, it occurs along the river banks at fringes of Terra Firme and overlies in weathered soils.

It is a dark coloured soil, rich with nutrients that contain high organic content to support agricultural needs. Terra preta has the ability to accumulate the stable organic carbon which can increase fertility and carbon storage in soil. Early studies had shown that terra preta soils were formed by Amerindians and pre-Columbian as they practiced “slash and char” technique in agriculture. The techniques involved ignition of vegetation and combining it with biomass within a small plot but only allowed it to burn without smoke. Then, it was buried under the soil to form terra preta.

1.3 EFFECTS OF BIOCHAR IN AGRICULTURAL SOIL:

Agricultural productivity has decrease due to depletion in nutrients of soil and soil organic matter. Fertilizers that contain chemical compounds had increases in agricultural productivity but the soil fertility is not a sustainable approach. Chemical fertilizer mostly consists of nitrogen which can deteriorate the soil environment and mineralize the organic matter. Hence, the biochar which is produce by biomass play a vital role which provides benefit to both agriculture and environment. In recent years, production of biochar through pyrolysis is a technique used to improve the soil quality. It is also helpful in coping with greenhouse gases (GHG) and increase in sequestering carbon. A lot of studies and evidence had been done to show the application of bio-char is useful.

1. **Improving soil for crop production**
2. **Nutrient availability in soil**
3. **Soil health**
4. **Role in dealing with climate change**
5. **Soil microbial activity**
6. **Soil and water conservation**

There are various techniques used for biochar production include pyrolysis, hydrothermal carbonization, gasification, flash carbonization and torrefaction of all these method mostly use to produce biochar. In this work we are using pyrolysis process for making biochar.

Taking into consideration to reduce carbon emission and impact of biomass burning increases the pollution in air and also decreases soil fertility so we have to utilize agricultural waste to produce biochar, with the help of biochar kiln. So, taking into consideration the research work was undertaken entitled “design and development of biochar kiln” having following objectives:

1. To develope a small scale biochar kiln for production of biochar from agriculture waste.
2. To develope a low cost biochar kiln.
3. To evaluate the performance of developed small scale biochar kiln.

CHAPTER II

REVIEW OF LITERATURE

Tryon (1948) found that due to application of biochar the mineral and organic components of soil contribute to soil water holding capacity, but only the latter can be actively managed. Water was held more tightly in small pores, so clayey soils retain more water. The lower soil bulk density generally associated with higher soil organic matter was a partial indication of how organic matter modifies soil structure and pore size distribution.

Tillman *et al*. (1981) developed a low cost biochar kiln and to standardize the operational procedures for biochar production from locally available crop and agroforestry residues.

Bourke *et al*. (2007) demonstrated that the quality of the feedstock and production conditions such as pyrolytic temperature and residence time has a significant influence on the quantity, quality and the elemental compositions of the biochar. He stated that selection of suitable feedstock and optimum pyrolytic protocol was crucial for biochar producers to produce a designer biochar amendment that was tailored to improve a specific soil issue in agriculture. He found that low temperature biochar has high volatile matter (VM) content, but lower fixed carbon (FC) and ash contents than the high temperature biochar.

Deenik *et al*. (2010) conclude that the total carbon (C), fixed carbon (FC) and ash content of the biochar was more dependent upon the feedstock than the pyrolysis temperature, while Volatile matter (VM) and biochar yield were sensitive to pyrolysis temperature.

Lammirato *et al*. (2011) said that biochar provides a suitable habitat for a large and diverse group of soil microorganisms. A higher retention of microorganisms in biochar amended soils may been responsible for greater activity and diversity due to a high surface area as well as surface hydrophobicity of both the microorganisms and biochar. Biochar was an effective to activate living things and improved natural environment. Carbonized biomass such as rice husk charcoal or wood ash had been valuable material as soil amendment.

Karhu *et al*. (2011) revealed that Biochar’s inherent physical quality contributes to the improvement in the soil porosity, surface area and soil aeration, thereby improves aerobic activity like methane. Applied biochar may provide habitats for growth of soil dwelling microorganisms and protect them against natural predators.

Jeffery S. *et al* (2011) Said that the effects of biochar application to soils on crop productivity used meta-analysis. includes improvement of soil physical properties that benefit crops, improved retention and availability of soil nutrients, improved biological activity, by providing metabolizable organic c substrates and consequently higher crop yields and societal advantages through mitigation of global warming by carbon sequestration

Aditya P. *et al* (2014) Researched on biochar production from agro-food industry residues a sustainable approached for soil and environmental management. The implementation of biomass based biochar into rainfed cropping systems generally requires a feedstock source that had been “real waste” so far and that did not had a competitive used. Otherwise, biochar systems may been in danger to put additional pressure on the fragile food supply in rainfed areas and could eventually trigger land-grabbing and promote deforestation.

M. Sparrevik *et al*. (2015) Explained emissions of gases and particles from charcoal/biochar production in rural areas used medium-sized traditional and improved ‘retort’ kilns. Reaction time was the time period required by the residues to attain the requisite thermal conditions for the appearance of grey and blue colour exhaust gases. The evolved hot exhaust gases was not collected nor quantified, but color of the hot exhaust gases was considered for approximation of internal kiln temperature

Narzari R, *et al* (2015) Studied biochar production, properties and potential benefits. From a chemical pointed of view, the most striking feature of biochar was its poly condensed aromatic structure caused by dehydration during thermo chemical conversion leading to its black colour. This structure was also responsible for its relative recalcitrance compared to other organic matter in the environment.

Thomsen *et al*. (2011) researched that for Biochar production from a variety of high-molecular lignocellulosic residue resource was a carbon-neutral process. A variety of thermal conversion processes could been used to prepare biochar. Pyrolysis systems employed to process unused and excess crop and agroforestry residues for biochar production can be categorized into four types: (1) slow pyrolysis, (2) fast pyrolysis, (3) flash pyrolysis, and (4) gasification.

Xiong *et al*. (2014) observed that cotton stalk biochar yield decreased from 37.35 to 31.23%, VM content decreased from 30.23 to 13.76% and the FC yield increased from 64.12 to 76.63% as the carbonization temperature increased from 400 to 800°C.

Venkatesh *et al*. (2015) revealed that in designing the kiln, both the requirements of controlling the loading rate and rate of thermo-chemical conversion periods to stoped the process when all of the crop and agroforestry residues had been converted to biochar have been addressed.

Venkatesh *et al*. (2015) developed a low cost portable biochar kiln unit to match the needed of the small and marginal farmers. The costed of one unit of the kiln including costed of metal drum, vent making charges and side fittings. A brief description of the kiln, Kiln design functions with bottom-lit direct natural up-draft principle. The cylindrical metal drum biochar kiln was based on a single barrel design of vertical chimney with perforated base at bottom. A strip of metal handle was welded at around $3/4^{th}$ height of kiln, to serve as lifting jack at the end of each test. A metal lid with handle was made to fit top square hole to stopped the conversion process.

Dume B. *et al* (2016) Studied on interactive effects of biochar in soil related to feedstock and pyrolysis temperature. Depending on feedstock sources and temperature conditions, biochars exhibit large ranges in porosity and bulk density (bd). Increased pyrolysis temperature results in a dramatic rose in porosity due to increases in dehydroxylation of watered molecules resulting in the formation of pores on the surface of biochar and decrease in bd of biochar due to greater proportion of biochar particles with smaller particle size distributions

Jeffery *et al*. (2017) studied on various pyrolysis technologies were commercially available that yield different proportions of biochar depending upon the residues used for production under varying operating conditions.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the assumptions and methodology adopted for the research work on “Design and Development of Small Scale Biochar Kiln” which was carried out at the Department of Renewable Energy Engineering, College of K. K College of Agricultural Engineering and Technology, Nashik, Mahatma Phule Krishi Vidyapeeth, Rahuri. The designed Biochar Kiln was fabricated in workshop and tested at Department of Renewable Energy Engineering, College of Agricultural Engineering and Technology, Nashik. The study area falls at 19° 99’ N latitude and 73° 78’ E longitude and at an altitude of 584 m above Mean Sea Level (MSL).

The design procedure, experimental procedure, material used to evaluate the performance of designed system, fabrication technique and installation of Biochar Kiln has been discussed in this chapter.

In designing the kiln, both the requirements of controlling the loading rate and rate of thermo-chemical conversion periods to stopped the process when all of the crop and agroforestry residues had been converted to biochar had been addressed. A low cost portable kiln unit was developed to match the needed of the small and marginal farmers. The costed of one unit of the kiln is 1500 (approx.) including cost of metal drum, vent making charges and side fittings. A brief description of the kiln is given below.

3.1 Material Selection:

After the conceptual design of a cylindrical shape biochar kiln, several factors need to be considered before fabrication. Material selection was one which interact between several other factors. The factors include availability of materials, resistance of corrosion, ability of fabrication, consideration of manufacturing process, thermal stability and cost of the material.

3.1.1 Material Comparison:

Some of the important criteria had been considered and compared during material selection which are listed in table between mild steel, cast iron and high carbon steel.

Mild steel had been selected for the fabrication at the workshop. It can be used for a long period since it does not corrode readily and the cost is cheaper compared to cast iron and high carbon steel.

Table No. 3.1: Comparison between cast iron, mild steel and high carbon steel.

Properties	Cast Iron	Mild Steel	High Carbon Steel
Carbon content	0.5 -1.5%	0.1 -0.29%	2-4%
Structure	Crystalline coarse granular structure	Bright fibrous	Fine granular
Mechanical Properties	1. Less tough and less Elastic. 2. Hard and Brittle. 3. Can be Welded.	1. Tougher and elastic than cast iron. 2. Malleable and ductile. 3. Readily forged and Welded.	1. Tough and elastic than mild steel. 2. Brittle and less ductile than mild steel. 3. Not easily to be forged and welded.
Melting Point	1200^{o} C	1400^{o} C	1300^{o} C
Rusting	Does not rush readily	Rusts readily	Rust rapidly
Shock Absorbing	Cannot absorb	Absorb shock	Absorb shock

3.2 Materials for biochar kiln fabrication:

The following materials are used for the construction of small scale biochar kiln.

1. **Mild steel sheet** was selected because MS cannot easily melt. Its melting point is 1400^{o} C as well easily weld by gas welding. The whole structure of biochar kiln was constructed by mild steel.
2. **Handle** was small round object which attached to a biochar kiln used for lifting and handling kiln easily.

3. **Lid** serves as the closure or seal, usually that completely closes the top side of pyrolysis chamber, and lid cannot allow to gases passout during pyrolysis process.
4. **Chimney-** The primary function of the chimney was to direct the smoke away from the biochar kiln, as well as it helps for maintaining temperature around the whole pyrolysis chamber during pyrolysis process.
5. **Stand** for supporting kiln from bottom side of biochar kiln.
6. **Digital thermometer** was used for measuring parts of biochar kiln size.
7. **Gas welding** was used for welding the parts of biochar kin, parts like the stand and chimney.
8. **Paint**

3.2.1 Design consideration: The following factors are taking into consideration;

1) Capacity
2) Low cost of fabrication
3) A variety of feedstock can be used
4) Smoke reduction
5) Safety
6) Cleanliness
7) Durability
8) Portability
9) Affordability
10) Time saving as it is the fastest way to produce biochar at the harvest site.

3.3 Design calculations:

In designing the kiln, both the requirements of controlling the loading rate and rate of thermo-chemical conversion periods to stop the process when all of the crop and agroforestry residues have been converted to biochar have been addressed. A low cost portable kiln unit was developed to match the needs of the small and marginal farmers. The cost of one unit of the kiln is Rs. 1500 including cost of metal drum, chimney making charges and side fittings.

3.3.1. Capacity of biochar kiln (cylindrical shape): It is total volume of metallic drum without chimney. capacity of biochar kiln was calculated by as follows:

$$\mathbf{V_{kiln} = V_{drum} - V_{chimney}} \quad \text{………(3.1)}$$

Now,

$$\mathbf{V_{drum} = \pi(R_d)^2 H_d} \quad \text{………(3.2)}$$

Where,

V_{drum} = Volume of metallic drum or pyrolysis chamber.

R_d = Radius of metallic drum or pyrolysis chamber.

H_d = Height of metallic drum or pyrolysis chamber.

Simillarly,

$$\mathbf{V_{chimney} = \pi(r_c)^2 h_c} \quad \text{………(3.3)}$$

Where,

$V_{chimney}$ = Volume of chimney.

r_c = Radius of chimney.

h_c = Height of chimney.

3.3.2. Design of kiln lid: Design of kiln lead is define as total area of covered in metallic drum. Design of lid was calculated as follows:

$$\mathbf{A_{lid} = \pi(R_L)^2} \quad \text{………(3.4)}$$

Where,

A_{lid} = Area of lid.

R_L = Radius of lid.

3.3.3. Design of chimney: It was used for removing burning gases from pyrolysis chamber. Design of chimney was calculated as follows:

$$\mathbf{A_c = 2\pi(R_c)} \quad \text{………(3.5)}$$

Where,

A_c = Area of chimney.

R_c = Radius of chimney.

3.3.4. Design of handle:

Handle was attached to both side of biochar kiln.

3.3.5. Design of stand:

Stand was weld to the bottom side of biochar kiln, for supporting purpose.

3.3.6. Efficiency of biochar kiln: It is percentage of ratio of total weight of biochar and total Weight of raw material. Efficiency was calculated as follows:

$$\eta\,(\%) = \frac{Wt.\ of\ biochar\ (kg)}{\mathrm{Wt.\ of\ raw\ material\ (kg)}}\ x\ 100 \qquad \text{………(3.6)}$$

3.3.7. Analytical methods of biochar analysis:

1. Biochar conversion efficiency: It is ratio of mass of biochar and mass stalk and its percentage.

$$\textbf{Biochar yield (\%)} = (M_{biochar} / M_{stalk}) \times 100 \qquad \text{……….(3.7)}$$

Where,

$M_{biochar}$ = Mass of the biochar (kg)

M_{stalk} = Mass of the raw material (kg)

2. Biochar ash content:

$$\textbf{Biochar ash content (\%)} = (M_{ash} / M_{biochar}) \times 100 \qquad \text{……….(3.8)}$$

Where,

M_{ash} = Mass of ash. (kg)

$M_{biochar}$ = Mass of biochar. (kg)

3.4. Technical specification of Biochar Kiln:

1) Kiln design functions with bottom-lit direct natural up-draft principle.
2) The cylindrical metal drum kiln of about 25 L capacity was based on a single barrel design of vertical chimney structure with perforated at base. The gross volume of the kiln was about 0.028 m^3.
3) The cabinet was circular in cross section and consists of an intact bottom and top section.
4) The kiln was about 15 cm in radius and 40 cm height with vertical chimney of 80 cm from bottom side of kiln, with a handle (10*3 cm).
5) Alternating and staggered arrangement was maintained by alternating the holes in chimney to avoid row arrangement.
6) Under open atmospheric conditions, the central and staggered holes at the kiln base hasten hot exhaust gas movement through the residues for uniform heat transfer by primary air movement while the kiln's top lid hole out the released water vapours and hot gases.
7) A strip of metal handle (10 cm length and 3 cm in width) was welded at around 3/4th height of kiln, to serve as lifting jack at the end of each test.
8) A metal lid (30 cm in diameter) was made to fit top square hole to stop the conversion process.

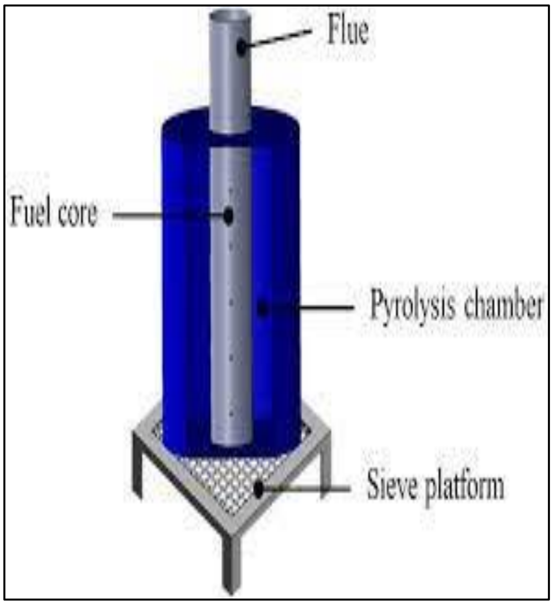


Fig. No. 3.1: Schematic diagram of Kiln.

3.5 Features of biochar kiln:

1) **Portability:** Easy mobility of the kiln to the source of crop and agroforestry residue and with access to most remote places helps to reduce collection, handling and transporting expenses.
2) **Simplicity:** Farmer-friendly, convenient-to-use and minimize operational labour costs.
3) **Adaptability:** Designed for non-competitive and surplus crop and agroforestry residue.
4) **Affordability and Durability:** Least expensive kiln (cost:1500/-) to match the needs of the small and marginal farmers and kiln can be operated for multiple batch process.

3.6 OPERATIONAL PROCCES FOR BIOCHAR PRODUCTION:

Biochar production from a variety of high-molecular lignocellulosic residue resource is a carbon-neutral process. A variety of thermal conversion processes can be used to prepare biochar. Pyrolysis systems employed to process unused and excess crop and agroforestry residues for biochar production can be categorized into four types:

(1) slow pyrolysis

(2) fast pyrolysis

(3) flash pyrolysis, and

(4) gasification

Slow pyrolysis performed under lower temperature (<400-500°C) and with long contact times often results in a high yield of biochar (35%). Faster pyrolysis or gasification operates at higher temperatures (<800°C) and gives a high yield of combustible gases in relation to the solid biochar (12%). The most commonly employed method is slow pyrolysis. This process involves direct thermochemical decomposition (exothermic reaction) to transform low-density residue matrix into a biochar at a temperature range of 450-500˚C under low-oxic or anoxic conditions in a closed reactor.

Biochar can be produced at scales ranging from large industrial facilities down to the individual farm and even at the domestic level through a distributed network of small facilities that are located close to the crop residue source. Small facilities to produce biochar are less complicated than larger units. Biochar production protocols are yet to be standardized in India. To make biochar technology popular among the farmers, it is imperative to develop low cost biochar kiln at community level or at individual farmer's level.

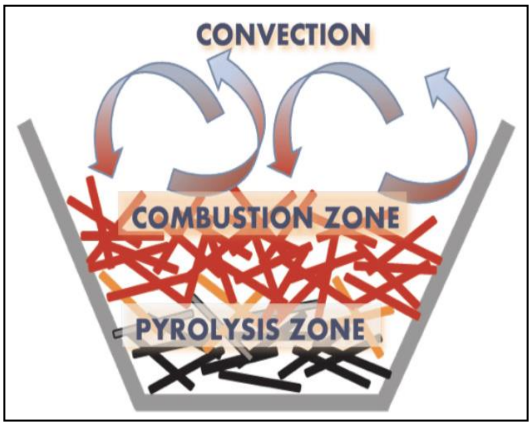


Fig. No. 3.2: Schematic diagram of Kiln operation.

3.6.1. Pyrolysis:

Pyrolysis is a process of thermo-chemical conversion of biomass under low oxygen concentration condition. It can be divided into three categories which fast pyrolysis, intermediate pyrolysis and slow pyrolysis, depending variables such as peak temperature, heating rate, residence time of the vapor phase, pressure, particle size and flow rate of sweeping gas. The conditions of pyrolysis can influence the amount of the three products such as bio-oil in liquid form, biochar in solid form and syngas in gas form.

The process of pyrolysis will continue under the heat from burning pyrolysis gases. The wood does not burn and it undergoes carbonization because the gas flame consumes all the oxygen which results in the pyrolysis zone. A smokeless fire can be created when the load is lit from the top so that the fire in the uppermost layer heats the next lower layer. Hence, the gas rises up through the flame where it is burned. The principle of smokeless fire is very important for the design of biochar kiln.

3.6.2 Fast pyrolysis:

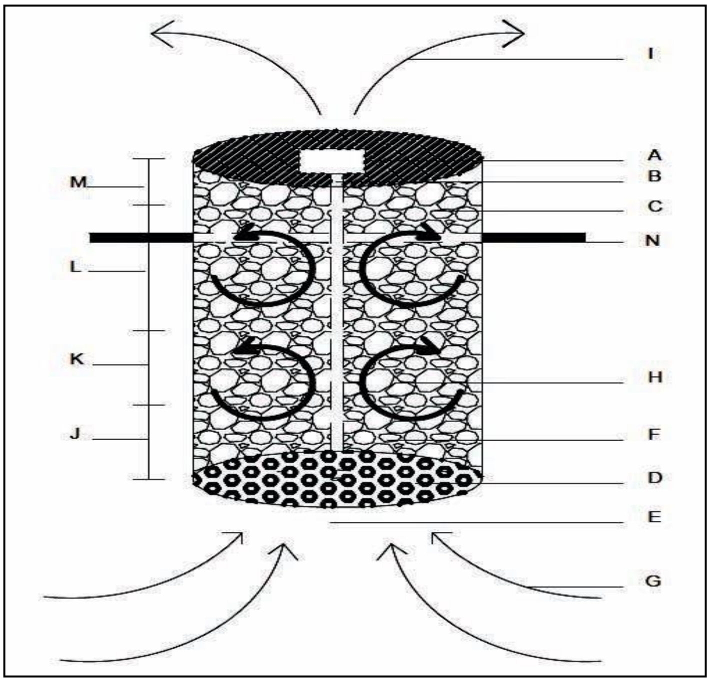
Chemical reaction kinetics play a significant role since fast pyrolysis occurs within short vapor residence time approximately 2 second at temperature between 500 until 550^{0}C depends on very quick heat transfer. It can minimize the exposure of biomass particles to surrounding environment with intermediate temperature. It yields about 12 percent of biochar, 13 percent of syngas and 75 percent of bio-oil. The main product of biomass that undergoes fast pyrolysis is the formation of bio-oil and less formation of biochar.

3.6.3 Slow pyrolysis:

Slow pyrolysis, has a long heating rate and long vapor residence time in order to produce bio-char. This process is usually carried out within a few days at atmospheric pressure. Generally, the energy source from the combustion of produced gas and the partial combustion of biomass feedstock. From the table 1, the amount of bio-char product yield through slow pyrolysis is the highest compared to fast pyrolysis and gasification. Under slow pyrolysis, about 35 percent of biomass ends up as bio-char, 35 percent as syngas and 30 percent as bio-oil. It can turn the waste into safely disposable substances which can retain up to 50% of the feedstock carbon. Slow pyrolysis can be applicable to small scale farmer production of bio-char.

3.6.4 Gasification:

Gasification is a thermochemical conversion at high temperature under limited amount of oxygen in the production of combustible gases. It mainly consists of hydrogen (H_2), methane (CH_4) and carbon monoxide (CO). Gasification is more efficient to produce syngas which reaches 85 percent of syngas since the syngas can be combusted at a higher temperature which is more than 800 °C.



A. Top feed and exhaust vent

B. A central continuous vent from bottom to top

C. Shade dried residues

D. Bottom vents for primary air flow

E. Initial firing point

F. Ignited residues

G. Primary air flow

H. Heat transfer process between hot gases and residues

I. Hot gas exhaust

J. Slow pyrolysis zone

K. De-moistursing zone

L & M. Reduction and bio-carbonization zone

Fig. No. 3.3: Operational process of biochar production.

The biochar was cool of by heat loss, after pyrolysis process transfer the kiln to flat ground. Then after cooling the lid can unsealed and unload the biochar slowly. Which shown in below pictures.

The above picture shows the whole process of biochar production in biochar kiln, from feeding of agricultural waste to the unloading the biochar from kiln. This process of biochar production takes near about 30-40 min. after this process biochar is take for cooling, and then apply in agricultural soil. After application of biochar in agricultural soil, the properties of soil is improved. Similarly it Improving soil for crop production, Nutrient availability in soil, Soil health, Soil microbial activity, Soil and water conservation.

3.8 FLOW CHART OF STEPS IN BIOCHAR PRODUCTION PROCESS:

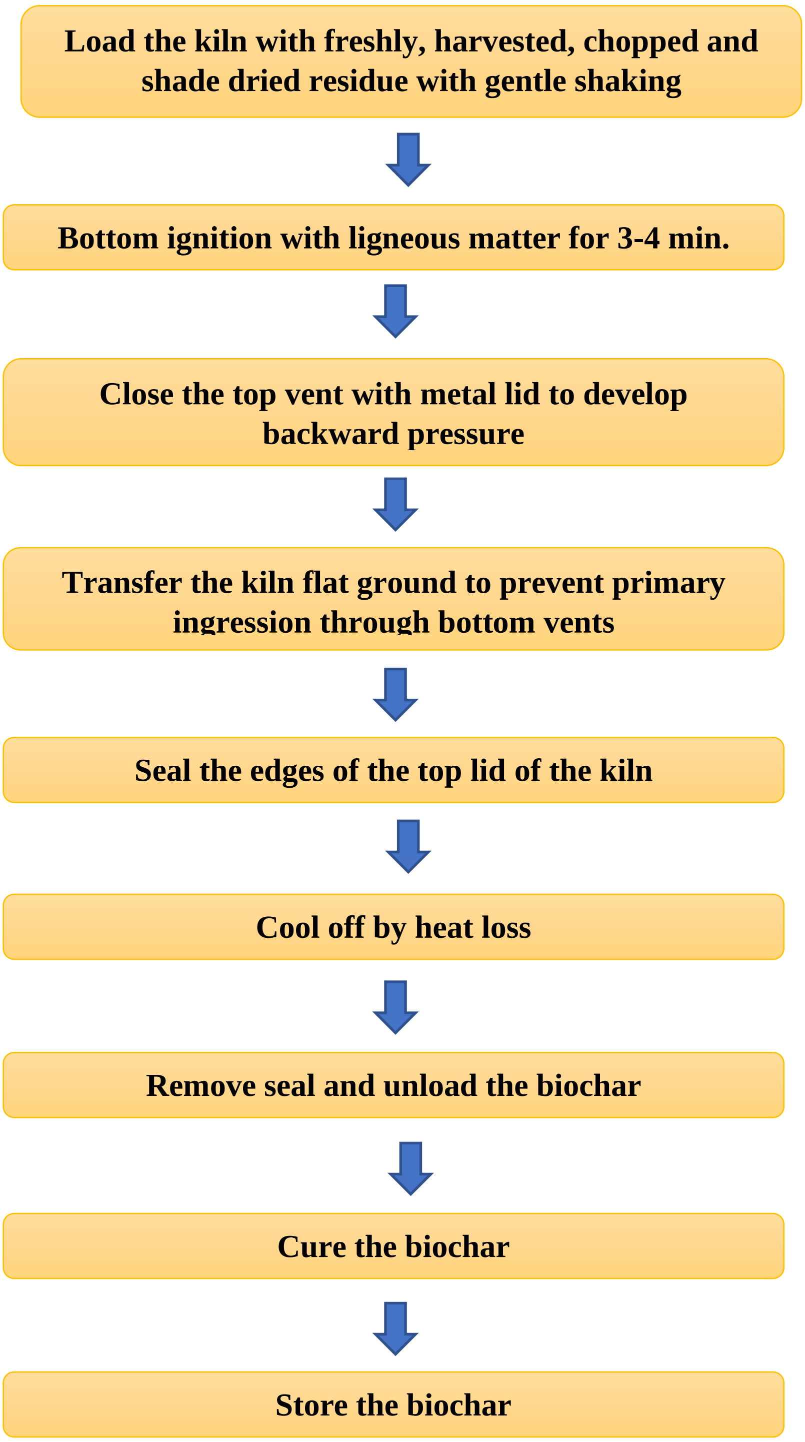


Plate No. 3.1: Testing of biochar kiln.

Plate No. 3.2: Residue feeding in kiln.

Plate No. 3.3: After combustion process transfer the kiln to flat ground.

Plate No. 3.4: Unsealing the lid and unloading biochar.

3.6 STORAGE OF BIOCHAR:

Biochar is very stable when cooled but some precautions must be taken to prevent any combustion during storage. This is due to the tendency of biochar to absorb oxygen when it removed from the kiln which can lead to combustion. Biochar should be clean and it must be located in open dry area for few hours before storage. Furthermore, it should be protected from rain during the cooling period. Once there is no heat store inside the biochar, it is safe for warehouse storage.

CHAPTER IV

RESULTS AND DISCUSSION

The small scale biochar kiln was fabricated in the workshop. The designed biochar kiln was tested to evaluate its performance, for the time required for the production of biochar. The data was collected during the load testing of the system along with recording of input feeding of agroforestry waste.

4.1 Design of the small scale biochar kiln:

The biochar kiln was designed according to the procedure mentioned in the chapter 3. The detailed design steps are given in the appendix. The technical specification of the system is as follows:

Table No. 4.1 technical specification of small scale biochar kiln

1. Pyrolysis chamber specification		
Sr. No.	**Parameters**	**Dimensions**
1	Diameter	34 cm
2	Height	46 cm
3	Thickness	2 mm
4	Capacity	25 lit.
5	Material of pyrolysis chember	MS Sheet

2. Chimney specification		
Sr. No.	**Parameters**	**Dimensions**
1	Diameter	9 cm
2	Height	80 cm
3	Thickness	2 mm
4	Material of chimney	MS Sheet

(a) Chimney

(b) Pyrolysis chamber

(c) Stand

(d) Handle

(e) Kiln lid

Plate No. 4.1: Parts of biochar kiln.

Plate No. 4.2: Developed biochar kiln.

4.2 performance evaluation of small scale biochar kiln:

The performance of small scale biochar kiln was initially carried out for fully loaded container. The test was conducted in winter season, in the month of November for three consecutive days. We took 3 samples for full load test of small scale biochar kiln which were corn cob, coconut shell and coconut fibres.

Table No. 4.2: Result obtain from analysis of biochar

Name of sample	Mass of raw material (kg)	Mass of biochar produce (kg)	Mass of ash (kg)	Time required (min)
Corn cob	3	2.85	0.15	130
Coconut shell	3.5	3.36	0.137	70
Coconut fibre	1.4	1.24	0.157	40

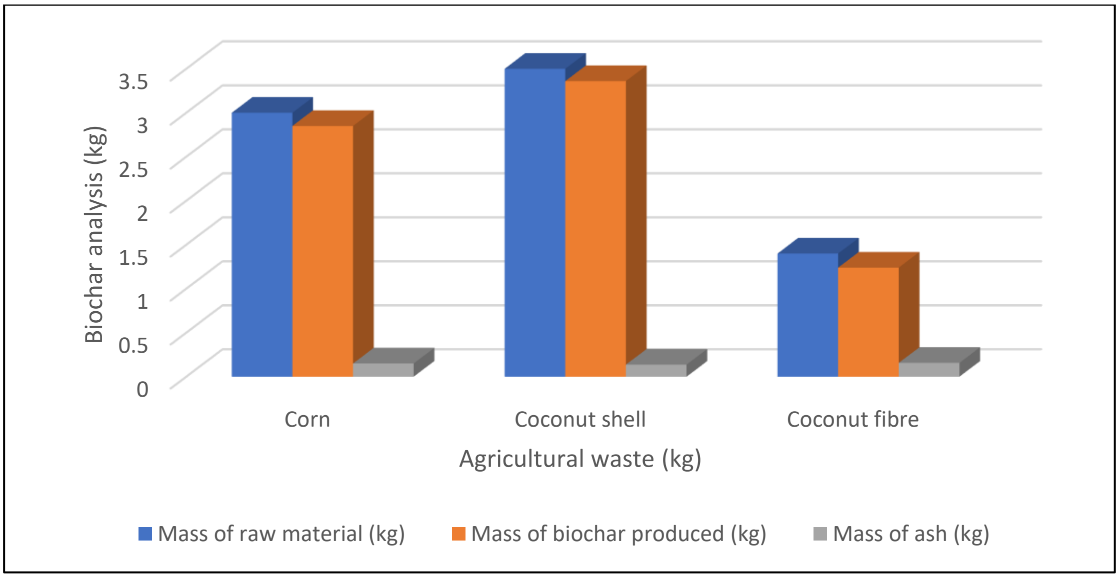


Fig. No. 4.1: Graph of analysis result of biochar produced.

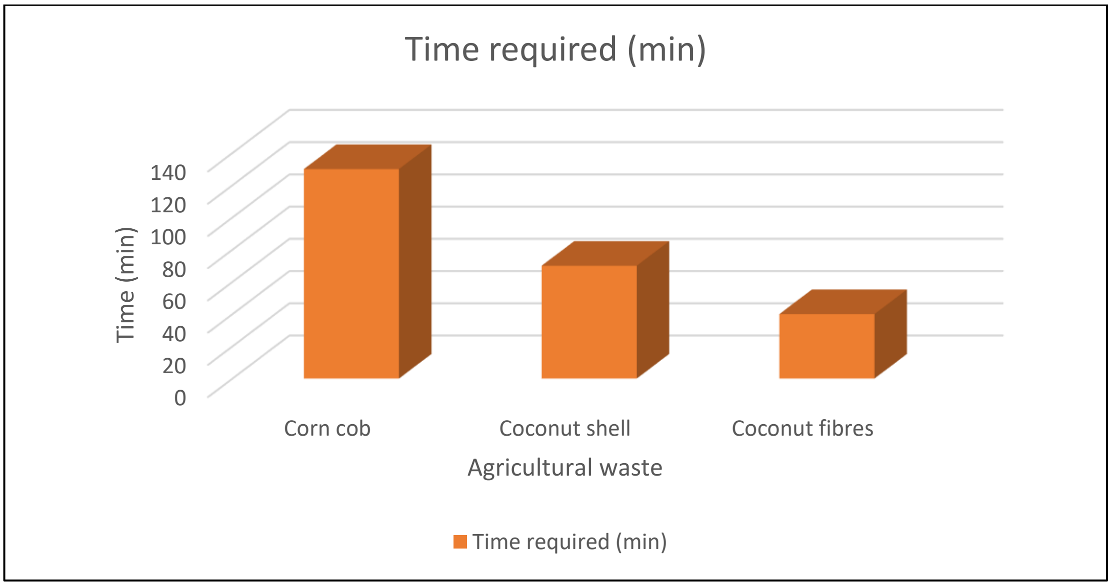


Fig. No. 4.2: Graph of time required for biochar production.

Table No.4.3: M.C and Biochar conversion efficiency of biochar kiln.

Name of sample	M.C of sample (%)	Ash content of sample (%)	Biochar conversion efficiency of biochar kiln (%)
Corn cob	1.2	5.26	95
Coconut shell	1.8	4.07	96
Coconut fibre	2.3	12.66	88

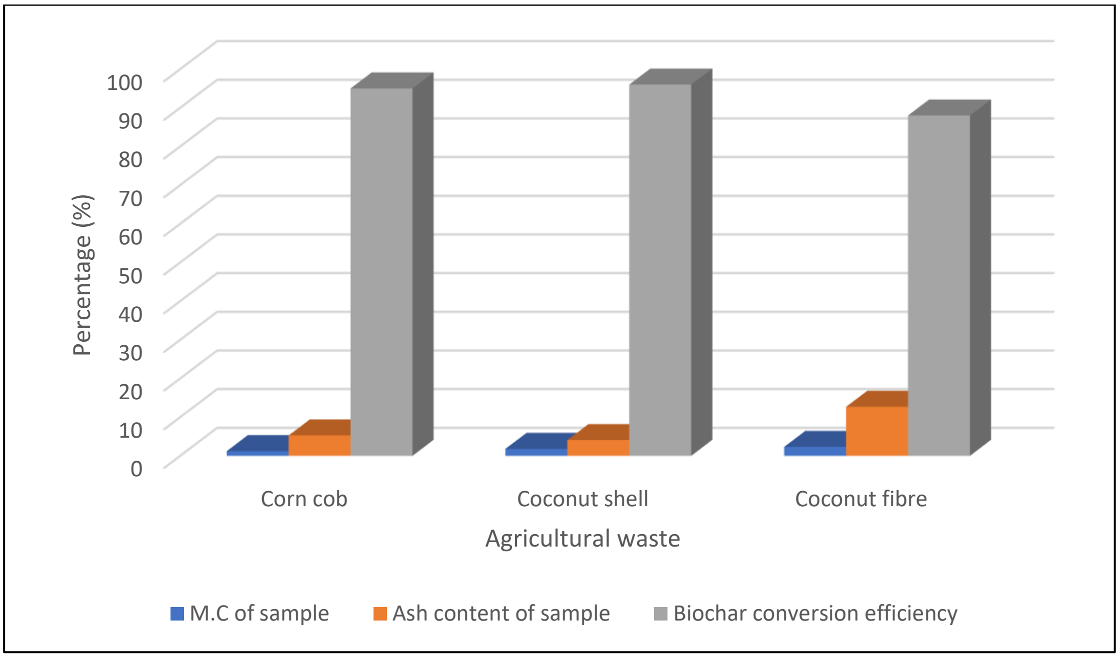


Fig. No.4.3: Graph of M.C and Biochar conversion efficiency.

CHAPTER V

SUMMARY AND CONCLUSION

This study had demonstrated that small farmer can produce biochar easily by using biochar kiln which can be fabricated easily by themselves. The production of biochar from the biomass must undergo pyrolysis process. Hence, the design specification of biochar kiln had been done through Solid Works. The design is simple and easy to fabricate and use by small farmer with less maintenance and low operating cost and it is safe. The general performance of the pyrolysis kiln is satisfactory under limited supply of oxygen.

5.1 Summary:

The small scale biochar kiln was developed at workshop and its performance evaluation was carried out at of the Department of Renewable Energy Engineering , College of Agricultural Engineering and Technology, Nashik. A small scale biochar kiln having height of 46 cm, diameter 34 cm and focal thickness of 2 mm, chimney height 80 cm, and chimney diameter 9 cm. developed small scale biochar kiln were tested for three different tests, which were corn cob, coconut shell and coconut fibre to evaluate their performance.

The results for newly developed small scale biochar kiln were analyzed during testing. The time required to biochar conversion 3 kg of Corn cob, 3.5 kg of Coconut shell and for 1.4 kg of Coconut fibre was 130 min, 70 min and 40 min respectively. Similarly mass of biochar produced during testing of Corn cob, Coconut shell and Coconut fibre was 2.85 kg, 3.36 kg and 1.24 kg respectively and biochar conversion efficiency was 96%, 96% and 88% resp.

5.2 Conclusion:

1) After performing we observe that the time required for coconut fibre was very less and other two sample (coconut shell , corn cob) take too much time.
2) The newly developed small scale biochar kiln was cheaper , lighter in weight, portable and easy to fabricate.
3) All type agriculture waste used for production of biochar.

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APPENDICES

1. Capacity of biochar kiln (cylindrical shape):

$$V_{kiln} = V_{drum} - V_{chimney}$$

Now,

$$V_{drum} = \pi (R_d)^2 H_d$$
$$= \pi (15)^2 * 40$$
$$= 28274 \text{ cm}^3$$

Where,

V_{drum} = Volume of metallic drum or pyrolysis chamber.

R_d = Radius of metallic drum or pyrolysis chamber. (15 cm)

H_d = Height of metallic drum or pyrolysis chamber. (40 cm)

Simillarly,

$$V_{chimney} = \pi (r_c)^2 h_c$$
$$= \pi (4.5)^2 * 40$$
$$= 2544 \text{ cm}^3$$

Where,

$V_{chimney}$ = Volume of chimney.

r_c = Radius of chimney. (4.5 cm)

h_c = Height of chimney. (40 cm)

Now,

$$V_{kiln} = V_{drum} - V_{chimney}$$
$$= (28274)-(2544)$$
$$= 25730 \text{ cm}^3$$
$$= 25 \text{ lit. (approx.)}$$

Therefore, capacity of biochar kiln is **25 lit**. approximately.

2. Design of kiln lid:

$$A_{lid} = \pi (R_L)^2$$
$$= \pi (15)^2$$
$$= 706 \text{ cm}^2$$

Where,

A_{lid} = Area of lid.

R_L = Radius of lid. (15 cm)

Therefore, size of the kiln lid is **706 cm²**.

3. Design of chimney:

Height of the chimney is 80(50+30) cm, which is easily pass out smoke in less amount into the atmosphere.

$$A_c = 2\pi (R_c)$$
$$= 2\pi (4.5)$$
$$= 30 \text{ cm}$$

Where,

A_c = Area of chimney.

R_c = Radius of chimney. (4.5 cm)

4. Design of handle:

Handle is attached to both side of biochar kiln, to operate easily (10*3) cm.

5. Design of stand:

Stand is weld to the bottom side of biochar kiln, for supporting purpose.

6. Efficiency of biochar kiln:

$$\eta\,(\%) = \frac{Wt.\ of\ biochar\ (kg)}{\text{Wt. of raw material (kg)}}\ x\ 100$$

- **BIOCHAR ANALYSIS:**

A. Biochar ash content:

1) Ash content of corn cob:

$$\text{Ash content (\%)} = \frac{Wt.\ of\ ash\ (kg)}{\text{Wt. of biochar produced (kg)}}\ x\ 100$$

$$= \frac{0.15}{2.85}\ x\ 100$$

$$= 0.05 \text{ x } 100$$

$$= 5.26\ \%$$

2) Ash content of coconut shell:

$$\text{Ash content (\%)} = \frac{Wt.\ of\ ash\ (kg)}{\text{Wt. of biochar produced (kg)}}\ x\ 100$$

$$= \frac{0.137}{3.36}\ x\ 100$$

$$= 0.0411 \text{ x } 100$$

$$= 4.11\ \%$$

3) Ash content of coconut fibre:

$$\text{Ash content (\%)} = \frac{Wt.\ of\ ash\ (kg)}{\text{Wt. of biochar produced (kg)}}\ x\ 100$$

$$= \frac{0.157}{1.24}\ x\ 100$$

$$= 0.1256 \text{ x } 100$$

$$= 12.56\ \%$$

B. Biochar conversion efficiency:

1) Biochar conversion efficiency of corn cob:

$$\eta\,(\%) = \frac{Wt.\ of\ biochar\ (kg)}{\text{Wt. of raw material (kg)}}\ x\ 100$$

$$= \frac{2.85}{3}\ x\ 100$$

$$= 0.95 \text{ x } 100$$

$$= 95\ \%$$

2) Biochar conversion efficiency of coconut shell:

$$\eta\,(\%) = \frac{Wt.\ of\ biochar\ (kg)}{\text{Wt. of raw material (kg)}}\ x\ 100$$

$$= \frac{3.36}{3.5}\ x\ 100$$

$$= 0.96 \text{ x } 100$$

$$= 96\ \%$$

3) Biochar conversion efficiency of coconut fibre:

$$\eta\,(\%) = \frac{Wt.\ of\ biochar\ (kg)}{\text{Wt. of raw material (kg)}}\ x\ 100$$

$$= \frac{1.24}{1.4}\ x\ 100$$

$$= 0.88 \text{ x } 100$$

$$= 88\ \%$$

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