STUDIES ON BIOCHAR PRODUCTION USING AGRICULTURE WASTE THROUGH PYROLYSIS METHOD

M. Tech. (Agril. Engg.) Thesis

by

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Thesis

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Indira Gandhi Krishi Vishwavidyalaya, Raipur

by

Abhishek Netam

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CERTIFICATE-I

This is to certify that the thesis entitled "**Studies on biochar production using agriculture waste through pyrolysis method**" submitted in partial fulfillment of the requirements for the requirements for the degree of **Master of Technology in Agricultural Engineering** of Indira Gandhi Krishi Viswavidyalaya, Raipur, is a record of bonafide research work carried out by **Abhishek Netam** under my guidance and supervision. The subject of the thesis has been approved by the students Advisory Committee and Director of Instructions.

No part of the thesis has been submitted for any other degree or diploma or certificate course. All the assistance and help received during the course of the investigation have been duly acknowledged.

Chairman

Date: 21/6/2021

THESIS APPROVED STUDENT'S ADVISORY COMMITTEE

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Member	(Dr. D. Padhee)	____________
Member	(Dr. Ravi Saxena)	____________
Member	(Er. N. K. Mishra)	____________

CERTIFICATE-II

This is to certify that the thesis entitled "**Studies on biochar production using agriculture waste through pyrolysis method**" submitted by **Abhishek Netam** to the Indira Gandhi Krishi Vishvidyalaya, Raipur, in partial fulfillment of the requirements for the degree of **Master of Technology in Agricultural Engineering** in the Department of Farm Machinery and Power Engineering has been approved by the evaluator and students advisory Committee after oral examination, under the chairmanship of head of department/Dean (in case of out campii).

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Date : *(Abhishek Netam)*

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cm	centimeter
^0C	Degree Celsius
g	Gram
PPM	Parts per million
m/s	Meter per second
h	Hour
K	Potassium
kW	Kilowatt
kg	Kilogram
Mg/ha/yr	Mega per hectare per year
M	Million
GJ/yr	Giga per year
h	Hour
m	Meter
mm	Millimeter
-	Minus
Min	Minute
N	Nitrogen
P	Phosphorus
%	Percent
+	Plus
₹	Rupees
Gm/cm^3	Gram per centimeter cube
W	Watt
Yr	Year

LIST OF ABBREVIATIONS

UKBRC	UK Biochar Research Center
CEC	Carbon exchange capacity
ANOVA	Analysis of Variance
BIS	Bureau of Indian Standard
CIAE	Central Institute of Agricultural Engineering
et al.	Et alibi
EC	Electrical Conductivity
Fig.	Figure
FC	Fixed carbon
ICAR	Indian Council of Agricultural Research
mc	moisture content
MS	Mild Steel
BD	Bulk density
MNRE	Ministry of New and Renewable Energy
SSR	Solid state relay
OC	Organic Carbon
CRD	Completely Randomized Design
TC	Temperature controller
SD	Standard Deviation
CV	Coefficient of variation
DDDCR	Down draft double chamber pyrolysis reactor
HTC	Hydrothermal carbonization

THESIS ABSTRACT

Title of thesis:	Studies on biochar production using agriculture waste through pyrolysis method
Full name of student:	Abhishek Netam
Major Subject:	Farm Machinery and Power Engineering
Major Advisor:	Dr. V.M. Victor, Associate Professor, Department of Farm Machinery and Power Engineering, S.V.C.A.E.T. and R.S.FAE, I.G.K.V., Raipur
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Degree to be awarded:	Master of Technology in Agricultural Engineering

Signature of the Student

Signature of Major Advisor

Date: 9/6/24

Signature of Head of Department

ABSTRACT

Biochar is a fine grained, carbon rich product remaining after biomass has been subjected to thermo-chemical conversion pyrolysis process at different temperature such as 300^0C to 500^0C. In this research work we are design and developed vertical type slow pyrolysis reactor. The developed machine was designed and fabrication was done at the workshop of the Swami Vivekanand College of Agricultural Engineering and Technology and Research Station, I.G.K.V., Raipur (C.G.) A laboratory scale small capacity (1kg) biomass pyrolyser system was developed for making the biochar from agriculture waste. The pyrolyser system mainly consist of a reactor, electrical heaters and insulation, temperature measurement and control device, hoper, stand etc. In this experiment used Four different agriculture waste biomass such as Rice Husk, Wheat Straw, Sugarcane Bagasse and Groundnut shell. The biochar Pyrolysis of agriculture waste raw material was carried out with

the help of developed biomass pyrolyser set up. The pyrolyser reactor was started for setting at the experimental temperature. The temperature of the reactor was set different temperature ranging from 350^0C, 400^0C, 450^0C and 500^0C for 90 minutes and controlled with the help of PID temperature controller. During this period one kg, required raw material was feed into the hopper and note down the starting time of the temperature controller and finally raised temperature experimental level than shut down the end of the experiment. The biochar was collected from the bottom of the reactor chamber. The final product biochar quantity was measured.

In this experiment, two types of parameters were analyzed first proximate analysis and second is ultimate analysis. Proximate analysis parameters such as moisture content, ash content, volatile matter, fixed carbon, bulk density and ultimate analysis parameters such as calorific Value, nitrogen content, phosphorus content, potassium content, copper content, iron content, Manganese Content, pH Content, Electrical Conductivity and Organic Carbon content were assessed during the experiment.

The analysis of data collected during the production process. The biochar process by developed pyrolizer that the average yield output of biochar is 0.3374 kg in 90 min per operation. The highest fixed carbon was found 22.31% in treatment T_3 (Sugarcane bagasse) and the lowest fixed carbon was found 4.84% in treatment T1 (Rice husk). The highest biochar bulk density was observed (1.92 g/cm^3) in treatment T_4 (Sugarcane bagasse) and the required lowest was found (1.47 g/cm^3) in treatment T_3(Sugarcane bagasse). The highest N, P, K was found 6.21%, 0.541%, 0.483% in T_4 (Groundnut shell) and lowest was found (0.99%, 0.269%, 0.169%) in T_2 (Wheat straw) respectively. The highest pH content was observed as 7.23 in treatment T_4 (Groundnut shell) so it is neutral and lowest was observed as 5.7 in treatment T_3 (Sugarcane bagasse) so it is slightly acid in biochar. The electrical conductivity was observed highest (5.122 m/s) in T_2 (Wheat straw) and lowest was found (0.289 m/s) in T_3 (Sugarcane bagasse). The organic carbon was found highest (9.25%) in T_4(Groundnut shell) and lowest 1.23% was found in T_3 (Sugarcane bagasse) respectively. The total cost of operation for treatment were calculated 45₹/kg.

शोध सारांश

शोध का शीर्षक	पायरोलिसिस विधि के माध्यम से कृषि अपशिष्टों का उपयोग करके बायोचार उत्पादन पर अध्ययन
विद्यार्थी का नाम	अभिषेक नेताम
मुख्य विषय	कृषि यंत्र एवं शक्ति अभियान्त्रिकी
मुख्य सलाहकार	डॉ. वी.एम. विक्टर, सह प्राध्यापक कृषि यंत्र एवं शक्ति अभियांतत्रिकी एस.वी.सी.ए.इ.टी. एंड आर.एस. इ.गा.कृ.वि. रायपुर (छत्तीसगढ़)
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सम्मानित किये जाने वाला उपाधि	एम.टेक. (कृषि अभियान्त्रिकी) कृषि यंत्र एवं शक्ति अभियान्त्रिकी

मुख्य सलाहकार के हस्ताक्षर

विद्यार्थी का हस्ताक्षर

दिनांक 9/6/24

विभागाध्यक्ष के हस्ताक्षर

सारांश

बायोचार एक महीन दाने का कार्बन युक्त उत्पाद है जिसे बायोमास के दहन उपरान्त प्राप्त पदार्थ करते है। बायोचार एक थर्मो–केमिकल (पायरालिसिस) प्रक्रिया है जो कि 350^0C तापमान में प्राप्त किया जाता है। इस शोध कार्य के अंतर्गत वर्टिकल टाइप स्लो पायरालिसिस रिएक्टर डिजाइन एवं विकास पूरा किया गया है। इस विकसित यंत्र का डिजाइन एवं निर्माण कार्य स्वामी विवेकानंद कृषि आभियांत्रिकी एवं प्रौद्योगिकी एवं अनुसंधान केन्द्र, रायपुर कार्यशाला में संपन्न हुआ। फसल अवशेष से बायोचार बनाने हेतु छोटी क्षमता वाले (1 कि.ग्रा.) बायोमास पायरोलाइसर विकसित गया विकसीत पायरालिसिस प्रणाली में मुख्य रूप से एक रिएक्टर, विद्युत हिटर, इन्सुलेशन, तापमान मापक एवं नियंत्रक उपकरण, हॉपर, स्टैण्ड आदि शामिल है। इस शोध कार्य में चार विभिन्न बायोमास का चयन किया गया, जैसे कि धान भूसा, गेहूँ

का भूसा, गन्ना का अवशेष एवं मूँगफली के छिलके। इस अवशेषों का बायोचार पाएरोलिसिस विकसित बायोमास पायरोलाइसर के माध्यम से किया गया। विकसित रिएक्टर के तापमान को 90 मिनट के लिए 350^0C 400^0C 450^0 एवं 500^0 पर निर्धारित कर तापमान नियंत्रक के सहायता से नियंत्रित किया गया। इस कार्य के दौरान एक किलोग्राम अवषेश को हॉपर द्वारा पायरोलाइजर में डाला गया। तापमान नियंत्रक द्वारा शुरूआती औसत समय का नोट किया गया अंत निर्मित बायोचार को रियक्टर कक्ष के निचे एकत्र किया गया। अंतिम उत्पाद बायोचार की मात्रा को मापा गया।

इस शोध कार्य में दो प्राकर के मापदण्डों का विश्लेषण किया गया। जिनमें से पहला 'समीपस्थ विश्लेषण' दूसरा अंतिम विशलेषण समीपस्थ विशलेषण के अंतर्गत निम्न तत्वों का विशलेषण किया गया। जैसे कि नमी, राख, वाष्पशील पदार्थ, स्थिर कार्बन, बल्क घनत्व एवं अंतिम विशलेषण के अंतर्गत उष्मीय मान नाइट्रोजन, फास्फोरस, पोटेशियम, तॉबा, लौह, मैगनीज, पीएच मान, विद्युत चालकता, एवं जैविक कार्बन का विशलेषण किया गया। बायोचार उत्पादन प्रकिया के दौरान एकत्र जानकारियों का विशलेषण किया गया। तदपश्चात प्राप्त परिणाम इस प्रकार से है।

बायोचार का औसत उत्पाद 0.3374 किलोग्राम गन्ना अवशेष, टी$_3$ गन्ना अवशेष में सर्वाधिक स्थिर कार्बन 22.31 प्रतिशत प्राप्त हुआ। एवं टी$_1$ धान के भूसों मे सबसे कम स्थिर कार्बन 4.48 प्रतिशत प्राप्त हुआ। टी$_4$ मूँगफली के छिलके में बायोचार बल्क घन्त्तव/सर्वाधिक 1.92ग्राम प्रति घन से.मी. पाया गया। एवं टी$_3$ गन्ना के अवशेष सबसे 1.47 ग्राम प्रति घन सें.मी. प्राप्त हुए। टी$_4$ मूँगफली के छिलके में सर्वाधिक एन.पी.के. की मात्रा 6.21 प्रतिशत, 0.541 प्रतिशत, 0.483 प्रतिशत पाया गया एवं टी$_2$ गेहूँ के भूँसे में सबसे कम एन.पी.के. की मात्रा 0.99 प्रतिशत, 0.269 प्रतिशत, 0.169 प्रतिशत पाया गया। इसी प्रकार के पीएच मान के संदर्भ में मूँगफली के छिलके टी$_4$ में उच्चतम मान 7.23 पाया गया एवं गन्ने के अवशेष टी3 में सबसे कम पीएच मान 7.5 प्राप्त हुआ जो कि दर्शाता है कि यह अम्लीय प्रवृत्ति का है। विद्युत चालकता के संदर्भ में गेहूँ के भूसे टी$_2$ उच्चतम मान प्राप्त हुआ जो कि 5.122 मी.प्रति सेकण्ड टी3 गन्ना के अवशेष में निम्न मान प्राप्त हुआ जो कि 0.289 मीटर प्रति सेकेन्ड प्राप्त हुआ। जैविक कार्बन का उच्चतम मान टी$_4$ एवं मूँगफली के छिलके 9.25 प्रतिशत प्राप्त हुआ एवं सबसे कम 1.23 प्रतिशत गन्ने के अवशेष टी$_3$ में पाया गया। सम्पूर्ण कियाओं की कुल लागत 45 रूपये प्रति किलोग्राम है।

CHAPTER-I

INTRODUCTION

Biomass is defined as an important renewable energy source derived from organic carbonaceous material originating from plants, animals and organism that contain energy in a chemical form that can be converted into fuel. It provides 10.6% of global primary energy supplies in the world. (World Energy Resources) Anon, 2016.

Biochar is charcoal produced from biomass to be used as a soil amendment it may be produced from biomass sources such as agriculture waste, wood and animal manure. The biomass used to produce biochar is termed the feedstock. It is produced through pyrolysis which is the process of heating biomass at a high temperature in the absence of oxygen. Biochar is characterized by high carbon content a steady chemical structure unaffected for several years, high porosity and high surface area (Lehmann *et al*.,2008). Biochar probable for global change moderation and improved soil quality. Biochar can be produced by incomplete combustion from any biomass and it is a by-product of the pyrolysis technology used for biofuel and bioenergy production. Biochar offers an opportunity to carbon sequestration, soil restoration, renewable energy production and waste rehypen.

In India, waste biomass produced over before agriculture crop production process is burned as how of easy disposal. The burning of these agriculture residues not only release harmful carbon dioxide into the atmosphere but also pointedly affected soil processes, plant institution and vegetation. However, in recent times agricultural waste may be has been observed as aprominent source of renewable energy and new advanced techniques are being searched to attach them in sustainable form. Biochar a carbon hyppen material gained by pyrolysis using different biomass could also be afeasible option for its efficient conversion. It has probable to produce farm based renewable energy in an ecological way.

According to MNRE, the current availability of biomass in India is estimated at about 500 million metric tones per year. The ministry has estimated the current availability of biomass in Chhattisgarh (2018-19) about 222.4 million metric tonnes per year. (MNRE) Anon, 2018

Agriculture disturbance has significantly increased soil greenhouse gas emissions such as methane (CH_4), Carbon dioxide (CO_2) and Nitrous oxide (N_2O). Biochar application is a potential option for regulating soil greenhouse gas. (Zhang *et al*., 2010).

Carbon sequestration is the capture and storage of carbon to prevent it from being released to the atmosphere. Studies suggest that biochar sequester approximately 50% of the carbon available within the biomass feedstock being pyrolyzed, depending upon the feedstock type (Lehmann *et al*., 2008)

Biochar is one of the best technological solutions to reducing CO_2 levels arguing that biochar has the potential to sequester almost 400 billion tons of carbon by 2100 and to lower atmospheric carbon dioxide concentrations by 37 PPM. The most forward effect of combining pyrolysis with biochar application to soil is a net withdrawal of CO_2 from the atmosphere. (Laird *et al*., 2019)

In modern agriculture repetition increase the absorption of chemical fertilizers declines the soil health and can also often produce detrimental effects of the surrounding ecosystem. So, a converted attention may be need of the hour to maintain sustainable tactics in agriculture crop production. It felt that proper dealing of the soil using agriculture waste may sustain vibrant nutrients necessary to keep soil health. Biochar is revelations high biodegradability and high organic carbon, as well as the optimal concentration of micro elements like potassium, magnesium, calcium, copper, zinc, iron). The structure of the biochar derived from the high temperature was refined to more compound, formed larger surface area and also showed higher carbon content and physicochemical properties promotes the absorption capacity for bioremediation as well as the unruly character for carbon confiscation.

The performance of biochar production and utilization system depends on feedstock used, the conversion process employed and the manner in which the biochar is handled, transported and applied. There are mainly three categories under the biochar conversion systems namely small or mobile type system, large scale pyrolysis and gasification system and hydrothermal carbonization units.

In this study it has been proposed to design and fabricate a pyrolysis reactor (laboratory scale) based on slow pyrolysis to obtain biochar for different types of agriculture waste and to evaluate their feasibility as a biofuel and nutrient for soil health. Pyrolysis technology facilitates the heating of biomass in a low oxygen atmosphere to temperature over 400^0C (Bridgwater *et al.,* 2004). The resulting thermal decomposition yield biochar, bio-oil and gases. When the char is applied for ecological and productivity benefits to soil it is described as biochar (Lehman *et al*., 2009). The end product composition of pyrolysis depends upon the pyrolysis parameters like temperature, feedstock and residence time.

According to (Zhang *et al.*, 2010). Biochar produced from slow pyrolysis at low temperature have low hydrophobicity, aromaticity, high polarity and acidity, presence of functional group decrease, while ash content increase with increase in pyrolysis temperature. The mixture of many biomass and pyrolysis technologies makes for a excess of biochar all varying in physicochemical properties.

Keeping in view the above, present study was undertaken with following specific objectives.

Objectives

1. To develop a pyrolizer for biochar production from agriculture waste.
2. To study physiochemical properties of different agriculture waste biochar.
3. To find out the cost estimation of biochar production.

CHAPTER-II
REVIEW OF LITERATURE

This chapter deals with the review of literature on major fields related to present study which includes effect of biochar, existing methods of biochar and the development of pyrolizer machines.

2.1 Biomass availability and its utilization

Shukla *et al.* (1997) investigated states of biomass energy in India and other developing countries concluded that biomass remains the primary source of energy in Asia's developing countries. Trees, livestock and agricultural waste remained the primary source of biomass energy. Biomass currently contributes 14% of global energy and 38% of energy in developing countries. Another issue with the obsolete biomass was the high social cost of extreme emissions.

Chauhan *et al*. (2009) studied the India produces over 370 million tonnes of biomass per year. Biomass was also developed as a commodity in many agro-based industries, such as rice husk from rice mills, bagasse from sugar mills. In addition to direct harvesting from trees. The available biomass 17GW of power was estimated to be produced through cogeneration and gasification.

Torres *et al.* (2011) investigated the availability of biomass in rural areas, as well as energy use and biochar production. In small farms, bioenergy method such as pyrolytic cook stoves needed a different biomass supply. As a result, they conducted a farm valuation of energy consumption for food preparation, biomass availability. The amount of biomass available for pyrolysis ranged from 0.7 to 12.4 Mg/ha/yr with a mean of 4.3 Mg/ha/yr. The total amount of woody energy in the farms (5.3 GJ/yr).

Ansari *et al*. (2012) studied the biomass energy and climate anxiety in developing countries. Since man discovered fire, biomass has been used as a source of energy. Biomass fuels are now used for a variety of tasks. The developing countries needed 75% of the total global population and consumed 25% of the world's oil.

Hiloidhari *et al.* (2014) reported that the coal dominated biomass energy used in India, accounting for 40% of total primary energy, wood fuel 34% and petroleum fuel 15%. Biomass was a systematic term for active matter produced from plants as a result of photosynthesis. It was approximately 3×1021 J/yr with 90% of the energy contained in tree.

Gopinath *et al.* (2018) observed that the agriculture waste is typically seen as a liability, most due to a lack of resources to turn it into an asset. As crop residues accumulate in fields, they many causes significant crop management issues. Paddy, wheat, millet, sorghum, pulses, oilseed crops (castor, mustard), maize, cotton and jute stick, sugarcane bagasse, roots material and twigs of various sizes, shapes and densities are the most common crop residues produced in India. Rice husk, groundnut shell, coffee husk, cassava peels and other agro-industries residues are examples. Agriculture by products is some of the most popular agricultural by products available in large quantities. Every year, India produces approximately 435.98 million tonnes of agro residues of which 313.62 million tonnes are surplus. The current biomass availability in India (2010-2011) is projected to be about 500 million tonnes per year. According to studies funded by India ministry of new and renewable energy (MNRE), biomass availability is projected to be about 120-150 million tonnes per year.

2.2 Effect of biochar on soil health

Brian *et al*. (2013) studied that the global population and agriculture demands grow, so does the demand for water. Currently it is estimated that 75% of freshwater use is used to grow agriculture crops, with just 10% to 30% of this water being made available to plants. The main goal of this study was to see how different mixture rates of woody biochar (yellow pine from pyrolysis at 400^0C) affected the water holding ability of loamy sand soil. Biochar mixture with a high percentage improves water holding capacity significantly. These findings indicate that using biochar to reduces drought and increase crop yield in loamy sand soil may be beneficial.

Milla *et al.* (2013) investigated the agronomic properties of rice husk biochar (RHB) and wood biochar (WB) and their impact on the growth rate of water spinach. Each biochar from was put to the test at five different rates: 4.0, 3.0, 2.0, 1.0, and 0.5 kgm^3. The application of rice husk biochar increases biomass quality in water spinach according to the findings. WB increased the plant weight of water spinach by increasing the root size and leaf width, while RHB increased the plant weight of water spinach by increasing the stem size and leaf length. We also suggested that the working mechanism of (WB) and (RHB) in soil is such that the decomposition of (OC) in biochar added soil to (OM) results in increased (WHC) and decreased silt. When the dosage was lower (1.5 kgm^3), (WB) biochar decomposed faster than RHB, but this pattern was reversed when the dosage was higher (>3.0 kgm^3).

Hossain *et al*. (2014) studied that the industrial waste, agriculture waste, mine tailing, and sewage sludge have contaminated a vast area of cultivation and fallow lands with a consequence of deterioration of soil and water quality and watercourses due to the erosion of contaminated soils for absence of vegetation cover. High concentrations of toxic elements, organic contaminated, acidic soils and harsh climatic conditions have made it difficult to re-established vegetation and produce crops there. Recently a significant body of work has focused on the suitability and may be potential of biochar as a soil remediation tool that increases seed emergence, soil and increase soil nutrients and water holding potential. This review looks at the functional properties of biochar and microbial nutrient cycling in soil. The effect of biochar on acid processing, acid mine drainage treatment and geochemical dynamics in mine tailing and the treatment of metal organic pollutants in soil using biochar.

Jindo *et al.* (2014) founded that the biochar has gained a lot of attention as a tool to combat carbon emissions. Not only has carbon fixation been accomplished but other benefits for agricultural use have been realized a result of the specific physical and chemical characteristics of the material such as the absorption of polluted compounds in soil the trapping of ammonia and methane emissions from manure and the improvement of fertilizer efficiency. Different agriculture waste feed stock (rice husk, wheat straw, sugarcane bagasse, groundnut shell, wood chips) were used in our study in Aomori, Japan, to make biochar at various temperatures. When it came to biochar processing lower temperature pyrolysis yield more biochar than higher temperature pyrolysis.

Parmar *et al*. (2014) observed that the hydrothermal carbonization (HTC, wet pyrolysis) an advanced biochar processing technique provides a choice for tapping the benefits if biomass residues from the food industry. Strong moisture content and low calorific value worth. HTC is more energy efficient due to its low power consumption. Higher biochar recovery and higher temperature operations a price (up to 9%). In terms of agronomy and environment management biochar has a lot of advantages. It has the potential to help mitigate climate change, increase plant productivity and crop production and clean up polluted areas.

Aabid *et al*. (2015) reported that biochar as a soil amendment faces the problem of having to benefit soil health because it cannot be isolated from soils once it is applied. Biochar has been shown to aid soil biology, regulate soil borne disease, enhance nitrogen fixation, improve soil physical and chemical properties reduce leaching and nitrous oxide emission and help with polluted soil remediation. However, only a small amount of biochar is used as a soil amendment. Since this field of study is still in its infancy, there are still more question than answer. Future research efforts should concentrate on conducting long hyppen required studies and uncovering the mechanism underlying these processes so that key question about the use of biochar can be answered before it is recommended for large hyppen required use.

Venkatesh *et al.* (2018) reported that the soil organic matter is a prerequisite for ensuring soil health and crop productivity in rainfed farming. Among the countries that practice rainfed agriculture, India first rank. In rainfed areas making efficient use of crop residues-based amendment in the soil is an effective strategy for improving soil fertility and productivity. India produces 500 million tonnes of crop residues per year, of which 141 million tonnes are surplus. Oilseed (29 mt), pulses (13 mt), and cotton (53 mt) produce the most residues in India. The conversion of crop residues into biochar through a thermochemical process (slow pyrolysis) is gaining popularity as a novel and cost-effective way of handling unusable and excess crop residues. Converting crop and on-site agroforestry residues to biochar and applying it to the soil as an amendment will convert. India previously surplus residues into a useful material for improving soil health and crop productivity.

Yadavalli *et al*. (2018) investigated that the biomass is a naturally abundant resource that has the potential to be one of the most environmentally friendly renewable energy sources available. Biochar is a carbon rich porous solid formed by the thermal decomposition of biomass at a moderate temperature under anoxic conditions. The production of biochar and its applications for soil remediation and pollutant removal have been extensively explored and reviewed. However, important reviews on the biochar formation process biochar material functionalization for catalysis and biofuels production applications are scarce. As a result, the existing literature on the activity and benefits of biochar derived material used in biofuel production was reviewed in this report. This analysis discusses the preparation methods and reaction conditions that influence the catalytic activity of biochar.

Abukari *et al*. (2019) discovered that the soil moisture plays an important role in crop cultivation. Its sufficiency and availability to crop water supplies are determined by soil management practices and the amount of water available to the soil. The impact of rice husk biochar on soil water holding ability in Ghana savannah ecological zone is investigated in this report. The water holding ability of soil increased as the rate of rice husk biochar increased. The treatments with 4t/ha rice husk biochar showed more noticeable variations. To improve the soil water holding capability 4 tonnes of rice husk biochar should be added per hectare.

2.3 Biomass conversion technology into biochar

Peter *et al*. (2009) conducted an experimented-on pyrolysis biochar system offers one of the few available options for sustainable carbon negative technology in the short term and are the subject of increasing international research. Biochar properties are generally resolute by choice of feedstock and creation condition. These needs principal to our technology strategy involving three scales of pyrolysis equipment termed stage (I) Aa laboratory batch reactor (II) a small-scale continuous reactor and (III) a pilot scale continuous reactor. The important of biochar stability is tinted and test method developed at (UKBRC) for biochar properties are introduced.

Ali *et al*. (2014) evaluated the heating of an organic material such as biomass, in the absence of oxygen called pyrolysis. Since there is no oxygen present, the substance does not burn, but the chemical compounds that make up the material (cellulose, hemicellulose and lignin) thermally decompose into combustible gases and charcoal. Most of these flammable gases can be dissolved into pyrolysis oil, a flammable liquid. However, certain gases are irreversible (CO_2, CO, H_2, light hydrocarbons). Thus, biomass pyrolysis yields three products: liquid, solid and gases. The proportion of these products is determined by several variables including the feedstock composition and process parameter. When the pyrolysis temperature is about 500^0C and heating rate is high (i.e., 1000^0c/s). Fast pyrolysis conditions the yield of bio-oil is optimized. Bio-oil yield of 60-70% can be obtained from a typical biomass feedstock under these conditions, with biochar yield of 15-25%. Syngas accounts for the remaining 10-15% of the total. Slow pyrolysis refers to processes that use slower heating speeds with biochar being the most common end product. The pyrolysis process can be self-sustaining because the syngas combustion and a small amount of bio-oil or biochar provide all of the energy required to drive the reaction.

Reddy *et al.* (2015) observed that the use of biomass for energy production has piqued people's interest. This research looks at the pyrolysis of four agriculture wastes in a fixed bed pyrolysis reactor (rice husk, wheat straw, sugarcane bagasse, groundnut shell). At 300^0C, 400^0C, 500^0C, 600^0C and 700^0C, the yield of char, liquid, and gas were measured, and the temperature and pressure effect were investigated. The pyrolytic liquid was divided into two phases: aqueous and oil. For qualitative and quantitative elements analysis of the liquids and solids developed over a wide temperature range, XRF spectroscopy was used. Calorific value analysis of liquid and solid was also carried out to determine energy content. Sawdust, sugarcane straw and cashew nut waste have been shown to have a high potential for use in the pyrolysis process for alternative fuel production.

Stephen *et al*. (2015) reported that the adding biochar generated by thermal decomposition of biomass to solid has been seen as a technique to boost and sequester carbon (C) but large-scale implementation of the technology necessitates devising innovative profitable solutions. An ambitious programme was introduced in 2012 on a 53-ha farm in western Australia to assess the costs and benefits of combining biochar with animal husbandry and development with an integrated system approach to establish biochar utilization with an integrated system approach. Biochar was mixture into the soil profile. Over the course of the year, we looked at how soil properties changed. Biochar was collected from fresh dung as well as from the soil to a depth of 40 cm. There was also preliminary financial review of the costs and benefits of this integrated strategy. This nutrient rich biochar could be transported into the soil profile by dung beetles. There was no evidence that the biochar recalcitrant portion was reduced by gut reaction or reaction on the soil. More research in needed to determine the long-term effect of incorporating biochar and dung beetles into cow rearing.

Demirbas *et al.* (2015) observed that the biochar is a highly stable type of carbon formed by slow pyrolysis of organic matter. The capacity of biochar to increase soil fertility for crop production was investigated in this report. In a fully randomized block configuration, the experiment used four different levels of biochar with three replicates. The experiments took place at the Pa-Deng Biochar Research Center (PDBRC), which is located in the Pa-Deng Sub-district of Petchaburi, Thailand. Biochar treatments showed higher rates of soil nutrients growth, dry matters and yields. Furthermore, the biochar treated soils had higher levels of total nitrogen and exchangeable potassium, according to the results. The difference was statistically significant at 0.005. TKN levels increased in direct proportion to the amount of biochar applied to the treatment while pH, organic carbon, usable phosphorus and carbon exchange capacity (CEC). Biochar treatment show statistically significantly different in soyabean growth and yield, including stem height. The most significantly results obtained in this analysis furthermore, when compared to the untreated control, treatments with 20 t/ha and 30 t/ha of biochar produced seed that were 28.0% and 36.8% heavier respectively.

Mitchell *et al.* (2015) investigated the original Belonio rice husk gasifier (OBRHG) for biochar production by air gasification of rice husk (RH) and the design was upscaled to height 1.65 m, diameter of 0.85 m and thickness of 0.16 m. The device can work with the centrifugal blower operating at a power input of 155W and a maximum flow rate of 1450 m^3/h controlled to test the gasifier output. The (UBRHG) is simple and inexpensive to build and with its relatively satisfactory efficiency, easy of construction and ease of operation, the (UBRHG) with (RH) as feed will find many applications in a rural setting for biochar production as well as thermal mechanical and electrical energy delivery.

Thierry *et al.* (2015) investigated the design of equipment for converting vegetable biomass waste to usable energy. The pyrolysis reactor was insulated with firebrick after its metallic design to reduce heat losses and protect the operator. Cashew nutshell, coconut shell, palm nutshell, rice husk, cassava peel was used to test the equipment. The five biomasses tested are convertible into gas (84.61%, 98.67%, 72.31%, 73.08% and 78.47%) for cashew shell, coconut shell, palm nut, rice husk, cassava peel and coal respectively (15.38%, 1.33%, 27.69%). The released energies for cashew shell 135.72%, coconut shell 113.75%, for palm nuts 89.7% for rice husk 89.7% and 117% for cassava peel. The maximum flame temperature was 763^0C.

Surya *et al*. (2016) observed that the wood industry residues are the major contributors to biomass waste in Indonesia. The traditional pyrolysis process which consumes a lot of energy and emits a lot of toxic chemicals into the atmosphere. As a result, a laboratory scale pyrolysis unit was developed. Which could be a good alternative for achieving zero waste and low energy costs. The aim of this paper is to discuss the design and system of a pyrolysis reactor that produced bio-oil and biochar at same time. Agriculture residues are the primary source of biomass Wates in Indonesia. Renewable energy has recently gained popularity as concern about global climate change, emission and the availability and protection of energy supply have grown as a result of the use of fossil energy resources. All organic matter generated by plants, as well as any conversion process involving life is referred to as biomass. Biomass thermochemical conversion methods must be well understanding to improve biomass as a renewable energy source. Depending on the source and equipment used, a variety of thermochemical processes turn biomass into higher value products. These processes include combustion pyrolysis and gasification.

Hassan *et al.* (2019) observed that pyrolysis is one of the most effective thermochemical energy conversion method for renewable energy sources. Pyrolysis has gotten a lot of attention among the various thermal conversion processes because the process conditions can be optimised to produce high energy density pyrolysis oil and chemical. A limited number of commercial scale pyrolysis plants have been built after various types of pyrolysis processes were studied and produced in the laboratory or on a pilot plant device. The findings of this study proved the technology viability and strongly indicated that pyrolysis is the most promising solid waste management technology. The stainless steel will be used to build the pyrolysis system in this project and the olive seeds will be used as the feed material. The inert environment in the reactor where the pyrolysis reaction will take place will be maintained with nitrogen gas.

2.4 Effect of biochar parameters

Omran *et al*. (2013) investigated the proximate analysis is commonly used to assess moisture, volatile matter, fixed carbon, and ash content of biochar. The ASTM D1762-84 standard was created to evaluate the consistency of hardwood charcoal for use as a fire. To assess the quality of various biochar for as a soil amendment we developed a modified proximate analysis process. To avoid the caused by sample oxidation we discovered that a N_2 purge is needed during both moisture and VM determinations. We tested a range of boundary temperature (350-950^{0}C) for separating VM and FC in biochar and found that 800^{0}C is the minimum temperature required to differential between the two. Furthermore, the fact that VM/FC and molar H/Corg ratios are related indicates that VM/FC ratio can be used to assess biochar stability. To reduce variance in analytical results among studies, the proposed modified method should be used.

Patrick *et al.* (2017) observed that the biomass pyrolysis and the valorization of co-products (biochar, bio-oil, and syngas) may be a sustainable management option for agricultural and forest residues. Biochar amended to soil can boost fertility depending on its properties. Furthermore, if the C/N ratio of biochar is less than 30, it is expected to reduce climate change by lowering soil greenhouse gas emission and sequestering carbon if the O/Corg and H/Corg ratio are less than 0.2 and 0.7 respectively. However, biomass feedstock and pyrolysis operating parameters have an effect on biochar yield and properties. The main aim of this study was to validate a response surface methodology-based approach for identifying the best pyrolysis operating parameters (temperature, solid residence time and carrier gas flow rate) for producing engineering biochar for carbon sequestration. To obtained biochar with the lowest H/Corg, O/Corg ratio, the optimal pyrolysis operating parameters were calculated. Validation pyrolysis experiments showed that the chosen method can be used to reliably predict the optimal operating parameters for generating biochar with the desired carbon sequestration properties.

Zanzi *et al.* (2018) observed that the carbon sequestration through the production of biochar is a viable way to combat global warming. Because of the high complexity and specificity of pyrolysis technology developing countries have yet to apply biochar processing technology on an industrial scale. As a result, the aim of this research was to assess a small-scale pyrolysis unit (Down draft double chamber pyrolysis reactor- DDDCR) for continuous biochar production using paddy husk as both feedstock and fuel. Field trials were used to assess the temperature variation, syngas composition and energy contents as well as the mass and energy balance of the DDDC reactor. From the bottom to the top of the reactor, the average temperature ranged from 330^0C to 560^0C meeting the pyrolysis temperature criterion. This indicated that a backup fuel supply would be needed to keep the reactor running for material input of 4.42 kg/h of paddy husk and 0.77 kg/h of coconut shell as fuel sources the reactor biochar recovery was 32% (dry matter basis) and the average biochar output rate was 1kg/hr. With an average energy content of 5.34 MJ/m^3, the raw syngas composition was 20.78%, CO 13.3%, CO_2 3.87%, CH_4 0.3%, H_2 6.91%, O_2 0.68% and N_2 54.16%. The potential for optimizing and scaling up a continuous mode paddy husk pyrolysis was demonstrated in this report.

Mihir et al. (2020) investigated the production of liquid fuel (hydrocarbon fuel) from four different types of waste plastic low density polyethylene and high-density polyethylene (LDPE and HDPE), polypropylene (PP) and polystyrene (PS) in a stainless-steel reactor system. Since the chemical and physical properties of each of the plastics vary, the tests were carried out separately for each of them. Container dispensing bottles and other items are made from LDPE and HDPE is used to make plastics bottle corrosion resistance tubing and other products. The plastics were melted using simple thermal degradation at temperatures ranging from 120 to 400^0C. The liquid hydrocarbon product was generated by condensation of vapors from melted plastic. During the manufacturing process each of the plastic was kept to the same set of requirements the impact of the reaction on the product quality and yield was investigated.

CHAPTER-III

MATERIALS AND METHODS

3.1 General

This chapter includes materials and methods adopted for the development, fabrication and testing of pyrolizer machine. Fabrication of the machine is done in accordance with the mechanical design consideration. The developed machine was designed and fabrication was done at the workshop of the SVCAET & RS and, FAE, I.G.K.V., Raipur (C.G.).

3.2 Geographical situation

The project research work was conducted at Swami Vivekananda College of Agricultural Engineering & Technology and Research Station, Faculty of Agricultural Engineering, Indira Gandhi Krishi Vishwavidyalaya, Raipur which is situated on national highway no.6 in the eastern part of Raipur city and located between 20º4´ North latitude and 81º39´ East longitude with an altitude of 293 m above mean sea level.

3.3 Climate condition

The climate of Raipur region is tropical wet, dry, sub humid and the region receives 1150 to 1450 mm rainfall in a year, from which around 88 percent rain is received by monsoon in the rainy season (June to September) and 8 per cent during the winter season (October to February). May is the hottest and December is the coldest month of the year. The rainfall pattern has great variations during rainy season from year to year. The temperature reaches as high as 48°C during May-June and drop to 6°C during from December to January (in winter).

3.4 Design considerations

A laboratory scale small capacity (1kg) biomass pyrolizer system was developed for making the biochar from agriculture waste. The pyrolyser system mainly consists of a reactor, electrical heaters and insulation, temperature measurement and control device, hoper, stand etc.

3.4.1 Design and Fabrication of vertical pyrolysis reactor

In the vertical pyrolysis unit, the foremost part was the planning and fabrication of a fire tube heater reactor for the project and thesis work. The size of the system is the key to design the fire-tube heating reactor system of the pyrolysis unit. It was designed in such a way in order that the feed material is going to be taken into it, and there would be a very short time in residence time in duration within the reactor, so that it would give a product which have higher pyrolysis biochar. The duration of volatile materiel and gases mixture is vital for the most biochar production. A cylindrical reactor was considered for simplistic design. The iron plates were used as a reactor material to avoid the corrosion problem which was occurring because of the character of pyrolytic biochar. The height of reactor was taken as 690 mm and therefore diameter was 1100 mm. The reactor had one inner feeder cylinder 900 mm diameter. This feeder was covered by a flat plate with the assistance of nut-bolts. At the bottom of the reactor, there was another throughout of 200 mm diameter for char removal. A vertical pyrolysis reactor is shown in Fig. 3.2 and 3.3. before installation and after reactor installation the 2 mm thick iron metal sheet was used inside the wall of reactor and also the outer wall of cylindrical shaped reactor shield was made by 2 mm thick sheet. Furnace utilized in reactor was 870 mm long and therefore the length of reactor shield 130 mm. The dimensional view of vertical reactor. the hollow portion was filled with insulating material. The furnace heater was maintaining the proper heating temperature as well as required temperature for reactor operation. burners were designed in such a way so that they can burn by electric of the furnace. They covered the correct heating inside the furnace.

3.5 Components of pyrolizer

The pyrolyser system mainly consists of a reactor, electrical heater and insulation, temperature measurement and control device, stand etc.

3.5.1 Reactor

The pyrolyser reactor is an air proof cylindrical chamber in which the pyrolyser process of agriculture waste is taking place in absence of air. The diameter of cylinder was 1100 mm and height of the cylindrical reactor was 690 mm respectively. The height of the reactor was kept as 690 mm provided the volume of 0.21 m^3 such that 1kg raw agriculture waste can be accommodated. The reactor chamber is made from 2 mm thick sheet. The temperature sensor port was also provided at the reactor chamber for installing the sensor. A 900mm opening is provided at the top of the reactor chamber to (feed) raw material from the inclined inlet feed pipe of hopper. A 900 mm diameter leak proof door was provided to center of the bottom of the reactor to remove the biochar produced after accomplishment of the process. Fig. 3.1 and 3.2 shows pyrolysis reactor.

Fig. 3.1: Pyrolysis Reactor

Fig. 3.2: During Pyrolysis Operation

3.5.2 Electrical heater and insulation

Thermal energy was supplied to the biomass with the help of electrical heaters installed at the bottom of the cylinder. Electrical heater having 1.5kW capacity was used in this study. The circular heater was installed at the bottom of the surface. The wall of pyrolyser was covered by electrical heaters. This electrical heater was insulated with the help of 50 mm thick insulating material covered on the heater to minimize the heat loss to the surrounding.

3.5.3 Temperature controller and measuring device

For controlling the temperature of the reactor chamber at the experimental temperature levels a PID temperature controller (DTC-981) was used as shown in fig. 3.4.

Fig. 3.3 K-type thermocouple

Fig. 3.4 Temperature controller

This temperature controller was used for controlling the temperature of the reactor as well as sensing temperature inside the reactor simultaneously. The electrical heater provided in the reactor was connected to the controller and then to the electrical mains viz. MCB. The experimental temperature level of the reactor was set with the help of up down switches provided on controller. The temperature was sensed by k-type thermocouple sensor (Fig. 3.3). The temperature range of k-type thermocouple sensor was 0-1200^{0}C. The temperature sensor was connected to the PID temperature controller. The temperature of the reactor was displayed on the display section of the controller.

3.5.4 Solid state relay

The solid-state relay was used to control voltage of temperature controller (Fig. 3.5). In this experiment FOTEK SSR-40 DA Solid State Relay Module 3-32 VDC/24- 380VAC 25A was used. Basically, SSR is an electronic switching device that switches on or off when an external voltage (AC or DC) is applied across its control terminals.

Fig. 3.5 Solid state relay

Fig. 3.6 Feeding hopper

3.5.6 Feeding hopper

The hopper was provided to feed the raw material into the reactor chamber. The feeding hopper is provided in such a way that the handle of inner cylinder. Feeding hopper dia 900 mm. Feeding pipe from the pyrolyser reactor chamber and provided bottom of the hopper feed control valve. Fig. 3.6 shows feeding hopper.

3.6 Design of pyrolizer

A lab scale pyrolizer based on slow pyrolysis principle is designed to have a pilot study of the conversion of agriculture biomass waste. The design and fabrication of a fire tube heating reactor for the batch type fixed bed pyrolysis unit was the major part of the project and thesis work. The fire tube heating reactor system of pyrolysis unit was designed on the basis of the size of the system. It was designed so that sufficient amount of feed material could be taken into it and in a way that there would be a short vapors residence time in the reactor, which would promote a high yield of pyrolysis liquid product. For simplicity of design a cylindrical reactor was considered to accommodate 1 kg of biomass reactor was developed as follows.

3.6.1 Residence time

Solid biomass moves under gravity with an acceptable space velocity provides the required residence time in different zones of reactor.

3.6.2 Calculation of total dimensions of reactor

The outer reactor dimensions were calculating by using following formula.

Total diameter of cylinder = d = 2r --- (3.1)

Where,

d = Diameter of cylinder

r = Radius

d = 2×550 = 1100 mm

Total height of cylinder = 690 mm

The inner cylinder diameter was calculating by using formula.

Total diameter of cylinder = d = 2r ---(3.2)

Total diameter of cylinder = d = 2× 450

d = 900 mm

Height of cylinder = 370 mm

The reactor chimney diameter was calculating using formula.

diameter of chimney = d = 2r ---(3.3)

d = 2 × 125

d = 250 mm

Height of chimney = 500 mm

3.6.3 Calculation of total volume of reactor

Outer cylinder volume of reactor $V_O = \pi r^2 h$ ---(3.4)

Where, V_0 = Volume of reactor

h = Height

r = radius

Volume of reactor $= \pi \times (55)^2 \times (69)$

Volume of reactor = 655728.9266 cm^3

Inner cylinder total volume $V_I = \pi r^2 h$ --- (3.5)

Volume of reactor $= \pi \times (45)^2 \times (37)$

Volume of reactor = 235383.8295 cm^3

Reactor chimney total volume $V_C = \pi r^2 h$ ---(3.6)

Volume of chimney $= \pi \times (12.5)^2 \times (50)$

Volume of chimney = 24543.6926 cm^3

3.6.4 Capacity of reactor

The capacity of reactor was calculated by using bulk density of feedstock and volume of reactor (kg/m^3).

$$\text{Bulk density} = \frac{Mass}{Volume} \quad \text{--- (3.7)}$$

Mass = Bulk density × Volume --- (3.8)

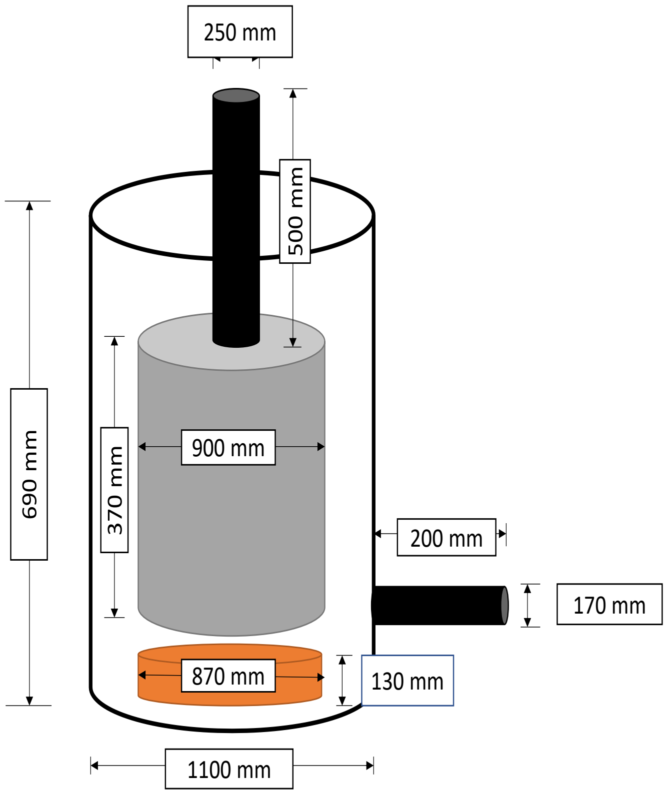

Fig. 3.7: Vertical pyrolizer

Table 3.1 Design specification and dimensions of pyrolizer

S. No.	Specifications	Dimensions
1	Total diameter of cylinder, mm	1100
2	Cylinder height, mm	690
3	Inner cylinder diameter, mm	900
4	Inner cylinder height, mm	370
5	Pyrolizer chimney diameter, mm	250
6	Pyrolizer chimney height, mm	500
7	Total weight of pyrolizer, kg	10.476

Table 3.2 Temperature controller specifications

Sr. No.	Specification	
1	Thermocouple type	k-type
2	Temperature range (^{0}C)	-200 to 1371
3	Power range, Watt	100-240

Table 3.3 Thermocouple and SSR specification

Sr. No.	Specification	
1	Types of thermocouples	k- type
2	Temperature range (^{0}C)	-35 to 1260
3	Voltage in mV	18.516

3.7 Collection of agriculture waste

For the preparation of biochar, four different types of agricultural crop residues/waste viz. rice husk, wheat straw, groundnut shell and sugarcane bagasse were used. Wheat straw was collected from research farm of Indira Gandhi Krishi Vishwavidyalaya Raipur. Sugarcane bagasse, groundnut shell and rice husk were procured from a sugar mill and rice mill respectively.

3.7.1 Sample weight

Before pyrolysis a sample of 1kg agriculture waste was taken and weighed by using an electronic balance weighing machine.

3.7.2 Pyrolysis test

Pyrolysis of agriculture waste raw material was carried out with the help of developed biomass pyrolyser set up. The pyrolyser reactor was started for setting at the experimental temperature. The temperature of the reactor was set at selected different temperatures viz.

350^0C, 400^0C, 450^0C and 500^0C and controlled with the help of PID temperature controller. The weighed raw material was feed in the reactor chamber through the hopper. After that the feed pipe was closed so as to provide the reactor chamber air proof. Note down the starting time of the temperature controller and finally raised temperature at 90 minutes experimental level. than switch off the end of the experiment. After shut down the experiment, the reactor was cool down for 2-3 hour to collect biochar. The biochar was collected from the bottom of the reactor chamber. Final product biochar quantity was measured.

3.7.3 Biochar yield

Dried biomass sample was pyrolyzed in an electrical furnace at different temperature ranging from 350^0C, 400^0C, 450^0C and 500^0C for 90 minutes. The percentage of biochar yield was calculated using the equation.

$$Yield_{biochar} = = \frac{\boldsymbol{m1}}{\boldsymbol{m2}} x\ 100 \qquad ---(3.10)$$

Where,

m1= Mass yield of biochar, kg

m2 = Mass of raw biochar, kg

3.8 Physical properties of agriculture waste raw material

Different size fractions of agriculture waste, rice husk, groundnut shells, sugarcane bagasse, wheat straw, were analyzed in terms of weight and length. Four samples of randomly selected, 1kg of each sample were considered for the analysis. Each sample of raw material was weighed using a weighing machine. The bulk density of raw material was determined by a weight of biomass placed in a container and divided by the space occupied. Each size fraction was weighed and measured randomly for its minimum and maximum length as considered in case of raw material. The bulk density of the biochar was also measured in each case.

Fig.3.8 Groundnut shell biomass

Fig. 3.9 Groundnut biochar

Fig. 3.10 Wheat straw biomass

Fig. 3.11 Wheat straw biochar

Fig. 3.12 Rice husk biomass

Fig. 3.13 Rice husk biochar

Fig. 3.14 Sugarcane bagasse biomass

Fig. 3.15 Sugarcane bagasse biochar

3.9 Experimental design

In this experiment pyrolizer machine was used for biochar production form different agriculture wastes. Experiment was laid-out in completely randomized block design with four treatments and five replications.

Raw materialswere taken as treatments in this study for experiment:

T_1 = Rice husk

T_2 = Wheat straw

T_3 = Sugarcane bagasse

T_4 = Groundnut shell

1. Design	: Completely randomized block design
2. Number of treatments	: 4
3. Number of replications	: 5
4. Input biomass	: 1kg
5. Machine used	: Pyrolizer reactor
6. Biomass type	: Rice husk, Wheat straw, Sugarcane bagasse, Groundnut shell

3.10 Desirable parameters and proximate analysis

Measurement of different parameters like proximate analysis, moisture content, ash content, volatile matter, fixed carbon and bulk density of produce biochar was carried out. Biochar product can be analyzed by the proximate analysis method to determine all parameters as suggested by (Bakshi *et al.*, 2017).

3.10.1 Moisture content

Moisture content is measured by weighing a sample before and after drying in an oven at 105^{0}C temperature. The ratio of weight of water to the initial weight of sample is the moisture content of sample on wet basis. Biochar sample was weight by using weighing machine, moisture content of biochar was calculated by using following equation:

$$\text{Moisture content (\%), db} = \frac{W_{(i)} - W_{(d)}}{W_{(i)}} \text{x } 100 \qquad \text{---(3.11)}$$

Where,

$W_{(i)}$: Initial weight of biochar
$W_{(d)}$: Dry weight of biochar

3.10.2 Ash content

Ash content is measured by grinding a biochar sample and placing it into an open-top ash crucible. The sample is heated in an exceedingly muffle furnace, at 500^0Ctemperature for half an hour. Heating continues until the biochar sample becomes a black to white powder with no black particles. The ratio of the ash weight to the dry biochar sample weight provides the ash content. Fig. 3.16 shows measurement of ash content.

$$\text{Ash content (\%)} = \frac{(W3-W1)}{(W2-W1)} \times 100 \qquad \text{---(3.12)}$$

Where,

W_1 = Weight of empty crucible (g)

W_2 = Weight of the sample + crucible (g)

W_3 = Final weight of sample (ash) + crucible (g)

3.10.3 Volatile matter

Volatile matter of solid biomass is the product, exclusive of moisture, given off by a material as a gas or vapors when solid biomass is heated out of contact with air under standardized conditions that may vary according to the nature of the material. Oven dried biomass sample is kept in the tarred crucible. Two drops of benzene are added in to displace air in the environment surrounding the sample. The crucible is closed with lid and placed in the muffle furnace and heated at 600^0C for six minutes and 900^0C for another six minutes. The loss in weight divided by the initial weight of biomass will give the volatile matter on dry basis in the biochar. Fig. 3.17 shows measurement of volatile matter

$$\text{VM (\%)} = \frac{\text{Loss in wt due to vm}}{\text{initial wt of biochar}} \text{x} 100$$

$$\text{Volatile matter (\%)} = \frac{(W2-W3)}{(W2-W1)} \times 100 \qquad \text{---(3.13)}$$

Where,

W_1 = Weight of the empty crucible (g)

W_2 = Initial weight of the sample + crucible (g)

W_3 = Final weight of sample + crucible (g)

3.10.4 Fixed carbon

Fixed carbon content increase from lignite to anthracite. Higher the percentage of fixed carbon greater is its calorific value and better is that the quality of biochar. The proportion of fixed carbon helps in designing the furnace and shape of the fire box because it is the fixed carbon that burns within the solid state. The fixed carbon represents the non-volatile combustible component of the biochar. After determining fuel moisture content (d.b), volatile matter (d.b) and ash content (d.b), the fixed carbon is estimated from the material balance equation.

Fixed carbon (%) = 100 - % (MC + VM +ASH) ---(3.14)

Where,

FC (% d.b) = Percentage of fixed carbon on dry basis

VM (% d.b) = Percentage of volatile matter on dry basis

ASH (% d.b) = Percentage of ash on dry basis

MC (% d.b) = Percentage of moisture content

Fig. 3.16Measurement of ash content

Fig. 3.17Measurement of volatile matter

3.10.5 Bulk density

The bulk density of biochar was determined by placing the sample of biochar in a measuring cylinder which is 5.4 cm in diameter and 36.7 cm in length. The sample taken in the cylinder was weighed using an electronic balance with the least count of 1g (Mohsenin *et al.*, 2009). Bulk density was calculated by using the following formula.

$$\text{Bulk density} = \frac{Mass\ of\ the\ sample\ (g)}{Volume\ of\ the\ flask\ occupied\ by\ the\ sample\ (cubic\ cm)} \quad \text{---(3.15)}$$

Fig. 3.18 (a) Measurement of bulk density

Fig 3.18 (b)100 ml measuring cylinder

3.11 Ultimate and elements analysis

Ultimate analysis is also known as elemental analysis, it is the method to determine the nitrogen, phosphorus, potassium, calorific value, copper content, iron content, pH, electrical conductivity and organic carbon. After pyrolyzing, ultimate analysis of the sample was carried out at Department of Soil science & Agriculture Chemistry, I.G.K.V. Raipur.

3.11.1 pH content

The pH value of biochar is positively correlated with the formation of carbonates and therefore the contents of inorganic alkalis. These groups are the most reason for alkaline pH. The content of total base cation and carbonates have reported to extend with increasing temperature, contributing to increased pH (Ranging from 6.5 to 10.8). Higher pH with increasing temperature has been related to the increases in ash content and oxygen functional groups that occur during pyrolysis. It consists of two electrodes are dipped in solution under test, the potential is developed in the solution. That potential difference between both the glass electrode and the measured.

3.11.2 Electrical conductivity

The electrical conductivity of raw material and biochar was measured at room temperature. Total soluble salt is estimated from electrical conductivity of biochar extracts. EC is a measure of the ability of a salt solution to carry electric current by the migration of ions under the influence of an electric field. Electrical conductivity of solution of raw material and biochar prepared by standard method was also measured by bench-top pH / conductivity. The electrical conductivity can be measured by the same bench-top pH / conductivity meter by using the suitable switch on the display section relevant to electrical conductivity measurement.

Fig.3.19 Measuring Electrical Conductivity

3.11.3 Calorific value

Thermal properties of raw material and its biochar was determined in terms of calorific values. Bomb calorimeter was used to determine the calorific value. 1g of air-dried sample was kept in the crucible. After that fuse wire was attached across the electrodes of the bomb. 15cm long cotton yarn around the wire such that loose end of the yarn will remain in contact with the sample. After that bomb was charged slowly with O_2upto 25 atmospheric pressure (25 kg/cm^2) without displacing its original air content. Then calorimeter vessel was transferred to the water jacket and connect in a circuit through a switch for firing of the charge. Thermometer was placed and stirring mechanism was started. Temperature was recorded at 1 min intervals. Water equivalent (w) of the calorimeter was obtained by conducting the experiment and using the benzoic acid as a standard sample having a known calorific value of ‘H’ equal to 6319 cal/g. (Toscano *et al*., 2012) The calorific value was calculated by using the following formula.

$$HHV = LHV + H_v\,({}^{n}H_2O, \text{out}) / ({}^{n}\textit{fuel}, \text{in}) \qquad \text{---(3.16)}$$

Where,

HHV = Higher heating value

LHV = Lower heating value

H_v = Heat of vaporization of water

^nH_2O, out = Moles of water vaporized

^{n}*fuel*, in = Number of moles of fuel combusted

3.11.4 Organic carbon

The organic carbon was measured by weight loss on ignition (LOI) method. Each sample of about 1.5 gm was taken and weighed on a microscale in a small cylinder of tin foil. Tin foil weight was recorded. Sample was dried at about 90^0C for 24h to remove water, placed in a desiccator to cool and weighed to determine the pre ignition weight of the sample. Subsample were then placed into glass vials and ignited in a furnace at 550^0C for five hours. After the five-hour burn, the glass vials containing the sample packets was cooled in a desiccator to prevent the addition of moisture to the samples. Once the sample was cooled than weighed using a microscale. (Chatterjee *et al.*,2009) The following equation was used to determine the percent of organic matter present in each biomass and biochar sample.

$$BOC = \frac{(\,pre\ ignition\ biochar\ sample - post\ ignition\ biochar\ sample\,)}{(\,pre\ ignition\ biochar\ sample\,)} \times 100 \quad \text{--- (3.17)}$$

Where,

BOC = Biochar organic carbon

3.12 Cost analysis

When a new technology is introduced, it is essential to know whether the machine will be profitable or not. Operational cost of the machine is the sum of fixed cost and variable cost of the machine. The machine operational cost (₹/h) was calculated by assuming some data. (Sahay *et al.*, 2013).

3.12.1 Fixed cost

It is the total cost of depreciation, interest on investment, tax, insurance and shelter. For calculating the depreciation of the machine, straight-line method was used.

(a) Depreciation

Depreciation (D) was calculated by the following expression.

$$D = \frac{C - S}{LH} \quad \text{--- (3.18)}$$

Where,

D = Depreciation/hour (₹/h)

C = Investment of capital

S = Value of salvages (10% capital)

L = Machine life (in year)

H = Working hours/ year

(b) Annual interest @ 15 % in investment

$$I = \frac{c+s}{2} \times \frac{i}{H} \quad \text{--- (3.19)}$$

Where,

I = Interest per hour;

(C+S)/2 = Average investment; and

i = Interest rate @ 15%.

3.12.2 Variable cost

(a) Repair and maintenance

Repair and maintenance cost was taken as 10% of initial investment.

$$Repair\ and\ maintainance\ cost = \frac{m}{100} \times \frac{c}{H} \quad \text{--- (3.20)}$$

Where,

m = Repair and maintenance rate, 10%;

H = Annual use, h; and

C = Unit cost.

(b) Electricity cost

It can be determined by on basis of total electricity consumption in the operation.

Electricity cost (₹/h) = Electric consumed (watt/h) × Electric rate (₹/unit) --- (3.21)

Variable cost = Repair and maintenance cost + Electricity charge

Total cost = Fixed cost + Variable cost

$$\text{Cost of biochar production(Rs/h)} = \frac{Total\ cost, Rs/h}{Pyrolizer\ capacity} \quad \text{--- (3.22)}$$

3.12.3 Standard Deviation (S.D.)

It is defined as the square root of the mean of the squares of the deviations taken from Arithmetic mean (Agarwal, 2013).

$$S.D. = \sqrt{\frac{\in x^2 - \frac{\in x^2}{n}}{n-1}} \quad \text{--- (3.23)}$$

Where,

σ = Standard deviation;

Σx = Sum of all observation;

n = Number of observations

x = Observation;

3.12.4 Coefficient of Variation (C.V.)

Coefficient of variation of a series of variable values is the ratio of the standard deviation to the mean multiplied by 100 (Agarwal *et al*., 2013).

$$\text{Coefficient of Variation (C.V.)} = \frac{\sigma}{x} \quad \text{--- (3.24)}$$

Where,

σ = Standard deviation;

$\bar{x}$ = Mean of set of values

CHAPTER-IV
RESULTS AND DISCUSSION

This chapter deals with the results and discussion of developed pyrolizer machine. In which machine are using different parameters like moisture content, ash content, volatile matter, fixed carbon, biochar nutrients analysis and ultimate analysis. During pyrolysis process we classified into four groups at different temperature (350^{0}C, 400^{0}C, 450^{0}C and 500^{0}C). The study was conducted at Swami Vivekanand College of Agricultural Engineering & Technology and Research Station, Raipur (C.G.).

4.1 Development of pyrolizer

The developed machine was designed and fabrication was done at the workshop of the Swami Vivekanand College of Agricultural Engineering & Technology and Research Station Raipur (C.G.). A laboratory scale small capacity (1kg) biomass pyrolizer system was developed for making the biochar from agriculture waste. The pyrolizer system mainly consist of a reactor, electrical heaters and insulation, temperature measurement and control device, hoper, stand etc.

4.2 Physical properties of biochar

The different size fractions of agriculture waste, rice husk, wheat straw, groundnut shells, sugarcane bagasse, wheat straw, was analyzed in terms of weight and length. Four samples of randomly selected 1kg of each sample was considered for the analysis. Each sample of raw material was weighed using a weighing balance. The bulk density of raw material was determined by weight of biomass placed in a container and divided by the space occupied

4.2.1 Particle size distribution of biochar

The particle size distribution of the biochar of different treatments was given in table 4.1 Sieve analysis is a simple technique and possibly the most common procedure in use for particle size distribution of material. It is used for determination of the relative proportion of different material sizes. (Asante *et al*., 2016). The highest particle size 0.85 mm was found in sieve no.3 and sieve no.2 (biochar made from sugarcane bagasse and wheat straw) and lowest 0.23 mm was found in sieve no. 4 (biochar made from wheat straw) respectively.

Table 4.1: Particle size distribution of biochar

Sample name	Sieve no.	Mesh no.	Particle size, (mm)
Rice husk	1	20	0.81
	2	25	0.71
	3	35	0.50
	4	40	0.42
Wheat straw	1	20	0.25
	2	25	0.83
	3	35	0.43
	4	40	0.23
Sugarcane bagasse	1	20	0.50
	2	25	0.60
	3	35	0.85
	4	40	0.42
Groundnut shell	1	20	0.68
	2	25	0.85
	3	35	0.50
	4	40	0.42

4.2.2 Bulk density

The bulk density of the biochar of different treatments and raw biomass was given in table 4.2 and shown in the fig. 4.1. The highest bulk density 1.92 gm/cm^3 was found in treatment T_4 (biochar made from groundnut shell) at 500^{0}C reactor temperature and lowest 1.47 gm/cm^3 was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^{0}C reactor temperature. In the case of biomass, highest (1.65gm/cm^3) and lowest (1.45 gm/cm^3) bulk density was observed in treatment T_4 (Groundnut shell) and in treatment T_3 (Sugarcane bagasse) respectively. From ANOVA it was observed that there is no significant differences in bulk density of biochar between all the treatments at 400^{0}C at 5% level of significance. But a significant difference was observed in bulk density of biochar made by agricultural residues at rest of the reactor temperatures.

Table 4.2: Bulk density of various treatments.

Treatments	Bulk density, gm/cm^3				
	Biochar at different temperature				Biomass
	350^{0}C	400^{0}C	450^{0}C	500^{0}C	
T_1: Rice husk	1.54	1.64	1.742	1.848	1.57
T_2: Wheat straw	1.488	1.602	1.624	1.768	1.54

T_3: Sugarcane bagasse	1.472	1.552	1.626	1.748	1.45
T_4: Groundnut shell	1.672	1.756	1.74	1.92	1.65
SE(m)±	0.015	0.084	0.014	0.014	0.013
CD at 5%	0.045	N/S	0.043	0.043	0.039
CV	2.164	11.468	1.898	1.728	1.725

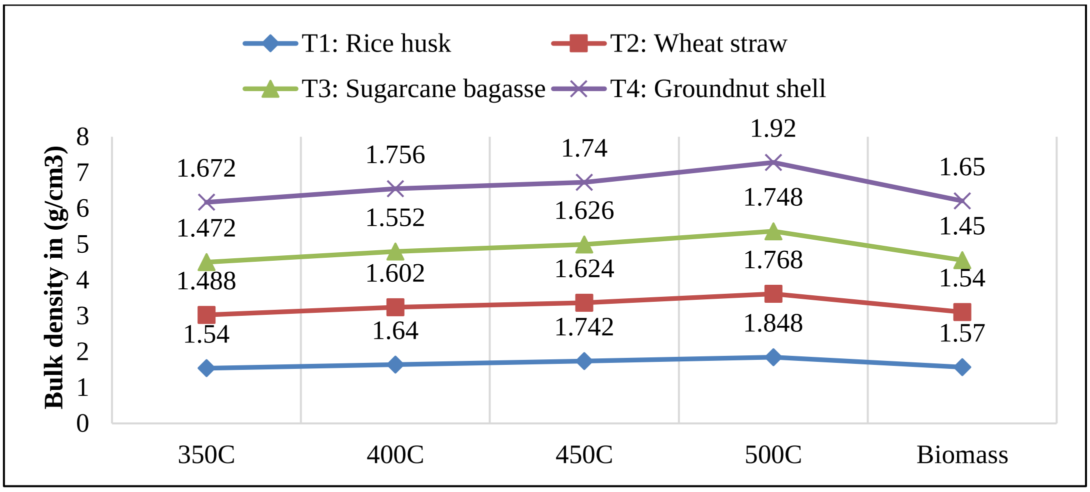

Fig. 4.1 Bulk density of biochar and biomass

4.3 Proximate analysis

The result on biochar and biomass parameters i.e., Moisture content, Volatile matter, Ash content, fixed carbon and bulk density are given in table and also shown in fig.

4.3.1 Moisture content

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

The average moisture content of the biochar of different treatments are given in the table 4.3 and shown in fig 4.2. The highest moisture content 11.43% was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^0C reactor temperature and lowest 5.24%was found in treatment T_2 (biochar made from wheat straw) at 500^0C reactor temperature. In case of biomass, highest (93.78%) and lowest (87.1%) moisture content was observed in treatment T_2 (Wheat straw) and in treatment T_1 (Rice husk) respectively. From ANOVA it was observed that there is a significant difference in moisture content of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.3: Moisture content of various treatments

Treatments	Moisture content, %				
	Biochar at different temperature				Biomass
	350^0C	400^0C	450^0C	500^0C	

T_1: Rice husk	9.25	7.152	6.148	4.832	87.1
T_2: Wheat straw	9.294	7.222	6.244	5.24	93.786
T_3: Sugarcane bagasse	11.431	9.384	8.744	7.568	92.258
T_4: Groundnut shell	10.252	8.89	7.842	6.782	92.416
SE(m)±	0.002	0.081	0.016	0.002	0.024
CD at 5%	0.007	0.246	0.048	0.006	0.072
CV	0.051	2.23	0.048	0.068	0.058

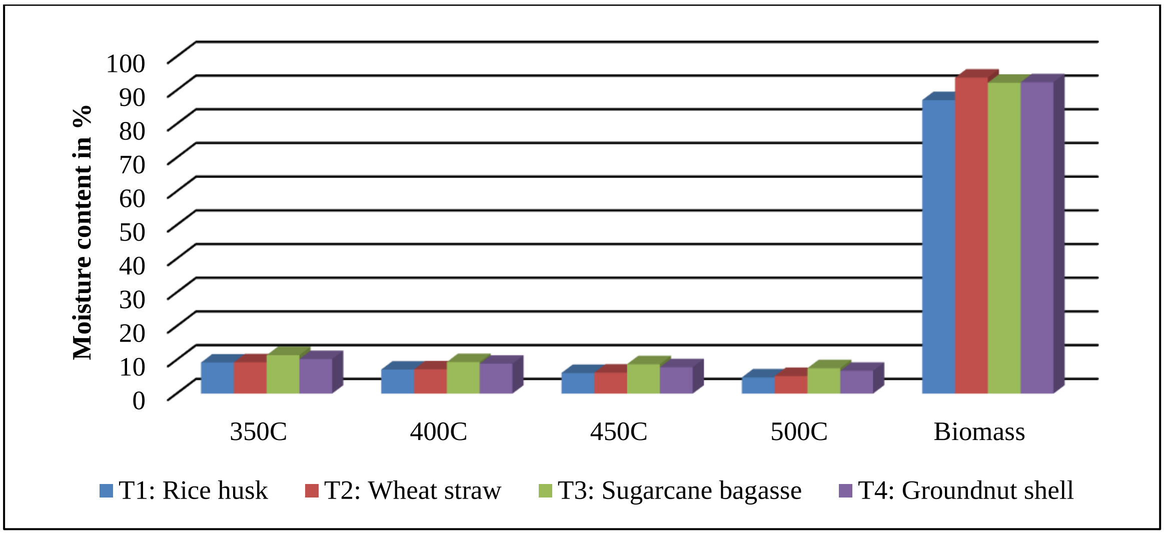

Fig. 4.2 Moisture content of biochar and biomass

4.3.2 Volatile matter

Volatile matter of various treatments was recorded after pyrolysis of agriculture waste and average values of volatile matter are given in table 4.4 and Fig 4.3. The highest volatile matter 78.29% was found in treatment T_2 (biochar made from wheat straw) at 500^0C reactor temperature and lowest 53.82% was found in treatment T_4 (biochar made from groundnut shell) at 350^0C reactor temperature. In case of biomass, highest (18.23%) and lowest (11.29%) volatile matter was observed in treatment T_1 (Rice husk) and in treatment T_4 (Groundnut shell) respectively. From ANOVA it was observed that there is significant differences in volatile matter of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.4 Volatile matter of biochar in various treatments.

Treatments	Volatile matter, %				
	Biochar at different temperature				Biomass
	350^0C	400^0C	450^0C	500^0C	
T_1: Rice husk	55.65	57.498	60.48	62.322	18.232
T_2: Wheat straw	67.214	69.72	73.264	78.298	14.706
T_3: Sugarcane bagasse	62.106	65.552	67.268	71.522	15.408
T_4: Groundnut shell	53.826	56.178	55.486	57.818	11.294
SE(m)±	0.125	0.015	0.023	0.026	0.037

CD at 5%	0.377	0.044	0.069	0.078	0.112
CV	0.468	0.052	0.08	0.086	0.555

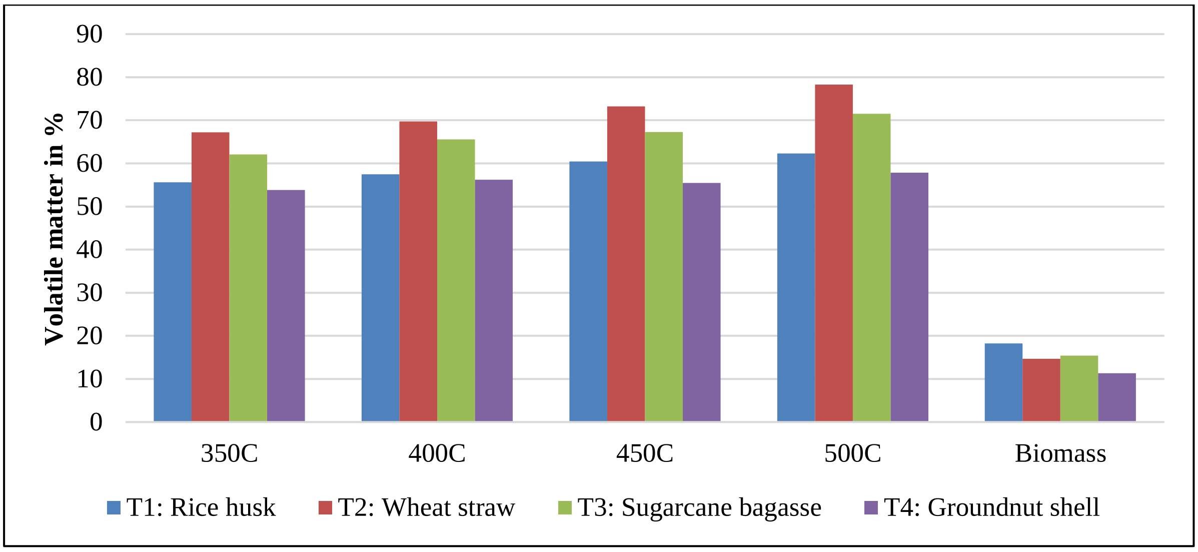

Fig. 4.3 Volatile matter of biochar and biomass

4.3.3 Ash content

Ash content of various treatments was recorded pyrolysis of agriculture waste and average Ash content is given in table4.5 and shown in fig 4.4. The highest ash content 28.47% was found in treatment T_1 (biochar made from rice husk) at 400^0C reactor temperature and lowest 10.61% was found in treatment T_2 (biochar made from wheat straw) at 450^0C reactor temperature. In case of biomass, highest (12.26%) and lowest (7.78%) ash content was observed in treatment T_2 (Wheat straw) and in treatment T_1 (Rice husk) respectively. From ANOVA it was observed that there is significant differences in ash content of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.5 Ash content of biochar in various treatments

Treatments	Ash content, %				
	Biochar at different temperature				Biomass
	350^0C	400^0C	450^0C	500^0C	
T_1: Rice husk	23.294	28.474	26.494	25.276	7.788
T_2: Wheat straw	11.516	14.848	10.616	12.52	12.268
T_3: Sugarcane bagasse	17.792	22.506	20.492	19.404	10.776
T_4: Groundnut shell	22.643	26.73	23.496	24.642	7.892
SE(m)±	0.008	0.066	0.025	0.023	0.018
CD at 5%	0.025	0.199	0.074	0.069	0.056
CV	0.099	0.635	0.271	0.25	0.426

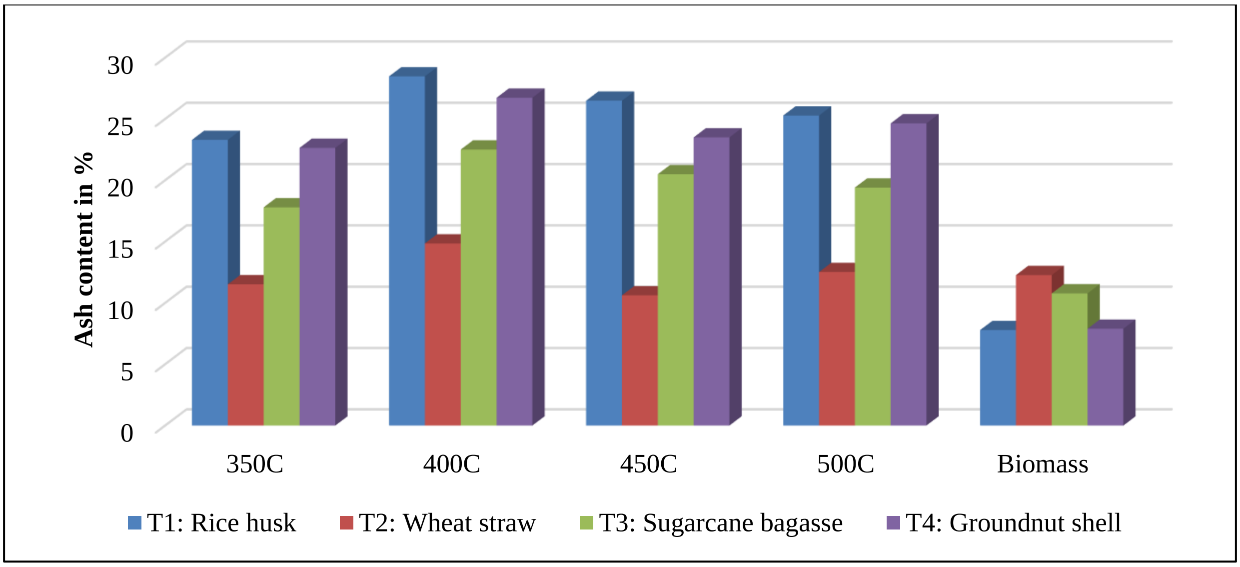

Fig. 4.4 Ash content of biochar and biomass

4.3.4 Fixed carbon

The fixed carbon of the biochar of different treatments was given in table 4.6 and shown in the fig. 4.5. The highest Fixed carbon 22.31% was found in treatment T_4 (biochar made from groundnut shell) at 400^0C reactor temperature and lowest 4.84% was found in treatment T_1 (biochar made from rice husk) at 350^0C reactor temperature. In case of biomass, highest (12.29%) and lowest (7.81%) fixed carbon was observed in treatment T_2 (Wheat straw) and in treatment T_1 (Rice husk) respectively. From ANOVA it was observed that there is significant differences in fixed carbon of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.6. Fixed carbon of various treatments

Treatments	Fixed carbon, %				
	Biochar at different temperature				Biomass
	350^0C	400^0C	450^0C	500^0C	
T_1: Rice husk	4.844	8.76	7.531	6.614	7.812
T_2: Wheat straw	6.758	10.77	9.429	8.678	12.292
T_3: Sugarcane bagasse	17.257	22.31	20.242	19.766	10.766
T_4: Groundnut shell	7.429	11.28	10.26	9.472	7.91
SE(m)±	0.001	0.034	0.002	0.018	0.021
CD at 5%	0.004	0.102	0.007	0.055	0.062
CV	0.03	0.565	0.041	0.368	0.476

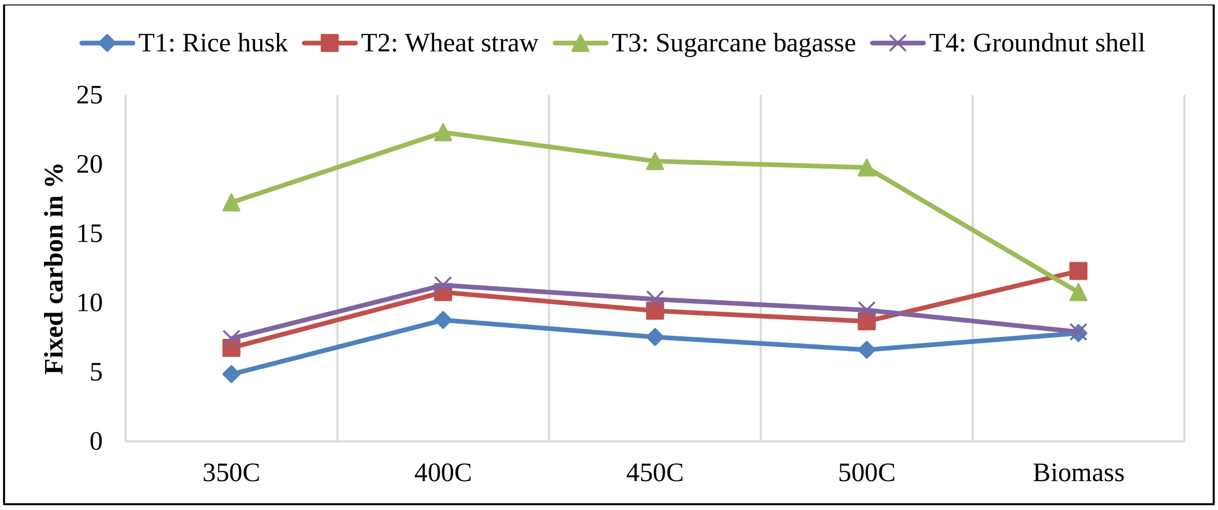

Fig. 4.5 Fixed carbon of biochar and biomass

4.4 Nutrient analysis

The nitrogen (N), phosphorus (P) and potassium (K) were measured after pyrolysis of different agricultural residues i.e. biochar and raw material i.e. biomass. The average values of different biochar and biomass nutrients were given in the table and show in fig.

4.4.1 Nitrogen content

The nitrogen content of the biochar of different treatments was given in table 4.7 and shown in the fig. 4.6. The highest nitrogen content 6.21% was found in treatment T_4 (biochar made from groundnut shell) at 500^0C reactor temperature and lowest 0.35% was found in treatment T_2 (biochar made from wheat straw) at 350^0C reactor temperature. In case of biomass, highest (1.78%) and lowest (1.416%) nitrogen content was observed in treatment T_4 (Groundnut shell) and in treatment T_2 (Wheat straw) respectively. From ANOVA it was observed that there is significant differences in nitrogen content of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.7 Nitrogen content in various treatments.

Treatments	Nitrogen content, %				
	Biochar at different temperature				Biomass
	350^0C	400^0C	450^0C	500^0C	
T_1: Rice husk	1.598	2.786	4.58	5.718	1.418
T_2: Wheat straw	0.352	0.587	0.687	0.99	1.416
T_3: Sugarcane bagasse	0.657	0.883	1.139	1.241	1.51
T_4: Groundnut shell	2.302	3.118	5.33	6.219	1.781
SE(m)±	0.013	0.015	0.009	0.011	0.01
CD at 5%	0.038	0.045	0.026	0.032	0.031
CV	2.312	1.822	0.659	0.669	1.482

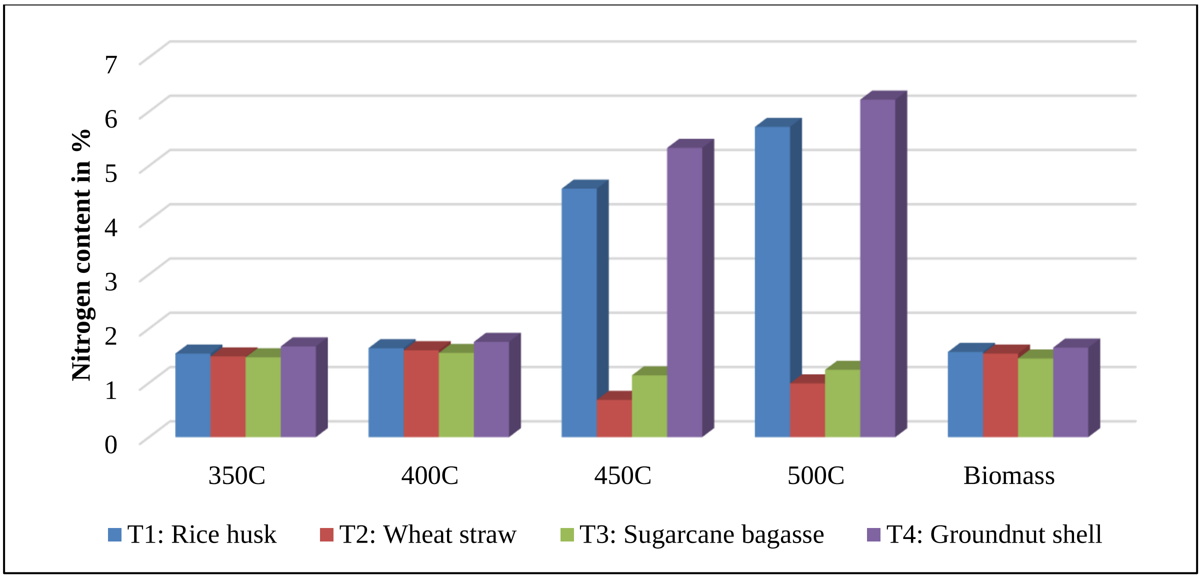

Fig. 4.6 Nitrogen content of biochar

4.4.2 Phosphorus content

The phosphorus content of the biochar of different treatments was given in table 4.8 and shown in the fig. 4.7. The highest phosphorus content 0.677% was found in treatment T_1 (biochar made from rice husk) at 500^0C reactor temperature and lowest 0.158% was found in treatment T_2 (biochar made from wheat straw) at 350^0C reactor temperature. In case of biomass, highest (0.304%) and lowest (0.216%) phosphorus content was observed in treatment T_1 (Rice husk) and in treatment T_2 (Wheat straw) respectively. From ANOVA it was observed that there is a significant difference in phosphorus content of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.8 Phosphorus content in various treatments.

Treatments	Phosphorus content, %				
	Biochar at different temperature				Biomass
	350^0C	400^0C	450^0C	500^0C	
T_1: Rice husk	0.189	0.28	0.49	0.677	0.304
T_2: Wheat straw	0.158	0.168	0.269	0.467	0.216
T_3: Sugarcane bagasse	0.187	0.19	0.292	0.479	0.266
T_4: Groundnut shell	0.234	0.259	0.461	0.541	0.284
SE(m)±	0.001	0.003	0.002	0.003	0.009
CD at 5%	0.004	0.009	0.005	0.009	0.027
CV	1.552	3.064	1.075	1.174	7.533

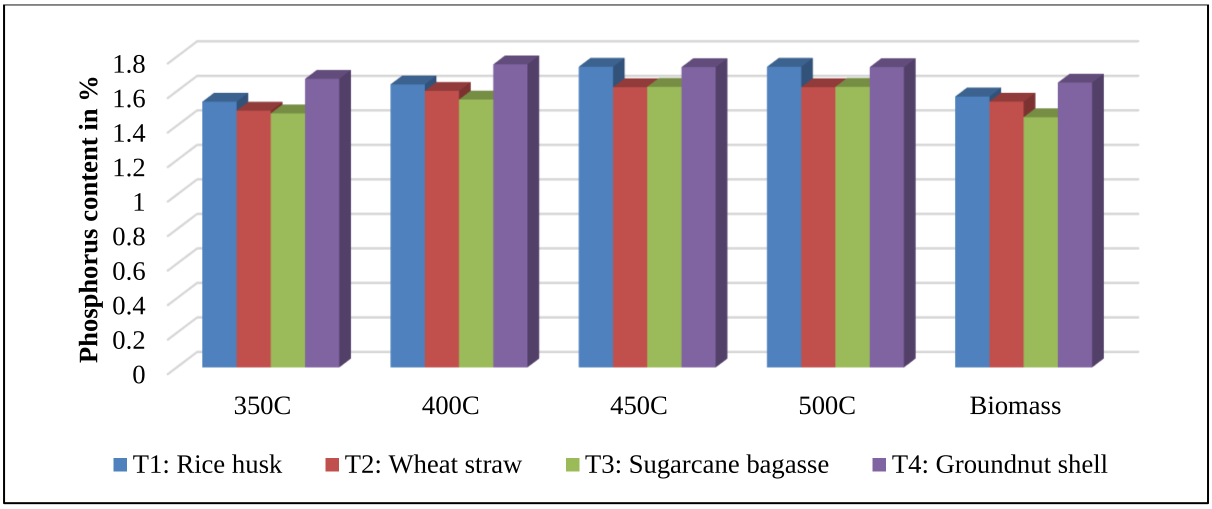

Fig. 4.7 Phosphorus content of biochar

4.4.3 Potassium content

The potassium content of the biochar of different treatments was given in table 4.9 and shown in the fig 4.8. The highest potassium content 0.483% was found in treatment T_4 (biochar made from groundnut shell) at 500^0C reactor temperature and lowest 0.169% was found in treatment T_1 (biochar made from rice husk) at 400^0C reactor temperature. In case of biomass, highest (0.355%) and lowest (0.186%) potassium content was observed in treatment T_1 (Rice husk) and in treatment T_3 (Sugarcane bagasse) respectively. From ANOVA it was observed that there is no significant differences in potassium content of biochar between all the treatments at 350^0C at 5% level of significance. But significant differences was observed in potassium content of biochar made by agricultural residues at rest of the reactor temperatures.

Table 4.9 Potassium content in various treatments.

Treatments	Potassium content, %				
	Biochar at different temperature				Biomass
	350^0C	400^0C	450^0C	500^0C	
T_1: Rice husk	0.218	0.169	0.199	0.239	0.355
T_2: Wheat straw	0.194	0.29	0.317	0.381	0.25
T_3: Sugarcane bagasse	0.261	0.342	0.347	0.429	0.186
T_4: Groundnut shell	0.272	0.378	0.391	0.483	0.32
SE(m)±	0.036	0.002	0.002	0.002	0.009
CD at 5%	N/S	0.007	0.007	0.005	0.028
CV	34.522	1.83	1.663	1.052	7.558

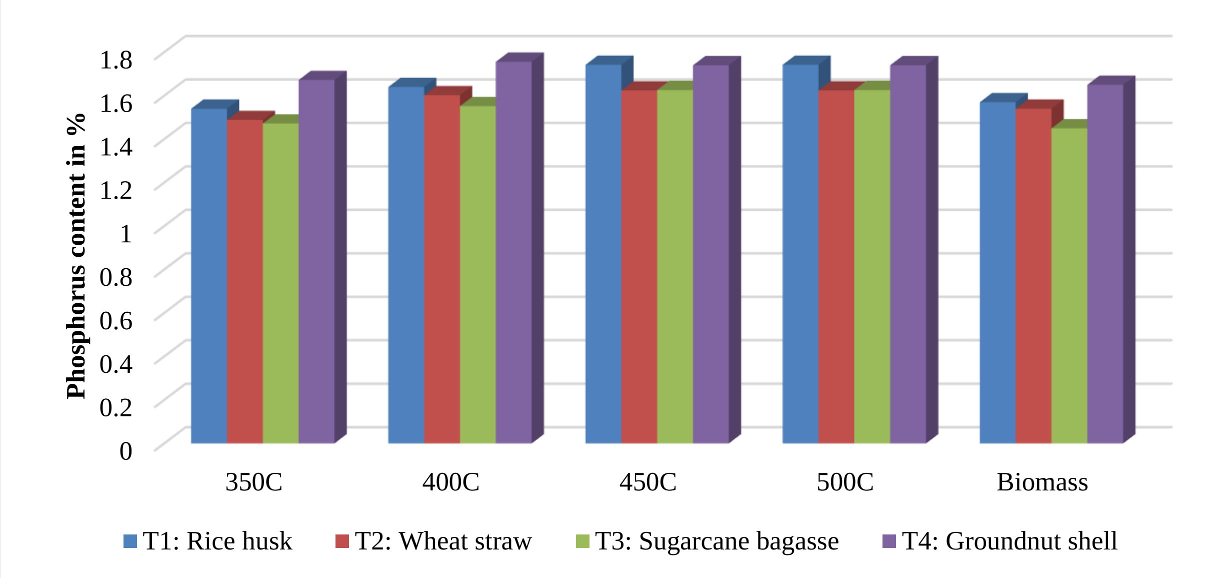

Fig. 4.8 Potassium content of biochar

4.5 Ultimate analysis

The ultimate analysis on biochar and biomass parameters i.e., Calorific value, Copper content, Iron content, pH, Electrical conductivity and Organic carbon.

4.5.1 Calorific value

The calorific value of the biochar of different treatments was given in table 4.10 and shown in the fig. 4.9. The highest calorific value 6130.01gm/cal was found in treatment T_4 (biochar made from groundnut shell) at 500^0C reactor temperature and lowest 2870.67gm/cal was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^0C reactor temperature. In case of biomass, highest (3292.21 gm/cal) and lowest (3168.32gm/cal) calorific value was observed in treatment T_4 (Groundnut shell) and in treatment T_1 (Rice husk) respectively. From ANOVA it was observed that there is significant differences in calorific value of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.10: Calorific value of various treatments.

Treatments	Calorific value, gm/cal				
	Biochar at different temperature				Biomass
	350^0C	400^0C	450^0C	500^0C	
T_1: Rice husk	4,142.79	4,239.95	4,337.50	4,431.92	3,168.32
T_2: Wheat straw	4,057.60	4,144.54	4,276.35	4,352.21	3,256.84
T_3: Sugarcane bagasse	2,870.67	3,738.28	3,724.85	3,929.92	3,243.42
T_4: Groundnut shell	5,628.40	5,875.83	5,972.91	6,130.01	3,292.21
SE(m)±	354.394	3.124	0.325	2.246	0.252
CD at 5%	1071.62	9.445	0.983	6.792	0.762
CV	18.981	0.155	0.016	0.107	0.017

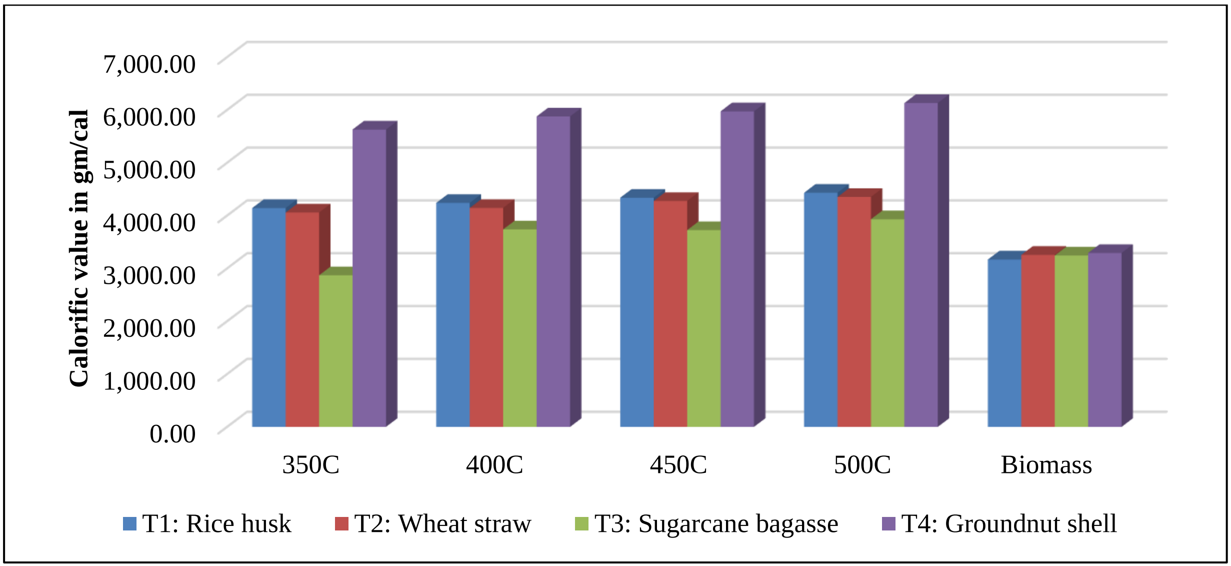

Fig. 4.9 Calorific value of biochar and biomass

4.5.2 Copper content

The copper content of the biochar of different treatments and raw biomass was given in table 4.11 and fig. 4.10. The highest copper content139.58 PPM was found in treatment T_1 (biochar made from rice husk) at 500^0C reactor temperature and lowest 46.86 PPM was found in treatment T_4 (biochar made from groundnut shell) at 350^0C reactor temperature. In case of biomass, highest (39.844 PPM) and lowest (19.236 PPM) copper content was observed in treatment T_3 (Sugarcane bagasse) and in treatment T_1 (Rice husk) respectively. From ANOVA it was observed that there is significant differences in copper content of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.11: Copper content of various treatments.

Treatments	Copper content, PPM				Biomass
	Biochar at different temperature				
	350^0C	400^0C	450^0C	500^0C	
T_1: Rice husk	136.484	137.564	138.464	139.58	19.236
T_2: Wheat straw	54.294	57.658	59.47	60.16	29.148
T_3: Sugarcane bagasse	62.414	63.862	65.4	66.402	39.844
T_4: Groundnut shell	46.86	48.758	47.906	50.69	38.544
SE(m)±	0.023	0.022	0.027	0.285	0.016
CD at 5%	0.07	0.066	0.08	0.863	0.048
CV	0.069	0.063	0.076	0.805	0.113

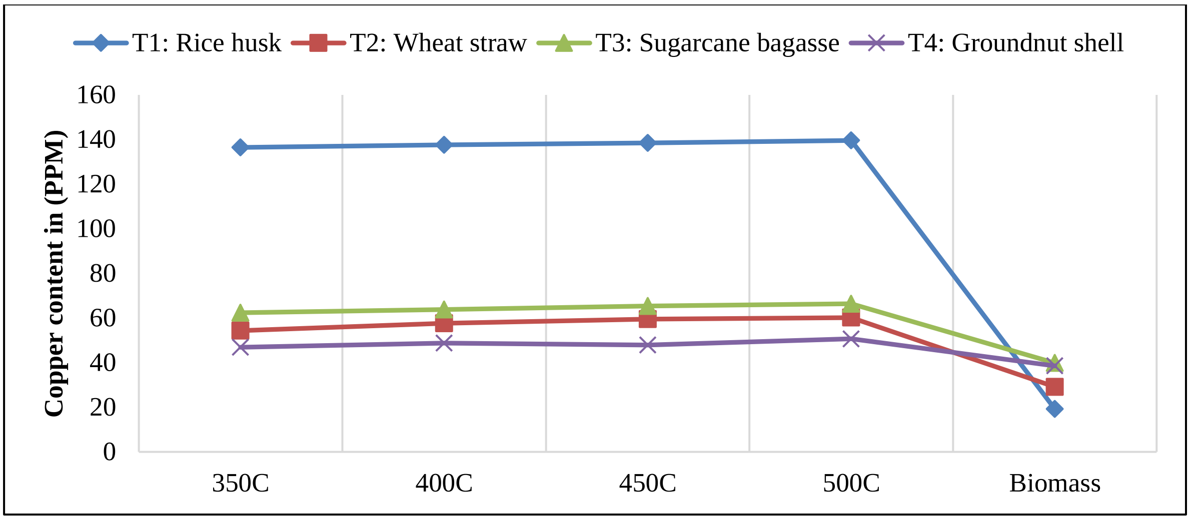

Fig. 4.10 Copper content of biochar and biomass

4.5.3 Iron content

The iron content of the biochar of different treatments and raw biomass was given in table 4.12 and shown in the fig. 4.11. The highest Iron content 4652.46 PPM was found in treatment T_3 (biochar made from sugarcane bagasse) at 500^0C reactor temperature and lowest 254.31 PPM was found in treatment T_1 (biochar made from rice husk) at 350^0C reactor temperature. In case of biomass, highest (877.086 PPM) and lowest (339.75 PPM) Iron content was observed in treatment T_3 (Sugarcane bagasse) and in treatment T_4 (Groundnut shell) respectively. From ANOVA it was observed that there is significant differences in Iron content of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.12 Iron content of various treatments

Treatments	Iron content, PPM				Biomass
	Biochar at different temperature				
	350^0C	400^0C	450^0C	500^0C	
T_1: Rice husk	254.31	260.938	262.452	264.298	702.35
T_2: Wheat straw	3752.52	3853.88	3860.46	3912.56	680.86
T_3: Sugarcane bagasse	4231.36	4134.12	4535.25	4652.46	877.086
T_4: Groundnut shell	426.784	429.26	431.542	490.474	339.75
SE(m)±	0.225	1.642	2.271	0.254	0.074
CD at 5%	0.679	4.964	6.867	0.769	0.222
CV	0.023	0.169	0.223	0.024	0.025

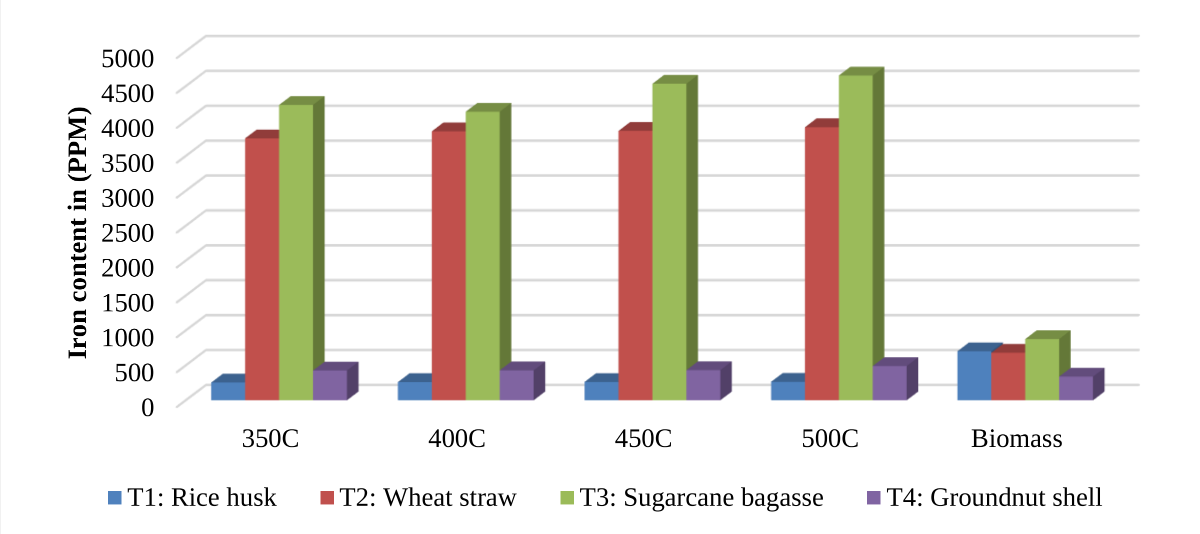

Fig. 4.11 Iron content of biochar and biomass

4.5.4 Manganese content

The manganese content of the biochar of different treatments and raw biomass was given in table 4.13 and shown in fig. 4.12. The highest manganese content 139.58 PPM was found in treatment T_1 (biochar made from Rice husk) at 500^0C reactor temperature and lowest 46.654 PPM was found in treatment T_4 (biochar made from Groundnut shell) at 350^0C reactor temperature. In case of biomass, highest (39.844 PPM) and lowest (19.236 PPM) manganese content was observed in treatment T_3 (Groundnut shell) and in treatment T_1 (Sugarcane bagasse) respectively. From ANOVA it was observed that there is significant differences in manganese content of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.13: Manganese content in various treatment**.**

Treatments	Manganese Content, PPM				Biomass
	Biochar at different temperature				
	350^0C	400^0C	450^0C	500^0C	
T_1: Rice husk	135.258	137.46	137.486	139.58	19.236
T_2: Wheat straw	55.478	57.624	58.758	60.16	29.148
T_3: Sugarcane bagasse	61.59	63.546	65.79	66.402	39.844
T_4: Groundnut shell	46.654	48.764	49.686	50.69	38.544
SE(m)±	0.023	0.018	0.025	0.285	0.016
CD at 5%	0.07	0.054	0.074	0.863	0.048
CV	0.069	0.052	0.07	0.805	0.113

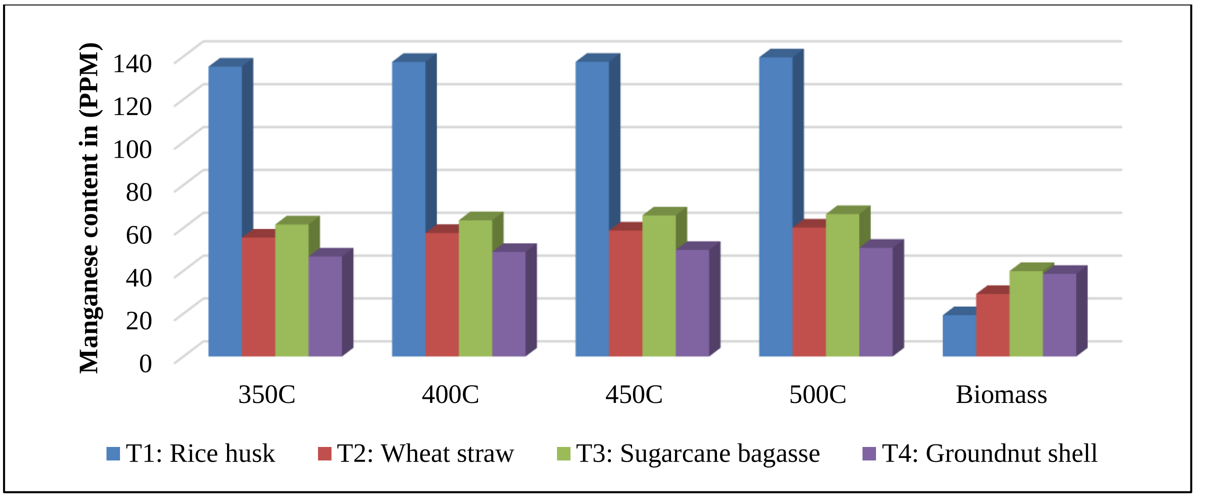

Fig. 4.12 Manganese content of biochar and biomass

4.5.5 pH content

The pH content of the biochar of different treatments was given in table 4.14 and shown in fig. 4.13. The highest pH content 7.28 was found in treatment T_4 (biochar made from groundnut shell) at 500^{0}C reactor temperature and lowest 5.7 was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^{0}C reactor temperature respectively. From ANOVA it was observed that there is a significant difference in pH content of biochar between all the treatments at 350^{0}C, 400^{0}C, 450^{0}C and 500^{0}C at 5% level of significance.

Table 4.14 pH of various treatments

Treatments	pH Content Biochar at different temperature			
	350^{0}C	400^{0}C	450^{0}C	500^{0}C
T_1: Rice husk	6.808	7.08	7.086	7
T_2: Wheat straw	6.074	6.04	6.466	6.54
T_3: Sugarcane bagasse	5.7	6	6.162	6.16
T_4: Groundnut shell	6.624	6.98	7.236	7.28
SE(m)±	0.042	0.175	0.017	0.202
CD at 5%	0.127	0.529	0.053	0.61
CV	1.489	5.995	0.58	6.684

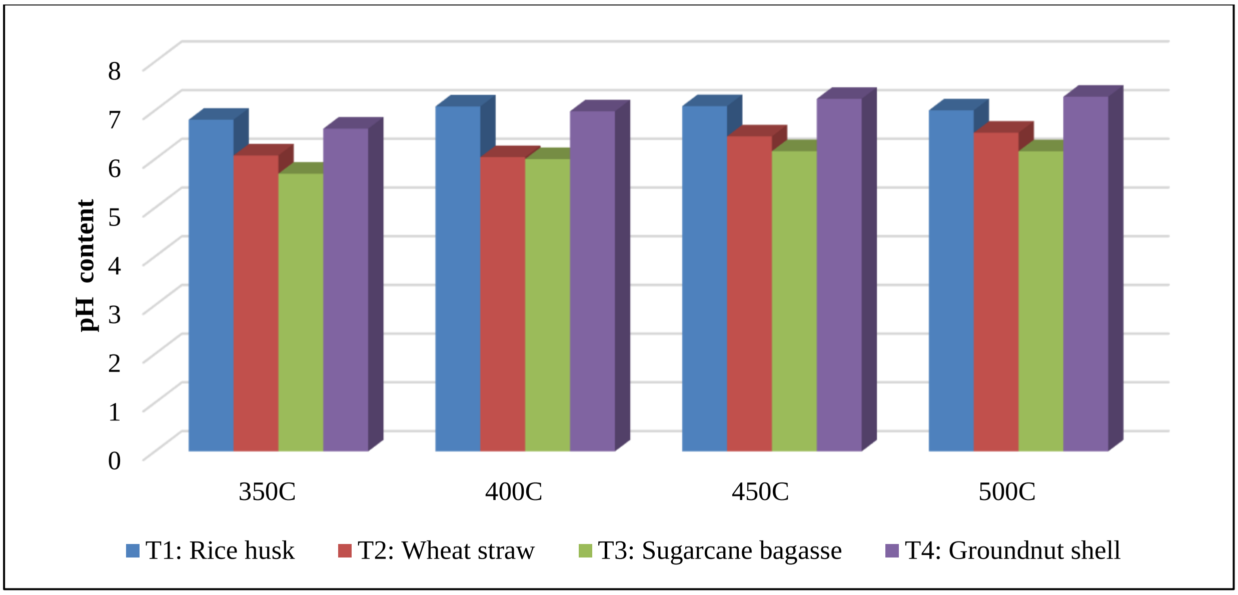

Fig. 4.13 pH content of biochar

4.6.6 Electrical conductivity

The electrical conductivity of the biochar of different treatments was given in table 4.15 and shown in fig. 4.14. The highest Electrical conductivity 5.15 m/s was found in treatment T_2 (biochar made from wheat straw) at 500^0C reactor temperature and lowest 0.289 m/s was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^0C reactor temperature respectively. From ANOVA it was observed that there is significant differences in Electrical conductivity of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.15: Electrical conductivity of various treatments

Treatments	Electrical conductivity, m/s			
	Biochar at different temperature			
	350^0C	400^0C	450^0C	500^0C
T_1: Rice husk	1.272	1.54	1.991	2.148
T_2: Wheat straw	3.916	4.36	5.122	5.15
T_3: Sugarcane bagasse	0.289	0.394	0.558	0.644
T_4: Groundnut shell	2.962	3.444	3.883	4.55
SE(m)±	0.011	0.132	0.01	0.017
CD at 5%	0.034	0.4	0.031	0.052
CV	1.201	12.163	0.786	1.235

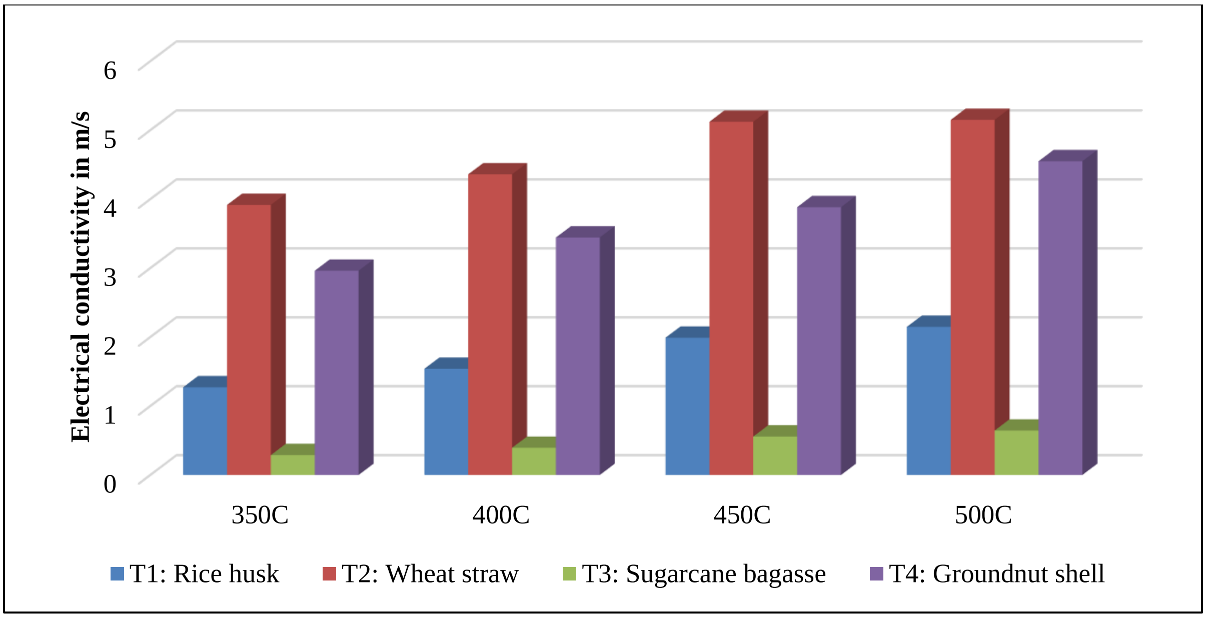

Fig. 4.14 Electrical conductivity of biochar

4.5.7 Organic carbon

The organic carbon of the biochar of different treatments was given in table 4.16 and shown in fig. 4.15. The highest organic carbon 9.25% was found in treatment T_4 (biochar made from groundnut shell) at 500^0C reactor temperature and lowest 1.23% was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^0C reactor temperature respectively. From ANOVA it was observed that there is significant difference in Organic carbon of biochar between all the treatments at 350^0C, 400^0C, 450^0C and 500^0C at 5% level of significance.

Table 4.16 Organic carbon of various treatments.

Treatments	Organic Carbon, %			
	Biochar at different temperature			
	350^0C	400^0C	450^0C	500^0C
T_1: Rice husk	5.672	6.682	7.64	8.668
T_2: Wheat straw	5.826	6.38	7.388	8.474
T_3: Sugarcane bagasse	1.234	2.168	2.446	3.24
T_4: Groundnut shell	6.67	7.664	8.468	9.25
SE(m)±	0.017	0.032	0.017	0.016
CD at 5%	0.052	0.097	0.052	0.048
CV	0.796	1.259	0.596	0.479

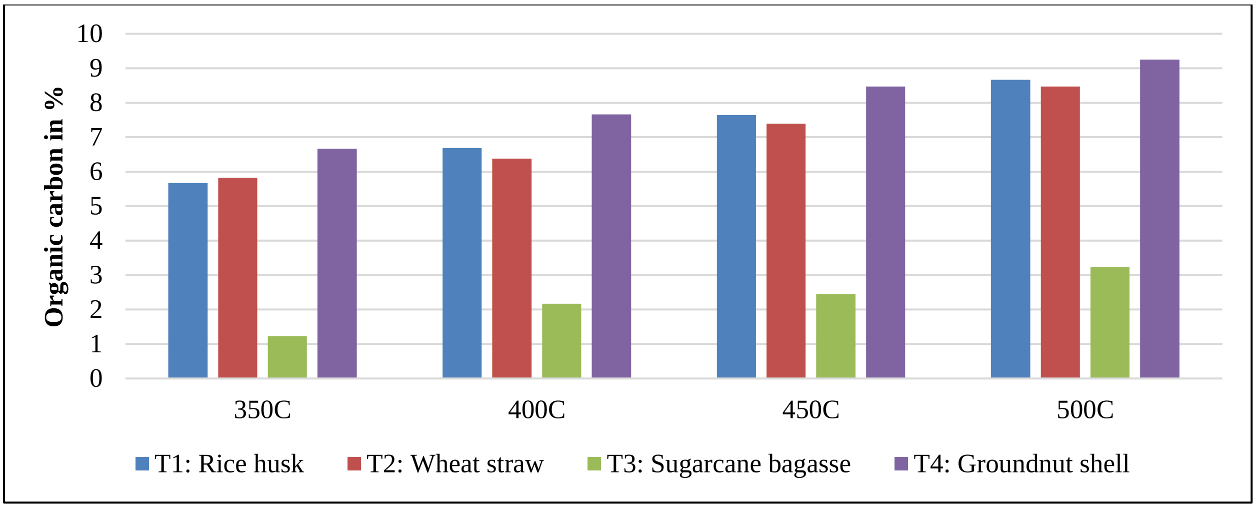

Fig. 4.15 Organic carbon of biochar

4.5.8 Performance of pyrolizer

A small-scale capacity of 1kg pyrolizer reactor was designed and fabrication to evaluate the performance and efficiency of the vertical pyrolizer technology to pyrolyze agriculture waste biomass.

4.5.8.1 Capacity of pyrolizer

The pyrolizer was able to produce biochar using of waste material. The yield of biochar made from different selected agricultural residues is given in table 4.17. However, the highest amount of biochar was found as 0.582 kg from treatment T_3 (Sugarcane bagasse) at 350^0C reactor temperature, while the lowest amount of 0.1234 kg biochar was obtained in treatment T_2 (Wheat straw) at 500^0C reactor temperature from 1 kg of sample. It was also observed that, as the temperature of reactor rises, the amount of biochar reduced in all the selected types of agricultural residues.

Table 4.17 Capacity of pyrolizer various treatments

Treatments	Input of biomass in (kg)	Time (min)	Biochar yield in (kg) at different temperature			
			350^0C	400^0C	450^0C	500^0C
T_1: Rice husk	1	90	0.4254	0.3143	0.2951	0.2124
T_2: Wheat straw	1	90	0.3752	0.2431	0.2089	0.1243
T_3: Sugarcane bagasse	1	90	0.5826	0.4765	0.4031	0.3889
T_4: Groundnut shell	1	90	0.4782	0.3432	0.2957	0.2321
Average			0.4653	0.3442	0.3007	0.2394

Average production of biochar was found an 0.3374 kg from 1 kg of biomass sample by developed pyrolizer.

4.5.9.2 Efficiency of pyrolizer

The developed pyrolizer unit was able to produce biochar using agriculture waste material efficiency. The efficiency of unit of pyrolizer production of biochar made from different selected agricultural residues is given in table 4.18. The highest efficiency of biochar was found as 0.58% from treatment T_3 (Sugarcane bagasse) at 350^0C reactor temperature, while the lowest efficiency of 0.12%was obtained in treatment T_2 (Wheat straw) at 500^0C reactor temperature from 1 kg of sample. It was also observed that as the temperature of reactor raises the amount of biochar reduced in all the types of agricultural residues.

Table 4.18 Efficiency of pyrolizer

Treatments	Input of biomass in (kg)	Time (min)	Efficiency of unit (%) at different temperature			
			350^0C	400^0C	450^0C	500^0C
T_1: Rice husk	1	90	0.42	0.31	0.29	0.21
T_2: Wheat straw	1	90	0.37	0.24	0.20	0.12
T_3: Sugarcane bagasse	1	90	0.58	0.47	0.40	0.38
T_4: Groundnut shell	1	90	0.47	0.34	0.29	0.23
Average			0.46	0.34	0.295	0.235

The average value of machine efficiency was found to be 0.33%.

4.6 Cost analysis

The operation cost was calculating in two-way fixed cost and operation cost. In operation cost include electricity charges, repair and maintenance.

4.6.1 Cost Estimation for development and operation

The pyrolizer machine was fabricated considering the economy in fabrication and locally available material was used for development. The material used for development is given in Appendix-E.

The unit cost of the prototype of pyrolizer machine was determined by taking the cost of different components. The quantity (mm) and rate (₹/h) of each of material was known for each component and the unit cost of each material (₹) was determined (Appendix-E). The estimated cost of the developed machine came out to be ₹5000/-.

The cost of operation included fuel charge and labour came out to be 30 ₹/h. The cost of operation of the machine is presented in Table 4.7 and Appendix-G. The annual use of the pyrolizer machine was taken only 300 h/year. The fixed cost of pyrolizer machine was 4.41 ₹/h and repair and maintenance cost was 1.66 ₹/h. The total variable cost was found 45 ₹/h.

Table 4.19: Calculation of cost of operation for developed machine per h

S. NO.	Particulars	Cost
1.	Cost of machine, ₹	5000
2.	Life machine year, y	5
3.	Annual use, h/year	300
4.	Annual deprecation, ₹ /h	3
5.	Annual interest @ 10% per annum, ₹/h	0.916
6.	Insurance 1%of the initial cost of machine	5
7.	Taxes 1% of the initial cost of machine	5
8.	Housing 1% of the initial cost of machine	5
Total	Fixed cost (₹/year) annual use 300* h	1924
A.	Fixed cost, (₹/h)	6.415
B.	Operational cost	
1.	Repair and maintenance cost of @ 10% of capital cost per annum, ₹/h	1.66
2.	Electricity charge₹/h	6.75
3.	Wages of operator (₹ 200/day) ₹/h	30(25)
C	Sum of operational cost, ₹/h	38.40
Total of (A+C)	Cost of operation, (₹/h)	45

CHAPTER-V

SUMMARY AND CONCLUSION

Biochar is charcoal produced from biomass to be used as a soil amendment it may be produced from biomass sources such as agriculture waste, wood and animal manure. The biomass used to produce biochar is termed the feedstock. It is produced through pyrolysis, which is the process of heating biomass at a high temperature in the absence of oxygen. Biochar is revelations high biodegradability and high organic carbon, as well as the optimal concentration of micro elements (potassium, magnesium, calcium, copper, zinc, iron). Hence, pyrolizer machine was developed and fabricated for biochar production from agriculture wastes with the following objectives.

Objectives

1. To develop a pyrolizer for biochar production from agriculture waste.
2. To study physiochemical properties of different agriculture waste biochar
3. To find out the cost estimation of biochar production

A laboratory hyppen small capacity (1kg) biomass pyrolyser system was developed for making the biochar from agriculture waste. In vertical pyrolysis unit the foremost part was the planning and fabrication of a fire –tube heater reactor for the project and thesis work. The pyrolyser system mainly consists of a reactor, electrical heaters and insulation, temperature measurement and control device, hoper, stand etc. The height of reactor was 690 mm and therefore diameter was 1100 mm. The reactor had one inner feeder cylinder, 900 mm in diameter. This feeder was covered by a flat plate with the assistance of nut-bolts. Furnace utilized in reactor was 870 mm long and therefore the length of the reactor shield 130 mm and internal diameter of the reactor shield 900 mm. The right firing of the burner can maintain the proper heating temperature as well as the required temperature for reactor operation. burners were designed in such a way so that they can burn by electric of the furnace. They covered the correct heating inside the furnace. Machine was designed to may be fulfill above the objective, strength, cost economics and functional requirement during operation. The material used was locally and easily available and fabricated in the workshop of SV CAET & RS and, FAE, I.G.K.V., Raipur (C.G.).

In the present research work, comparative performance of biomass and biochar was evaluated. We have taken Four different biomass samples such as (Rice husk), (Wheat straw), (Sugarcane bagasse), (Groundnut shell). In this study, four different agriculture residues like rice husk was used for biochar test. Pyrolysis of agriculture waste raw material was carried out with the help of developed biomass pyrolyser set up. The pyrolyser reactor was started for setting at the experimental temperature. The temperature of the reactor was set different temperature ranging from 350^0C, 400^0C, 450^0C and 500^0C and controlled with the help of PID temperature controller. During this period one kg raw material was weighed with the help of weight balance. The weighed raw material was feed in the reactor chamber through the hopper. After that the feed pipe was closed so as to provide the reactor chamber as air proof. Note down the starting time of the temperature controller and finally raised temperature experimental level than shut down the end of the experiment. After shut down the experiment, the reactor was cool down up to 2-3h to collect biochar. The biochar was collected from the bottom of the reactor chamber. Final product biochar quantity was measured.

Measurement of biochar parameters like proximate analysis, moisture content, Ash content, volatile matter, fixed carbon and bulk density and Ultimate analysis is also known as elemental analysis, it is the method to determine the Nitrogen phosphorus, potassium, Calorific value, copper content, Iron content, pH content, electrical conductivity and organic carbon. After testing the sample was gave in the Department of Soil science & Agriculture Chemistry, I.G.K.V. Raipur. Furth more the costs of operation of different operations were also evaluated for cost estimation.

Findings

Following results were obtained as per the objectives of the present study:

- The highest particle size 0.85 mm was found in sieve no.3 and sieve no.2 (biochar made from sugarcane bagasse and wheat straw) and lowest 0.23 mm was found in sieve no. 4 (biochar made from wheat straw) respectively.
- The highest bulk density 1.92 $gm/cm^3$was found in treatment T_4 (biochar made from groundnut shell) at 500^0C reactor temperature and lowest 1.47 gm/cm^3 was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^0C reactor temperature. In cases of biomass, highest (1.65 gm/cm^3) and lowest (1.45 gm/cm^3) bulk density was observed in treatment T_4 (Groundnut shell) and in treatment T_3 (Sugarcane bagasse) respectively.
- The highest moisture content 11.43% was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^0C reactor temperature and lowest 5.24% was found in treatment T_2 (biochar made from wheat straw) at 500^0C reactor temperature. In case

of biomass, highest (93.78%) and lowest (87.1%) moisture content was observed in treatment T_2 (Wheat straw) and in treatment T_1 (Rice husk) respectively

- The highest volatile matter 78.29% was found in treatment T_2 (biochar made from wheat straw) at 500^0C reactor temperature and lowest 53.82% was found in treatment T_4 (biochar made from groundnut shell) at 350^0C reactor temperature. In case of biomass, highest (18.23%) and lowest (11.29%) volatile matter was observed in treatment T_1 (Rice husk) and in treatment T_4 (Groundnut shell) respectively.
- The highest ash content 28.47% was found in treatment T_1 (biochar made from rice husk) at 400^0C reactor temperature and lowest 10.61% was found in treatment T_2 (biochar made from wheat straw) at 450^0C reactor temperature. In case of biomass, highest (12.26%) and lowest (7.78%) ash content was observed in treatment T_2 (Wheat straw) and in treatment T_1 (Rice husk) respectively
- The highest Fixed carbon 22.31% was found in treatment T_4 (biochar made from groundnut shell) at 400^0C reactor temperature and lowest 4.84% was found in treatment T_1 (biochar made from rice husk) at 350^0C reactor temperature. In case of biomass, highest (12.29%) and lowest (7.81%) fixed carbon was observed in treatment T_2 (Wheat straw) and in treatment T_1 (Rice husk) respectively.
- The highest nitrogen content 6.21% was found in treatment T_4 (biochar made from groundnut shell) at 500^0C reactor temperature and lowest 0.35% was found in treatment T_2 (biochar made from wheat straw) at 350^0C reactor temperature. In case of biomass, highest (1.78%) and lowest (1.416%) nitrogen content was observed in treatment T_4 (Groundnut shell) and in treatment T_2 (Wheat straw) respectively.
- The highest phosphorus content 0.677% was found in treatment T_1 (biochar made from rice husk) at 500^0C reactor temperature and lowest 0.158% was found in treatment T_2 (biochar made from wheat straw) at 350^0C reactor temperature. In case of biomass, highest (0.304%) and lowest (0.216%) phosphorus content was observed in treatment T_1 (Rice husk) and in treatment T_2 (Wheat straw) respectively
- The highest potassium content 0.483% was found in treatment T_4 (biochar made from groundnut shell) at 500^0C reactor temperature and lowest 0.169% was found in treatment T_1 (biochar made from rice husk) at 400^0C reactor temperature. In case of biomass, highest (0.355%) and lowest (0.186%) potassium content was observed in treatment T_1 (Rice husk) and in treatment T_3 (Sugarcane bagasse) respectively.
- The highest calorific value 6130.01gm/cal was found in treatment T_4 (biochar made from groundnut shell) at 500^0C reactor temperature and lowest 2870.67gm/cal was

found in treatment T_3 (biochar made from sugarcane bagasse) at 350^0C reactor temperature. In case of biomass, highest (3292.21gm/cal) and lowest (3168.32 gm/cal) calorific value was observed in treatment T_4 (Groundnut shell) and in treatment T_1 (Rice husk) respectively

- The highest copper content 139.58 PPM was found in treatment T_1 (biochar made from rice husk) at 500^0C reactor temperature and lowest 46.86 PPM was found in treatment T_4 (biochar made from groundnut shell) at 350^0C reactor temperature. In case of biomass, highest (39.844 PPM) and lowest (19.236 PPM) copper content was observed in treatment T_3 (Sugarcane bagasse) and in treatment T_1 (Rice husk) respectively
- The highest Iron content 4,652.46 PPM was found in treatment T_3 (biochar made from sugarcane bagasse) at 500^0C reactor temperature and lowest 254.31 PPM was found in treatment T_1 (biochar made from rice husk) at 350^0C reactor temperature. In case of biomass, highest (877.086 PPM) and lowest (339.75 PPM) Iron content was observed in treatment T_3 (Sugarcane bagasse) and in treatment T_4 (Groundnut shell) respectively.
- The highest manganese content 139.58 PPM was found in treatment T_1 (biochar made from Rice husk) at 500^0C reactor temperature and lowest 46.654 PPM was found in treatment T_4 (biochar made from Groundnut shell) at 350^0C reactor temperature. In case of biomass, highest (39.844 PPM) and lowest (19.236 PPM) manganese content was observed in treatment T_3 (Groundnut shell) and in treatment T_1 (Sugarcane bagasse) respectively.
- The highest pH content 7.28 was found in treatment T_4 (biochar made from groundnut shell) at 500^0C reactor temperature and lowest 5.7 was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^0C reactor temperature respectively
- The highest Electrical conductivity 5.15 m/s was found in treatment T_2 (biochar made from wheat straw) at 500^0C reactor temperature and lowest 0.289 m/s was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^0C reactor temperature respectively.
- The highest organic carbon 9.25% was found in treatment T_4 (biochar made from groundnut shell) at 500^0C reactor temperature and lowest 1.23% was found in treatment T_3 (biochar made from sugarcane bagasse) at 350^0C reactor temperature respectively.

- the highest amount of biochar was found as 0.582 kg from treatment T_3 (Sugarcane bagasse) at 350^0C reactor temperature, while the lowest amount of 0.1234 kg biochar was obtained in treatment T_2 (Wheat straw) at 500^0C reactor temperature from 1 kg of sample.
- The highest efficiency of biochar was found as 0.58% from treatment T_3 (Sugarcane bagasse) at 350^0C reactor temperature, while the lowest efficiency of 0.12% was obtained in treatment T_2 (Wheat straw) at 500^0C reactor temperature from 1 kg of sample.
- The total cost of operation for biochar production was calculated 45₹/h.

Conclusion

- Small scale pyrolizer for pyrolysis of agriculture waste was successfully developed and fabricated for 1kg capacity to produce biochar.
- Physico-chemical properties of agriculture residues and biochar was studied and found the fixed carbon was highest 22.31% in biochar made by sugarcane bagasse.
- Cost of making 1kg of biochar was estimated as Rs 45₹/h.

Suggestion for future work

1. The machine should be tested for other agriculture waste like chickpea shell, soyabean shell, stalks of different crops etc.
2. Condensation of the gas released from the pyrolyser can be used as a biofuel.
3. Solar system in place of electricity can be used for pyrolysis.

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APPENDICES

APPENDIX-A

Table A-1: Moisture content at 350^0C

Treatments	Moisture content at 350^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	9.243	9.247	9.249	9.253	9.257	87.1
Wheat straw	9.289	9.292	9.295	9.297	9.299	93.786
Sugarcane bagasse	11.425	11.429	11.432	11.434	11.437	92.258
Groundnut shell	10.245	10.248	10.252	10.256	10.258	92.416

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	15.801	5.267	2,03,080.57	0.007	0.051
Error	16	0	0			
Total	19	15.801				

Table A-2 Moisture content at 400^0C

Treatments	Moisture content at 400^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	7.11	7.19	7.15	7.21	7.10	87.1
Wheat straw	7.26	7.21	7.28	7.19	7.17	93.786
Sugarcane bagasse	9.90	9.60	9.11	9.13	9.18	92.258
Groundnut shell	8.88	8.82	8.89	9.00	8.86	92.416

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	19.635	6.545	197.565	0.246	2.23
Error	16	0.53	0.033			
Total	19	20.165				

Table A-3 Moisture content at 450^0C

Treatments	Moisture content at 450^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	6.1	6.13	6.15	6.17	6.19	87.1
Wheat straw	6.2	6.22	6.24	6.27	6.29	93.786
Sugarcane bagasse	8.7	8.72	8.74	8.77	8.79	92.258
Groundnut shell	7.8	7.82	7.84	7.86	7.89	92.416

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	24.044	8.015	6,308.32	0.048	0.048
Error	16	0.02	0.001			
Total	19	24.065				

Table A-4 Moisture content at 500^0C

Treatments	Moisture content at 500^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	4.825	4.829	4.832	4.835	4.837	87.1
Wheat straw	5.234	5.237	5.239	5.243	5.246	93.786
Sugarcane bagasse	7.562	7.566	7.569	7.571	7.574	92.258
Groundnut shell	6.776	6.779	6.781	6.784	6.788	92.416

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	24.847	8.282	4,75,735.39	0.006	0.068
Error	16	0	0			
Total	19	24.848				

Table A-5 biochar Analysis of unit

Treatments	Input of biomass in (kg)	Time (min)	Biochar yield in (kg) at different temperature			
			350^0C	400^0C	450^0C	500^0C
T_1: Rice husk	1	90	0.4254	0.3143	0.2951	0.2124
T_2: Wheat straw	1	90	0.3752	0.2431	0.2089	0.1243
T_3: Sugarcane bagasse	1	90	0.5826	0.4765	0.4031	0.3889
T_4: Groundnut shell	1	90	0.4782	0.3432	0.2957	0.2321
Average			0.4653	0.3442	0.3007	0.2394

Table A-6 biochar efficiency of unit

Treatments	Input of biomass in (kg)	Time (min)	Efficiency of unit (%) at different temperature			
			350^0C	400^0C	450^0C	500^0C
T_1: Rice husk	1	90	0.42	0.31	0.29	0.21
T_2: Wheat straw	1	90	0.37	0.24	0.20	0.12
T_3: Sugarcane bagasse	1	90	0.58	0.47	0.40	0.38
T_4: Groundnut shell	1	90	0.47	0.34	0.29	0.23
Average			0.46	0.34	0.295	0.235

Table A-7 Particle size distribution of biochar

Sample name	Sieve no.	Mesh no.	Particle size, (mm)
Rice husk	1	20	0.81
	2	25	0.71
	3	35	0.50
	4	40	0.42
Wheat straw	1	20	0.25
	2	25	0.83
	3	35	0.43
	4	40	0.23
Sugarcane bagasse	1	20	0.50

Sample name	Sieve no.	Mesh no.	Particle size, (mm)
	2	25	0.60
	3	35	0.85
	4	40	0.42
Groundnut shell	1	20	0.68
	2	25	0.85
	3	35	0.50
	4	40	0.42

APPENDIX-B

Table B-1: Volatile matter at 350^{0}C

Treatments	Volatile matter at 350^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	55.08	55.02	56.01	56.09	56.05	18.232
Wheat straw	67.23	67.21	67.18	67.29	67.16	14.706
Sugarcane bagasse	62.01	62.08	62.11	62.18	62.15	15.408
Groundnut shell	53.81	53.86	53.79	53.91	53.76	11.294

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD(5%)	CV
Treatment	3	565.766	188.589	2,420.48	0.377	0.468
Error	16	1.247	0.078			
Total	19	567.013				

Table B-2: Volatile matter at 400^{0}C

Treatments	Volatile matter at 400^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	57.42	57.47	57.49	57.53	57.58	18.232
Wheat straw	69.716	69.718	69.72	69.723	69.725	14.706
Sugarcane bagasse	65.548	65.549	65.552	65.554	65.558	15.408
Groundnut shell	56.173	56.176	56.178	56.181	56.183	11.294

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD(5%)	CV
Treatment	3	630.807	210.269	1,98,986.80	0.044	0.052
Error	16	0.017	0.001			
Total	19	630.824				

Table B-3: Volatile matter at 450^{0}C

Treatments	Volatile matter at 450^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	60.41	60.43	60.47	60.52	60.57	18.232
Wheat straw	73.21	73.24	73.26	73.29	73.32	14.706
Sugarcane bagasse	67.21	67.24	67.27	67.29	67.33	15.408
Groundnut shell	55.42	55.45	55.48	55.52	55.56	11.294

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	906.595	302.198	1,15,489.11	0.069	0.08
Error	16	0.042	0.003			
Total	19	906.637				

Table B-4: Volatile matter at 500^0C

Treatments	Volatile matter at 500^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	62.24	62.29	62.32	62.37	62.39	18.232
Wheat straw	78.24	78.27	78.29	78.33	78.36	14.706
Sugarcane bagasse	71.45	71.47	71.52	71.56	71.61	15.408
Groundnut shell	57.75	57.78	57.82	57.85	57.89	11.294

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	1,266.62	422.207	1,25,611.59	0.078	0.086
Error	16	0.054	0.003			
Total	19	1,266.67				

Table B-5: Ash content at 350^0C

Treatments	Ash content at 350^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	23.25	23.27	23.29	23.32	23.34	7.788
Wheat straw	11.512	11.514	11.516	11.519	11.521	12.268
Sugarcane bagasse	17.786	17.789	17.792	17.795	17.797	10.776
Groundnut shell	22.638	22.64	22.643	22.645	22.647	7.892

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	445.142	148.381	4,26,259.35	0.025	0.099
Error	16	0.006	0			
Total	19	445.148				

Table B-6: Ash content at 400^0C

Treatments	Ash content at 400^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	28.41	28.46	28.52	28.39	28.59	7.788
Wheat straw	14.69	15.21	14.83	14.79	14.72	12.268
Sugarcane bagasse	22.43	22.41	22.49	22.57	22.63	10.776
Groundnut shell	26.68	26.62	26.73	27.01	26.61	7.892

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	552.492	184.164	8,521.14	0.199	0.635
Error	16	0.346	0.022			
Total	19	552.838				

Table B-7: Ash content at 450^{0}C

Treatments	Ash content at 450^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	26.42	26.47	26.49	26.52	26.57	7.788
Wheat straw	10.56	10.58	10.62	10.65	10.67	12.268
Sugarcane bagasse	20.42	20.46	20.48	20.53	20.57	10.776
Groundnut shell	23.42	23.47	23.49	23.53	23.57	7.892

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	711.97	237.323	78,714.64	0.074	0.271
Error	16	0.048	0.003			
Total	19	712.018				

Table B-8: Ash content at 500^{0}C

Treatments	Ash content at 500^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	25.21	25.24	25.29	25.31	25.33	7.788
Wheat straw	12.46	12.49	12.52	12.54	12.59	12.268
Sugarcane bagasse	19.34	19.37	19.41	19.43	19.47	10.776
Groundnut shell	24.58	24.61	24.63	24.67	24.72	7.892

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	524.208	174.736	66,851.77	0.069	0.25
Error	16	0.042	0.003			
Total	19	524.25				

Table B-9: Fixed carbon at 350^{0}C

Treatments	Fixed carbon at 350^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	4.842	4.84	4.844	4.846	4.849	7.812
Wheat straw	6.754	6.756	6.757	6.759	6.762	12.292
Sugarcane bagasse	17.253	17.255	17.257	17.259	17.263	10.766
Groundnut shell	7.425	7.427	7.429	7.431	7.435	7.91

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	464.648	154.883	2,02,54,920.93	0.004	0.03
Error	16	0	0			
Total	19	464.648				

Table B-10: Fixed carbon at 400^{0}C

Treatments	Fixed carbon at 400^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	8.78	8.71	8.67	8.81	8.83	7.812
Wheat straw	10.75	10.71	10.83	10.87	10.69	12.292
Sugarcane bagasse	22.26	22.21	22.32	22.37	22.39	10.766
Groundnut shell	11.24	11.18	11.27	11.32	11.39	7.91

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	561.357	187.119	33,199.62	0.102	0.565
Error	16	0.09	0.006			
Total	19	561.447				

Table B-11: Fixed carbon at 450^{0}C

Treatments	Fixed carbon at 450^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	7.526	7.528	7.531	7.533	7.536	7.812
Wheat straw	9.425	9.427	9.429	9.431	9.435	12.292
Sugarcane bagasse	20.245	20.247	20.249	20.234	20.237	10.766
Groundnut shell	10.255	10.257	10.259	10.262	10.265	7.91

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	487.378	162.459	67,18,822.11	0.007	0.041
Error	16	0	0			
Total	19	487.378				

Table B-12: Fixed carbon at 500^{0}C

Treatments	Fixed carbon at 500^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	6.58	6.57	6.62	6.64	6.66	7.812
Wheat straw	8.62	8.65	8.68	8.71	8.73	12.292
Sugarcane bagasse	19.72	19.74	19.78	19.77	19.82	10.766
Groundnut shell	9.42	9.45	9.47	9.49	9.53	7.91

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	518.68	172.893	1,03,188.54	0.055	0.368
Error	16	0.027	0.002			
Total	19	518.706				

Table B-13: Bulk density at 350^0C

Treatments	Bulk density at 350^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	1.5	1.52	1.54	1.56	1.58	1.57
Wheat straw	1.45	1.47	1.48	1.51	1.53	1.54
Sugarcane bagasse	1.43	1.45	1.47	1.49	1.52	1.45
Groundnut shell	1.63	1.65	1.67	1.69	1.72	1.65

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.124	0.041	36.94	0.045	2.164
Error	16	0.018	0.001			
Total	19	0.141				

Table B-14: Bulk density at 400^0C

Treatments	Bulk density at 400^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	1.6	1.2	1.9	1.4	2.1	1.57
Wheat straw	1.59	1.51	1.61	1.67	1.63	1.54
Sugarcane bagasse	1.58	1.52	1.63	1.54	1.49	1.45
Groundnut shell	1.75	1.71	1.78	1.73	1.81	1.65

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.113	0.038	1.069	N/S	11.468
Error	16	0.564	0.035			
Total	19	0.677				

Table B-15: Bulk density at 450^0C

Treatments	Bulk density at 450^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	1.7	1.72	1.74	1.76	1.79	1.57
Wheat straw	1.63	1.61	1.58	1.64	1.66	1.54
Sugarcane bagasse	1.61	1.62	1.59	1.64	1.67	1.45
Groundnut shell	1.78	1.72	1.74	1.7	1.76	1.65

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.067	0.022	21.992	0.043	1.898
Error	16	0.016	0.001			
Total	19	0.084				

Table B-16: Bulk density at 500^{0}C

Treatments	Bulk density at 500^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	1.8	1.83	1.85	1.87	1.89	1.57
Wheat straw	1.73	1.75	1.77	1.79	1.8	1.54
Sugarcane bagasse	1.71	1.73	1.75	1.76	1.79	1.45
Groundnut shell	1.88	1.9	1.92	1.94	1.96	1.65

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.093	0.031	31.44	0.043	1.728
Error	16	0.016	0.001			
Total	19	0.109				

APPENDIX-C

Table C-1: Nitrogen content at 350^0C

Treatments	Nitrogen content at 350^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	1.56	1.58	1.59	1.62	1.64	1.418
Wheat straw	0.348	0.35	0.352	0.354	0.357	1.416
Sugarcane bagasse	0.652	0.654	0.657	0.659	0.663	1.51
Groundnut shell	2.25	2.27	2.29	2.34	2.36	1.781

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	11.917	3.972	4,932.38	0.038	2.312
Error	16	0.013	0.001			
Total	19	11.93				

Table C-2: Nitrogen content at 400^0C

Treatments	Nitrogen content at 400^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	2.76	2.79	2.83	2.86	2.69	1.418
Wheat straw	0.598	0.586	0.581	0.579	0.589	1.416
Sugarcane bagasse	0.878	0.871	0.889	0.893	0.886	1.51
Groundnut shell	3.115	3.118	3.123	3.127	3.109	1.781

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	25.076	8.359	7,409.23	0.045	1.822
Error	16	0.018	0.001			
Total	19	25.094				

Table C-3: Nitrogen content at 450^0C

Treatments	Nitrogen content at 350^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	4.53	4.56	4.58	4.6	4.63	1.418
Wheat straw	0.682	0.685	0.687	0.689	0.694	1.416
Sugarcane bagasse	1.135	1.137	1.139	1.141	1.143	1.51
Groundnut shell	5.325	5.327	5.329	5.332	5.335	1.781

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	83.587	27.862	74,534.59	0.026	0.659
Error	16	0.006	0			
Total	19	83.593				

Table C-4: Nitrogen content at 500^0C

Treatments	Nitrogen content at 500^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	5.67	5.68	5.71	5.75	5.78	1.418
Wheat straw	0.985	0.987	0.989	0.993	0.995	1.416
Sugarcane bagasse	1.234	1.237	1.242	1.246	1.248	1.51
Groundnut shell	6.213	6.216	6.219	6.223	6.225	1.781

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	118.544	39.515	70,438.57	0.032	0.669
Error	16	0.009	0.001			
Total	19	118.553				

Table C-5: Phosphorus content at 350^0C

Treatments	Phosphorus content at 350^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	0.185	0.187	0.189	0.191	0.193	0.304
Wheat straw	0.154	0.156	0.158	0.159	0.161	0.216
Sugarcane bagasse	0.183	0.185	0.187	0.189	0.191	0.266
Groundnut shell	0.232	0.234	0.236	0.238	0.231	0.284

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.015	0.005	563	0.004	1.552
Error	16	0	0			
Total	19	0.015				

Table C-6: Phosphorus content at 400^0C

Treatments	Phosphorus content at 400^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	0.276	0.279	0.283	0.271	0.289	0.304
Wheat straw	0.163	0.159	0.167	0.173	0.179	0.216
Sugarcane bagasse	0.196	0.191	0.187	0.183	0.194	0.266
Groundnut shell	0.254	0.251	0.259	0.263	0.269	0.284

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.043	0.014	303.021	0.009	3.064
Error	16	0.001	0			
Total	19	0.044				

Table C-7: Phosphorus content at 450^{0}C

Treatments	Phosphorus content at 450^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	0.485	0.487	0.489	0.492	0.495	0.304
Wheat straw	0.264	0.267	0.269	0.271	0.274	0.216
Sugarcane bagasse	0.287	0.289	0.292	0.295	0.297	0.266
Groundnut shell	0.456	0.458	0.46	0.463	0.467	0.284

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.193	0.064	3,899.47	0.005	1.075
Error	16	0	0			
Total	19	0.193				

Table C-8: Phosphorus content at 500^{0}C

Treatments	Phosphorus content at 500^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	0.672	0.674	0.678	0.68	0.683	0.304
Wheat straw	0.462	0.464	0.467	0.469	0.472	0.216
Sugarcane bagasse	0.475	0.476	0.479	0.482	0.485	0.266
Groundnut shell	0.542	0.544	0.547	0.549	0.523	0.284

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.14	0.047	1,153.11	0.009	1.174
Error	16	0.001	0			
Total	19	0.14				

Table C-9: Potassium content at 350^{0}C

Treatments	Potassium content at 350^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	0.142	0.144	0.147	0.149	0.51	0.355
Wheat straw	0.189	0.192	0.194	0.197	0.199	0.25
Sugarcane bagasse	0.256	0.258	0.261	0.263	0.268	0.186
Groundnut shell	0.267	0.269	0.272	0.274	0.276	0.32

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.02	0.007	0.991	N/S	34.522
Error	16	0.107	0.007			
Total	19	0.126				

Table C-10: Potassium content at 400^0C

Treatments	Potassium content at 400^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	0.168	0.163	0.167	0.172	0.174	0.355
Wheat straw	0.294	0.297	0.289	0.281	0.291	0.25
Sugarcane bagasse	0.347	0.341	0.349	0.338	0.336	0.186
Groundnut shell	0.378	0.372	0.375	0.381	0.386	0.32

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.126	0.042	1,438.22	0.007	1.83
Error	16	0	0			
Total	19	0.126				

Table C-11: Potassium content at 450^0C

Treatments	Potassium content at 450^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	0.192	0.194	0.197	0.199	0.212	0.355
Wheat straw	0.312	0.315	0.317	0.319	0.324	0.25
Sugarcane bagasse	0.342	0.345	0.347	0.349	0.352	0.186
Groundnut shell	0.386	0.389	0.391	0.393	0.395	0.32

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.101	0.034	1,243.06	0.007	1.663
Error	16	0	0			
Total	19	0.102				

Table C-12: Potassium content at 500^0C

Treatments	Potassium content at 500^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	0.234	0.237	0.239	0.241	0.245	0.355
Wheat straw	0.376	0.378	0.381	0.383	0.385	0.25
Sugarcane bagasse	0.423	0.427	0.429	0.432	0.435	0.186
Groundnut shell	0.478	0.48	0.483	0.485	0.487	0.32

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	0.164	0.055	3,361.90	0.005	1.052
Error	16	0	0			
Total	19	0.164				

APPENDIX-D

Table D-1: Calorific value at 350^{0}C

Treatments	Calorific value at 350^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	4142.74	4142.76	4142.79	4142.82	4142.86	3,168.32
Wheat straw	4057.53	4057.56	4057.59	4057.63	4057.67	3,256.84
Sugarcane bagasse	3579.42	3579.45	3579.47	3579.49	35.52	3,243.42
Groundnut shell	5628.34	5628.36	5628.39	5628.42	5628.47	3,292.21

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	1,91,42,338.94	63,80,779.65	10.161	1,071.62	18.981
Error	16	1,00,47,594.12	6,27,974.63			
Total	19	2,91,89,933.07				

Table D-2: Calorific value at 400^{0}C

Treatments	Calorific value at 400^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	4237.82	4241.87	4233.12	4247.78	4239.18	3,168.32
Wheat straw	4145.74	4139.71	4149.62	4135.19	4152.43	3,256.84
Sugarcane bagasse	3732.47	3741.12	3739.18	3735.27	3743.34	3,243.42
Groundnut shell	5889.2	5872.12	5863.19	5878.41	5876.24	3,292.21

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	1,33,35,624.51	44,45,208.17	91,120.11	9.445	0.155
Error	16	780.545	48.784			
Total	19	1,33,36,405.05				

Table D-3: Calorific value at 450^{0}C

Treatments	Calorific value at 450^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	4337.45	4337.47	4337.49	4337.52	4337.56	3,168.32
Wheat straw	4276.28	4276.32	4276.37	4276.39	4276.41	3,256.84
Sugarcane bagasse	3724.79	3724.81	3724.85	3724.89	3724.91	3,243.42
Groundnut shell	5972.85	5972.87	5972.92	5972.95	5972.97	3,292.21

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	1,41,12,381.17	47,04,127.06	89,05,450.58	0.983	0.016
Error	16	8.452	0.528			
Total	19	1,41,12,389.62				

Table D-4: Calorific value at 500^{0}C

Treatments	Calorific value at 500^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	4428.42	4429.86	4431.42	4433.62	4436.28	3,168.32
Wheat straw	4345.62	4348.23	4351.43	4356.42	4359.36	3,256.84
Sugarcane bagasse	3923.52	3927.12	3929.78	3932.46	3936.71	3,243.42
Groundnut shell	6123.43	6126.23	6129.42	6133.48	6137.51	3,292.21

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	1,41,51,579.05	47,17,193.02	1,86,987.57	6.792	0.107
Error	16	403.637	25.227			
Total	19	1,41,51,982.69				

Table D-5: Copper content at 350^{0}C

Treatments	Copper content at 350^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	136.42	136.44	136.48	136.52	136.56	19.236
Wheat straw	54.23	54.27	54.29	54.32	54.36	29.148
Sugarcane bagasse	62.34	62.38	62.42	62.46	62.47	39.844
Groundnut shell	46.8	46.83	46.85	46.89	46.93	38.544

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	25,796.44	8,598.81	31,79,488.11	0.07	0.069
Error	16	0.043	0.003			
Total	19	25,796.48				

Table D-6: Copper content at 400^{0}C

Treatments	Copper content at 400^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	137.5	137.53	137.57	137.59	137.63	19.236
Wheat straw	57.6	57.63	57.65	57.69	57.72	29.148
Sugarcane bagasse	63.8	63.83	63.86	63.89	63.93	39.844
Groundnut shell	48.7	48.73	48.75	48.79	48.82	38.544

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	25,061.62	8,353.87	35,52,556.25	0.066	0.063
Error	16	0.038	0.002			
Total	19	25,061.66				

Table D-7: Copper content at 450^{0}C

Treatments	Copper content at 450^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	138.42	138.42	138.46	138.49	138.53	19.236
Wheat straw	59.42	59.44	59.47	59.49	59.53	29.148
Sugarcane bagasse	65.32	65.36	65.39	65.45	65.48	39.844
Groundnut shell	47.85	47.87	47.92	47.94	47.95	38.544

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	25,317.63	8,439.21	23,82,679.09	0.08	0.076
Error	16	0.057	0.004			
Total	19	25,317.69				

Table D-8: Copper content at 500^{0}C

Treatments	Copper content at 500^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	139.3	141.2	138.4	139.8	139.2	19.236
Wheat straw	60.7	60.2	60.5	59.8	59.6	29.148
Sugarcane bagasse	66.1	66.7	66.3	67.01	65.9	39.844
Groundnut shell	50.8	50.2	50.4	51.01	51.04	38.544

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	24,924.35	8,308.12	20,415.83	0.863	0.805
Error	16	6.511	0.407			
Total	19	24,930.86				

Table D-9: Iron content at 350^{0}C

Treatments	Iron content at 350^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	254.24	254.27	254.31	254.36	254.37	702.35
Wheat straw	3752.42	3752.49	3752.52	3752.56	3752.59	680.86
Sugarcane bagasse	4231.27	4231.32	4231.36	4231.39	4231.44	877.086
Groundnut shell	426.71	426.75	426.79	426.82	426.85	339.75

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	6,73,10,781.71	2,24,36,927.24	8,89,06,228.59	0.679	0.023
Error	16	4.038	0.252			
Total	19	6,73,10,785.75				

Table D-10: Iron content at 400^0C

Treatments	Iron content at 400^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	260.9	260.5	261.01	261.08	261.2	702.35
Wheat straw	3853.7	3853.1	3853.9	3851.9	3856.8	680.86
Sugarcane bagasse	4131.4	4139.2	4136.8	4133.4	4129.8	877.086
Groundnut shell	429.4	426.2	421.7	432.4	436.6	339.75

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	6,68,39,550.52	2,22,79,850.18	16,53,345.18	4.964	0.169
Error	16	215.61	13.476			
Total	19	6,68,39,766.13				

Table D-11: Iron content at 450^0C

Treatments	Iron content at 450^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	262.4	262.43	262.45	262.47	262.51	702.35
Wheat straw	3865.6	3845.63	3855.65	3866.69	3868.72	680.86
Sugarcane bagasse	4531.2	4533.22	4535.24	4537.28	4539.32	877.086
Groundnut shell	431.5	431.52	431.54	431.56	431.59	339.75

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	7,53,55,390.64	2,51,18,463.55	9,74,137.95	6.867	0.223
Error	16	412.565	25.785			
Total	19	7,53,55,803.20				

Table D-12: Iron content at 500^0C

Treatments	Iron content at 500^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	264.23	264.27	264.29	264.32	264.38	702.35
Wheat straw	3912.5	3912.53	3912.56	3912.59	3912.62	680.86
Sugarcane bagasse	4652.4	4652.42	4652.46	4652.49	4652.53	877.086
Groundnut shell	490.4	490.42	490.48	490.51	490.56	339.75

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	7,77,46,459.07	2,59,15,486.36	8,00,85,048.61	0.769	0.024
Error	16	5.178	0.324			
Total	19	7,77,46,464.25				

Table D-13: Manganese content at 350^{0}C

Treatments	Manganese content at 350^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	135.2	135.23	135.25	135.29	135.32	19.236
Wheat straw	55.42	55.44	55.47	55.49	55.57	29.148
Sugarcane bagasse	61.52	61.56	61.59	61.63	61.65	39.844
Groundnut shell	46.6	46.63	46.65	46.67	46.72	38.544

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	24,975.99	8,325.33	31,10,772.41	0.07	0.069
Error	16	0.043	0.003			
Total	19	24,976.03				

Table D-14: Manganese content at 400^{0}C

Treatments	Manganese content at 400^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	137.40	137.42	137.46	137.49	137.53	19.236
Wheat straw	57.56	57.59	57.62	57.66	57.69	29.148
Sugarcane bagasse	63.5	63.52	63.55	63.57	63.59	39.844
Groundnut shell	48.7	48.73	48.77	48.79	48.83	38.544

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	25,045.17	8,348.39	53,26,494.59	0.054	0.052
Error	16	0.025	0.002			
Total	19	25,045.20				

Table D-15: Manganese content at 450^{0}C

Treatments	Manganese content at 450^{0}C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	137.42	137.44	137.49	137.52	137.56	19.236
Wheat straw	58.7	58.72	58.76	58.79	58.82	29.148
Sugarcane bagasse	65.72	65.76	65.79	65.82	65.86	39.844
Groundnut shell	49.62	49.65	49.68	49.72	49.76	38.544

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	24,297.93	8,099.31	26,85,415.11	0.074	0.07
Error	16	0.048	0.003			
Total	19	24,297.98				

Table D-16: Manganese content at 500^0C

Treatments	Manganese content at 500^0C					Biomass
	R_1	R_2	R_3	R_4	R_5	
Rice husk	139.3	141.2	138.4	139.8	139.2	19.236
Wheat straw	60.7	60.2	60.5	59.8	59.6	29.148
Sugarcane bagasse	66.1	66.7	66.3	67.01	65.9	39.844
Groundnut shell	50.8	50.2	50.4	51.01	51.04	38.544

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	24,924.35	8,308.12	20,415.83	0.863	0.805
Error	16	6.511	0.407			
Total	19	24,930.86				

Table D-17: pH content at 350^0C

Treatments	pH content at 350^0C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	6.86	6.87	6.89	6.7	6.72
Wheat straw	6.04	6.06	6.08	6.09	6.1
Sugarcane bagasse	5.98	5.6	5.62	5.64	5.66
Groundnut shell	6.58	6.6	6.62	6.64	6.68

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	3.87	1.29	146.515	0.127	1.489
Error	16	0.141	0.009			
Total	19	4.011				

Table D-18: pH content at 400^0C

Treatments	pH content at 400^0C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	6.8	7	7.3	6.5	7.8
Wheat straw	6.2	6.3	5.8	5.5	6.4
Sugarcane bagasse	5.8	6.4	5.5	6.2	6.1
Groundnut shell	7	6.5	6.9	7.2	7.3

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	5.129	1.71	11.175	0.529	5.995

Error	16	2.448	0.153			
Total	19	7.578				

Table D-19: pH content at 450^{0}C

Treatments	pH content at 450^{0}C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	7.04	7.06	7.08	7.11	7.14
Wheat straw	6.42	6.44	6.47	6.48	6.52
Sugarcane bagasse	6.11	6.14	6.16	6.18	6.22
Groundnut shell	7.19	7.21	7.24	7.26	7.28

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	3.874	1.291	844.84	0.053	0.58
Error	16	0.024	0.002			
Total	19	3.899				

Table D-20: pH content at 500^{0}C

Treatments	pH content at 500^{0}C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	6.6	6.8	7.3	6.5	7.8
Wheat straw	6.5	6.2	6.4	6.3	7.3
Sugarcane bagasse	5.6	5.8	6.2	6.4	6.8
Groundnut shell	7.2	7.3	7.5	6.8	7.6

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	3.677	1.226	6.031	0.61	6.684
Error	16	3.252	0.203			
Total	19	6.929				

Table D-21: Electrical conductivity at 350^{0}C

Treatments	Electrical conductivity at 350^{0}C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	1.23	1.25	1.27	1.29	1.32
Wheat straw	3.87	3.89	3.92	3.94	3.96
Sugarcane bagasse	0.287	0.286	0.289	0.291	0.293
Groundnut shell	2.957	2.959	2.962	2.964	2.966

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	40.022	13.341	20,784.25	0.034	1.201

Error	16	0.01	0.001			
Total	19	40.032				

Table D-22: Electrical conductivity at 400^{0}C

Treatments	Electrical conductivity at 400^{0}C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	1.2	1.4	1.7	1.5	1.9
Wheat straw	4.1	4.3	4.6	4.9	3.9
Sugarcane bagasse	0.34	0.31	0.46	0.39	0.47
Groundnut shell	3.5	3.6	3.9	3.1	3.12

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	48.452	16.151	184.206	0.4	12.163
Error	16	1.403	0.088			
Total	19	49.855				

Table D-23: Electrical conductivity at 450^{0}C

Treatments	Electrical conductivity at 450^{0}C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	1.987	1.989	1.991	1.994	1.996
Wheat straw	5.08	5.1	5.12	5.14	5.17
Sugarcane bagasse	0.52	0.54	0.56	0.58	0.59
Groundnut shell	3.879	3.882	3.884	3.885	3.887

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	61.072	20.357	39,510.88	0.031	0.786
Error	16	0.008	0.001			
Total	19	61.08				

Table D-24: Electrical conductivity at 500^{0}C

Treatments	Electrical conductivity at 500^{0}C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	2.1	2.13	2.15	2.17	2.19
Wheat straw	5.1	5.13	5.16	5.17	5.19
Sugarcane bagasse	0.59	0.63	0.64	0.67	0.69
Groundnut shell	4.5	4.52	4.54	4.58	4.61

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	66.206	22.069	14,834.74	0.052	1.235

Error	16	0.024	0.001			
Total	19	66.229				

Table D-25: Organic carbon at 350^{0}C

Treatments	Organic carbon at 350^{0}C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	5.63	5.65	5.67	5.69	5.72
Wheat straw	5.78	5.8	5.83	5.85	5.87
Sugarcane bagasse	1.18	1.21	1.24	1.26	1.28
Groundnut shell	6.62	6.64	6.67	6.69	6.73

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	90.081	30.027	20,125.83	0.052	0.796
Error	16	0.024	0.001			
Total	19	90.105				

Table D-26: Organic carbon at 400^{0}C

Treatments	Organic carbon at 400^{0}C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	6.54	6.76	6.58	6.81	6.72
Wheat straw	6.36	6.31	6.39	6.43	6.41
Sugarcane bagasse	2.1	2.16	2.14	2.23	2.21
Groundnut shell	7.68	7.61	7.73	7.63	7.67

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	88.784	29.595	5,699.30	0.097	1.259
Error	16	0.083	0.005			
Total	19	88.867				

Table D-27: Organic carbon at 450^{0}C

Treatments	Organic carbon at 450^{0}C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	7.58	7.62	7.64	7.67	7.69
Wheat straw	7.34	7.37	7.39	7.41	7.43
Sugarcane bagasse	2.4	2.42	2.45	2.47	2.49
Groundnut shell	8.42	8.44	8.47	8.49	8.52

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	111.976	37.325	25,010.36	0.052	0.596
Error	16	0.024	0.001			

Total	19	112				

Table D-28: Organic carbon at 500^0C

Treatments	Organic carbon at 500^0C				
	R_1	R_2	R_3	R_4	R_5
Rice husk	8.62	8.64	8.67	8.69	8.72
Wheat straw	8.43	8.45	8.47	8.49	8.53
Sugarcane bagasse	3.2	3.22	3.24	3.26	3.28
Groundnut shell	9.21	9.23	9.25	9.27	9.29

Source of Variation	DF	Sum of Squares	Mean Squares	F-Cal	CD (5%)	CV
Treatment	3	117.446	39.149	31,090.65	0.048	0.479
Error	16	0.02	0.001			
Total	19	117.466				

APPENDIX-E

1) Calculation of operational cost of developed pyrolizer machine.

The cost of operation for developed **pyrolizer** machine was calculated by following procedure. The operating cost includes fixed and variable cost.

1) Fabrication cost

Weight of pyrolizer with all components

N = 10.476kg

a) Material cost

Material cost was taken as @ 40 ₹/kg.

Cost of Material = Total weight x 40 ₹.

= 10.476 x 40

= 420₹.

b) Machine charges

It was taken ₹.@150/day

= 3 x 150

= 450 ₹.

c) Workshop expenditure

It was taken @₹. 150/day

= 3 x 150

= 450 ₹.

d) Electrical components

Temperature controller

= 2500 ₹.

Thermocouple

= 600

Solid state relay

= 580₹.

Total fabrication and component cost = a + b + c + d

= 5000₹.

2) Analysis of economics of use

To do the analysis, the following assumption were made

a) Expected life of the machine 5 years

b) Annual use of machine 300 days per year

Total annual used = 300 h/year (300 days × 1 man x 1 hours)

Unit cost (prototype) = 5000₹

c) Scrap value of the pyrolizer machine 10 percent of initial cost

d) Overhead cost

A. Fixed cost

a) Depreciation (₹/h) = $\frac{C-S}{L \times H}$

Where,

C = Unit cost

S = Salvage value 10 % of unit cost

L = Life of equipment in year

H = Working hours per year

$$D = \frac{5000-500}{5 \times 300} = 3\text{₹/h} \ (900\text{₹/year})$$

b) Interest per hour $I = \frac{C+S}{2} \times \frac{i}{H}$

@ 10 percent on average cost

Where,

$\frac{C+S}{2}$ = Average investment

i = Interest rate 10%

$$I = \frac{5000+500}{2} \times \frac{0.1}{300} = 0.916 \text{ ₹/h} \ (274.8\text{₹/year})$$

c) Housing = $\frac{5000 \times 5}{100 \times 300}$ = 0.833₹/h (250₹/year)

d) Tax = 0.833₹/h (250₹/year)

e) Insurance = 0.833 ₹/h (250₹/year)

Total overhead cost, ₹ = 900 + 274.8 + 250 + 250 + 250 = 1925₹/year

Hence, total fixed cost (overhead) per hour

$$= \frac{1925}{300} = 6.41₹/h$$

B. Operating Cost

(a) Cost of repair and maintenance per hour i.e., charged

@ 10 % of original cost

$$= \frac{5000 \times 10}{100 \times 300} = 1.66₹/h \ (500₹/year)$$

(b) Electricity charge

Electric heater power = 1500kW

Electricity charge per unit = 3₹

Electricity cost = 1.5 × 4.5 = 6.75 ₹/h

(c) Wage of 1 labour

Number of working hours per day = 1 h

300/day per labour = 300/day = 30 ₹/h

Operating cost = 1.66 + 6.75 + 30 = 38.40 ₹/h

1) Total cost = fixed cost + operating cost

= 6.41+ 38.40 = 44.81 ₹/h ≈ 45 ₹/h

2) Total Cost ₹ per kg =

$$\frac{\text{total cost, ₹/h}}{\text{Pyrolizer capacity, kg/h}}$$

= 45 ₹/kg

RESUME

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B.TECH.	Agricultural Engineering	IGKV, Raipur	2018	6.17

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