Conversion of Cud and Paper Waste to Biochar Using Slow Pyrolysis Process and Effects of Parameters

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Research Article

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Conversion of Cud and Paper Waste to Biochar Using Slow Pyrolysis Process and Effects of Parameters

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Abstract

In this study, a series of laboratory experiments were conducted to investigate the effects of slow pyrolysis parameters of temperature, air mass flow rate, heating rate, and residence time on cud and waste paper char yields. Cud and waste paper were heated with a slow pyrolysis temperature (167^0C) to produce the biochar. The degree of decomposition depends on the feedstock used and process conditions. As the results revealed that the biochar yield, depends mainly on the applied controlled temperature and airflow rate. During the experiment, the primary airflow rate makes the process more slowly pyrolysis. Both primary and secondary air inlet opening at the same time provides high temperature and less biochar yield. The experiment was conducted under a slow pyrolysis temperature of 167^0C, moisture 15%, and air mass flow rate of (0.35 - 1.5kg/s). At this temperature; 30kg of feedstock, cup, and paper in the reactor produces 10kg- 23kg and 10-20kg respectively of biochar yield at the same airflow rate of 0.35m/s. Temperature gradient appears and tends to increase as the airflow rate increases within the limited values. But the biochar yield reduces as the pyrolysis temperature and airflow rate increase.

Keywords: Char production, the effect of airflow rate on char yield, the effect of heating rate on char yield

1. Introduction

Organic residual wastes found in a slaughterhouse or meat industry is the Couse of groundwater pollution. The Converting of the waste to char for soil fertilizer application is an indirect method to control pollution. A slow pyrolysis process is a method to produce a char that recovers and sustains the soil's nutrients [1]. Pyrolysis is one of the most effective and efficient processes to get energy in the form of char [2]. It is a thermochemical process in which biomass is thermally degraded in its chemical constituents under an inert or very low stoichiometry oxygen atmosphere. It is the conventional type of pyrolysis which is characterized by a slow heating rate and long residence time [3]. In the slow Pyrolysis process, a limited or low-temperature thermal conversion process was embroiled to convert waste into char [4]. To minimize the high-temperature impact on the product, the pyrolysis process was carried out under the temperatures of 350^0C. Usually, biomass decomposed under an oxygen-limited process [5, 6] The degree of biomass decomposition depends on the feedstock used and process temperature [7, 8]. In the slow pyrolysis process, biomass moisture removes, and the cellulose and lignin are broken down from long to short carbon structures[9]. The thermal bonds are cracked (lysis) under the action of heat (pyro) [10] and carbonaceous material biochar is a typical product during the process [11-13]. Validation of biochar as a beneficial soil amendment and carbon sink in the world would give economic value to the pyrolysis process and more adoption of waste utilization[14]. Depending on the operating conditions used, Pyrolysis processes are classified as fast pyrolysis and slow pyrolysis [15]. The term "slow pyrolysis" is arbitrarily used with no particular definition with reference tied to the holding period or the rate of heating [16]. The slow pyrolysis condition typically employs heating rates of ($1 \leq 350°C/min$) in the absence of oxygen, and long char residence times (hours to days) [17]. However, the pyrolysis parameters: air flow rate, temperature, humidity, and pressure can be varied to change the relative quantities and quality of the resulting products [17, 18]. Biochar can be produced from different waste materials [19]. In this study, it was produced from waste animal cud and paper. The carbon-rich biochar can be used in varying applications such as carbon sequestration, soil conditioning, and filtration of pollutants from aqueous and gas media [20]. The pyrolysis process was affected by temperature, moisture content, particle size, and biomass physical properties [21]. The pyrolysis condition was determined the production of char yields, and the properties it has [22]. Specifically, heating rate and temperature were the most influential pyrolysis parameters affecting the amount of char product [21, 23] Authors have well estimated the main factors influencing the production of biochar from animal cud and waste paper as feedstock composition, process temperature, heating rate, and holding time. The main objective of this research is to develop a reactor and to investigate the effects of slow pyrolysis reactor parameters such as airflow rate, temperature, particle size, heating rate, and flue gas circulation on the yield of biochar. Widespread work has been performed to evaluate the pyrolysis conditions to find the appropriate biochar yield.

2. Materials and methods

2.1 Feedstock Preparation

Before heating the biomass, the material was prepared in the form of a briquette and dried at low moisture content. The two different feedstocks, animal cud, and waste paper are used for biochar production. Both are available potential and accessible resources in Ethiopia that could be unfocused to use an input for biochar production. The waste paper was obtained from the University and other sector offices, and animal cud found in the slaughterhouses as well as in the field was used. The cud was first collected from the slaughterhouse located in central Gondar ($12^0$44'59.99" N, 37° 00' 0.00" E), Ethiopia, which was naturally sun-dried below moisture of 15%. The waste paper was first collected in the office in the form of a sheet and prepared in the form of a mold briquette using water and drying it with the same procedure of cud. Figure 1 (a) shows the molded form of paper and Figure. 1 (b) was drying of cud biomass. The spread out and removal of moisture content depends on the humidity, temperature, and pressure of the environment and accumulated techniques. With the higher humidity at night, the feedstock forms precipitation and gains moisture. To avoid this, the first moisture removing or drying biomass keeps in the store. The prepared biomass was manually loaded into the reactor. The rate of loading depends on the availability, expected weather conditions, and the pyrolysis process.

Figure 1 (a) mold preparation form of paper (b) dried form of animal cud

To prepare a paper in the form of briquette mold improves the carbon and heat-storing and water holding capacity of the char. As char Kruger studied, biochar production via pyrolysis still provides a large C sequestration potential and heating value even after emissions from process energy are subtracted, which represents a counterbalance of about 2.93MT CO2 per MT biochar applied to the soil. (MT = metric, ton = 1000kg or 2200lb), and can substitute for agricultural lime by raising soil PH. This can make biochar profitable when trading prices per metric ton of CO_2 $16.44 for smaller mobile and $3.39 for transportable facilities [24].

2.2 Pyrolysis System Design

To carry out the pyrolysis experiment, a high-temperature core of the pyrolysis process, a reactor, was necessary to fabricate. In the reactor, 30kg of feedstock below a moisture content of 15% can be pyrolyzed and converted into char per run at the temperature of 167^0C. The pyrolysis system shown in (Figure 2) consists of an internal pipe that was extended up to the bottom of a reactor and has secondary air inlets. The dense accumulated cud biomass requires a secondary air mass flow rate to produce the char. The air from an environment flows through the inlet with a mass flow rate of air 0.35kg/s to the reactor. The produced biochar was physically a black carbon material from the decomposition of biomass organic matter in a low- or zero-oxygen environment (pyrolysis) useful for soil amendment, heat generation, and other benefits [25, 26]. The amount of biochar produced and its characteristics were determined by process temperature. The reactor was heated to a slow pyrolysis temperature below 167^0C to produce the char. This slow pyrolysis temperature range was kept by controlling the secondary and primary airflow rate through the inlets.

The amount of biochar produced depends on the airflow rate and temperature in the reactor. The pyrolysis process was evaluated interims of temperature, feedstock particle size, airflow rate, and heating rate in the system. Transferring heat through biomass in the reactor assists the roasting of biomass and the conversion process. Small heating rates at the beginning of the pyrolysis process ensured that the pyrolyzing biomass removes moisture, less air flow rate into the reactor and the temperature was maintained below a slow pyrolysis temperature. Increasing the airflow rate in the process also increases the temperature at which the biochar is produced. More air-flow rate results in high pyrolysis temperature and biochar was exposed with high temperature and produces less amount of biochar yield. This temperature in the reactor is regulated by controlling the air flow rate through the inlet. Because of high temperature, completely change the biochar into ash.

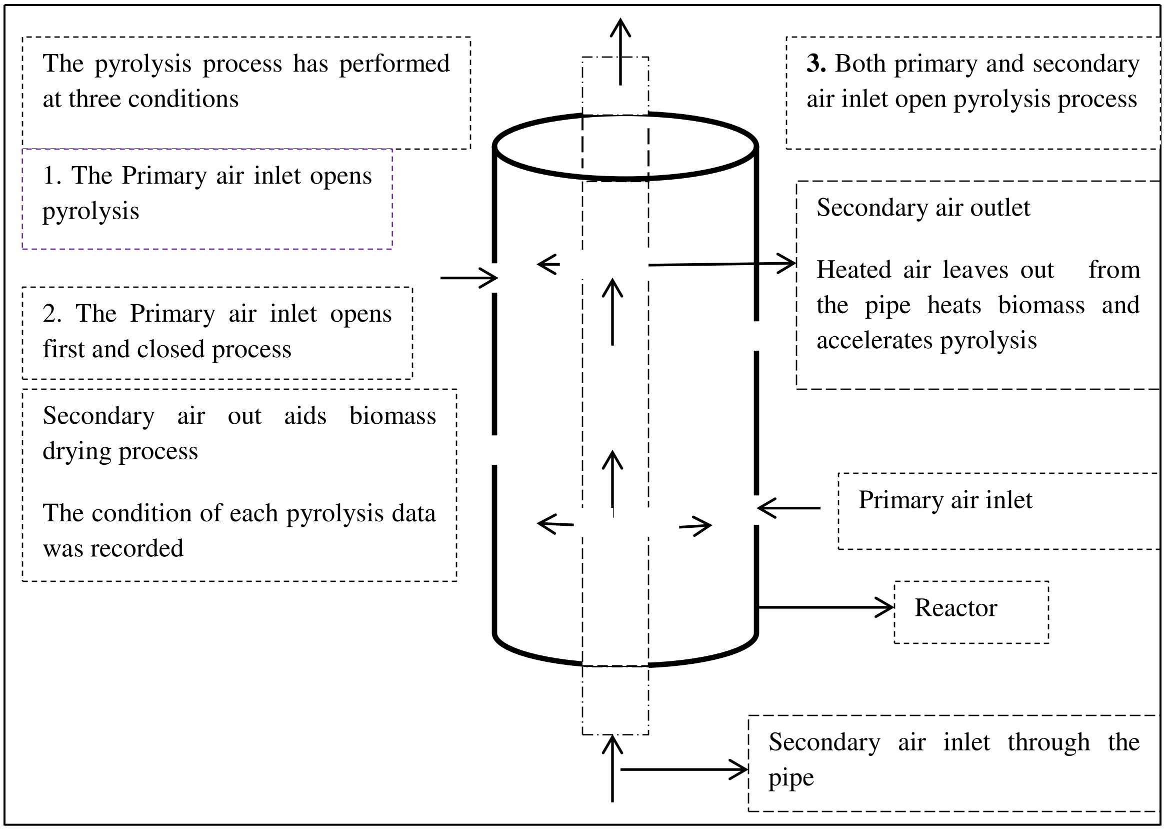

Figure 2 Schematic diagrams of the system

2.3 Design of Pyrolysis Experiment

The slow pyrolysis setup consisted of a reactor that has 1m long stainless steel. The dry feedstock was measured using a digital balance before it was inserted into the reactor for the process. The starting environmental temperature was measured using an infrared thermometer. Manually loaded feedstocks into pyrolysis reactor were initiated or ignited by an external source of energy hatch fire. After 20 minutes, the pyrolysis process temperature change in the reactor was started to record. The maximum temperature (167^0C) was measured in the reactor. Due to the primary and secondary air inlet opening, there was a temperature variation in the process. To know the temperature variation in the reactor, different pyrolysis experiments were performed and repeated at various temperatures during biochar production in the case of both waste paper and cud feedstock. The temperature measurement was performed at the same air mass flow rate (0.35kg/s) and moisture contents (15%). The weight of the biochar obtained compared to the initial feedstock determines the amount of char yield. To achieve high-quality biochar yield, pyrolysis conditions must be controlled. Temperature and airflow rate in the reactor were the most important variables to control during the pyrolysis process. Two ways to control the heat in the pyrolysis: (1) to limit the high temperature produced in the reactor, moist biomass should be added, (2) close both the primary and secondary air inlet and make the system completely non-oxygen process. Though the entire air intake ports are sealed, the chimney must remain open until the flue gas in the system has ceased. This limits the high-temperature flue gas present within the system and immediately closes to prevent any incoming air from the environment.

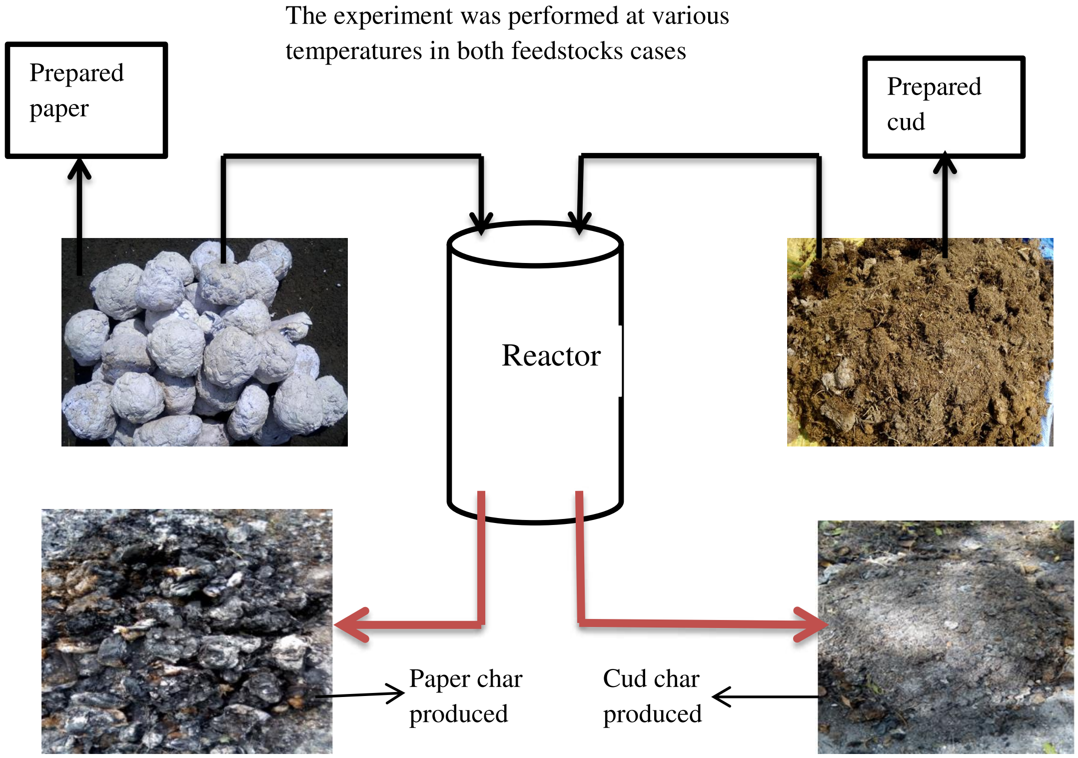

Figure 3 Schematic diagrams of Conversion techniques of biomass to the char

2.4. Air mass flow rate calculation

During the experiment, the air was supplied to the pyrolysis reactor through the inlets at a controlled rate. All air inlets have the same cross-sectional area and which determines the flow rate of air into the reactor. The ideal gas law relation was considered to calculate the flow rate of air into the reactor. Air mass flow rate was an independent variable and an ideal substitute in this work as its value remains constant through the inlet[27]. The airflow rate was often better expressed in volumetric terms.

$$\dot{m}_a = \frac{P\dot{V}}{RT} \text{ kg/s} \quad (1)$$

Where P = atmospheric pressure (1atm)

$\dot{V}$ = volumetric flow rate (m^3/s)

R = gas constant (kJ/kg.k)

T = temperature (k)

Based on the flow situation, the volumetric flow rate can be expressed by:

$$\dot{V} = \text{velocity} \times \text{flow area} = C \times \frac{\pi d^2}{4} m^3/s$$

Where C velocity of air in m/s (0.35m/s)

Equivalence ratio (ER)

To summarize the effects of both air flow and biomass feeding rates, the ER is defined as

ER = actual air fuel ratio/ stoichiometric air fuel ratio

$$ER = \frac{(air\ /fuel)actual}{\left(\frac{air}{fuel}\right)stoichiometric}\ ,\quad \text{Air / fuel ratio } \left(\frac{air}{fuel}\right) \text{ stoichiometric} = \frac{mass\ of\ air}{mass\ of\ \ feedstock} \qquad (2)$$

$$\text{Air/fuel ratio } \left(\frac{air}{fuel}\right) \text{ actual} = \frac{mass\ of\ air}{mass\ of\ \ biochar\ produced}$$

During the experiment, energy was temporarily generated by exothermic combustion reactions. However, after oxygen was limited, pyrolysis and endothermic reduction reaction were dominated. Correspondingly, the mass reduction rate of biomass (feedstock) particles is closely related to the gaseous species concentration and the temperature distribution profile inside the reactor. In the natural convection region, there is a fast mass loss for biomass particles since volatiles are released by pyrolysis reactions. In the mixed convection region, which is near the air inlet, the heterogeneous reactions between carbon and gaseous species occur quickly leading to a higher temperature and higher oxygen concentration. In addition, it was noted that there was a similar trend for the particle mass change across the different ER conditions and the particle mass decreased with the increase of ER[28].

Table 1 Air flow rate and equivalence ratio (ER) calculating data

Parameters	Values	parameter	Values
Pressure	1atm (1.01325bar)	diameter of inlets	50mm
Average temperature	295K	gas constant (R)	8.314kJ/kg.k
Average velocity of air	0.35m/s	Mass of feedstock	30kg/run
Density of air	1.125kg/m^3	Mass of biochar produced	19kg

3. Result and Discussion

3.1 Effects of pyrolysis operating parameters on biochar yield

Biochar production through pyrolysis is influenced by the process parameters such as temperature, process time, particle size, airflow rate, and heating rate. These operating parameters not only control the char yield but also affect the quality of the pyrolysis products. Most of the time the purpose of pyrolysis is to maximize the product yield so it is important to discuss the effect of these process conditions on biochar production [1].

Biochar is produced using a slow pyrolysis process to reduce contamination of carbon [22]and is efficient to convert biochar carbon into a stable form. During pyrolysis, animal cud was burnt with very little oxygen. As it burns, it releases little to no contaminating smokes/fumes. The feedstocks are converted into a stable form of biochar and approximately 70% of its composition is carbon. The remaining percentage consists of nitrogen, hydrogen, and oxygen among other elements. The chemical composition varies depending on the feedstock used to make it and the methods used to process it. The carbonization and stability of biochar also vary according to the pyrolysis process, amount of temperature, and environmental conditions [29]. To obtain a good result, parameters of pyrolysis time, temperature, particle size, the primary and secondary air flow rate should be adjusted during the experiment. The resulting char product is shown in figure 4**.**

Figure 4 (a) Waste paper biochar product (b) Animal cud biochar at different temperature

Biochar from the two feedstocks was produced under different pyrolysis temperatures of 167^0C. 30kg of each feedstock was pyrolyzed per run, resulting in 10-23kg of biochar in animal cud and 10-21kg biochar in the paper were produced per run. The yield of the biochar obtained from each of the feedstocks depends on the pyrolysis temperature. The more temperature in the reactor, the less biochar yield is obtained. The dense accumulation of the cud feedstock reduces the temperature distribution in biomass and increases the char.

3.2 Effects of Operating Parameters

3.2.1 Effects of Air Flow Rate

The quality, characteristics, composition of the biochar products, and carbon sequestration ability were influenced by pyrolysis parameters [30]. The airflow rate through the primary air inlet was heated biomass and removed the moisture it contains. The airflow rate through the secondary air inlet can further increase the temperature in the reactor which determines the quantity of biochar produced. The more the airflow rate, the temperature reached its peak value and the less biochar was obtained. This is because the higher airflow rate promotes the exothermic combustion reactions and more reaction heat was generated and hence the temperature inside the reactor increased. The amount of biochar yield also depends on the moisture contents of feedstock contain and the airflow rate to the reactor. During the experiment, the primary airflow rate makes the process a slower pyrolysis process and provides more biochar yield than the secondary air flow rate process. Both primary and secondary air inlet opening at the same time process gives less biochar and more ash product. In the waste paper feedstock char production process, the black ink product was observed on the pan of the reactor by secondary air inlet hole opening practice. However, the primary and secondary air inlet hole closed process circulates the flue gas more times and increases the temperature of biochar inside the reactor. The experiment was conducted with pyrolysis temperature (75, 85, 105, 125, 132, 148,155 and 167^0C), 15% moisture, an airflow rate of 0.35, 0.6, 0.92, 1.5, 1.75, 2.5, 2.75, and 3 m^3/s respectively. It can be observed that the higher the airflow rate into the reactor, the more temperature and fewer biomass yields in the process. In the reactor produces 11kg- 25kg of biochar yield was obtained from 30kg of feedstock. The result depends on the feedstock types and processes. The effect of air flow rate on the char yield was clearly shown in Figure5.

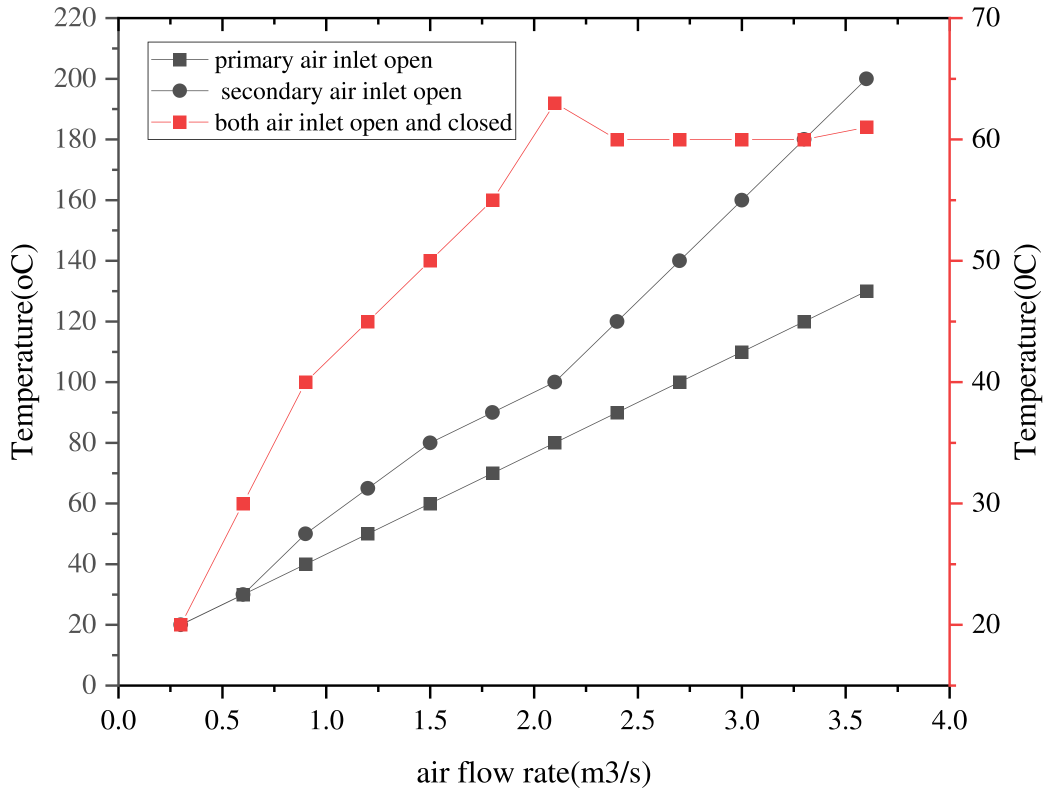

Figure 5 Effects of airflow rate and temperature on biochar yield

To control temperature, temperature data were recorded at the end of the chimney at different times throughout the heating process. The pyrolysis temperature in the reactor is cost-effective and can be built easily by farmers using locally, available materials and biomass. When cud biomass is pyrolyzed, both the primary and secondary air inlet holes should be opened at the same time to improve biochar production. Different reactions may occur but experimentally difficult to determine their contribution to the carbonization process. This is often evaluated indirectly by calculating the energy and mass balance in the system. However, the stability of biochar varies according to the type of biomass, the pyrolysis process, and environmental conditions.

3.3. Residence time and biochar yield

Cud feedstock is being dense in accumulation which may create difficulties in the transfer of heat during the pyrolysis process and to provide more biochar yield. Since low temperature associated with long residence time is required for high biochar production. Increasing the vapor residence time helps the biomass constituents to pyrolyze and remove the moisture by taking sufficient time during the process.

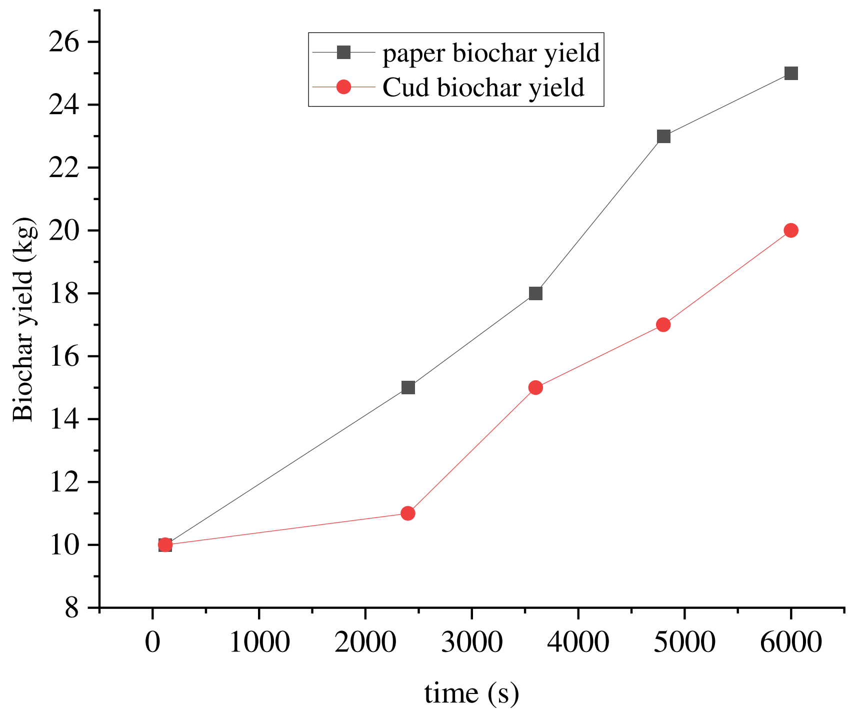

Figure 6 Heat distributions through feedstock during the biochar production process

Residence time not only affects the biochar yield but also influences the quality and characteristics of the biochar by promoting the development of micro and macro-pores. It has been observed that at high residence time, an increase in biochar yield

3.4. Effect of heating rate

Heating rate plays an important role in the pyrolysis of biomass as the rate of change of heat influences the nature and composition of the final product up to a certain extent. At a low heating rate, the possibility of secondary biomass pyrolysis reaction can be reduced. A low heating rate also ensures that no thermal cracking of biomass takes place resulting in more biochar yield. However, a high heating rate backs the fragmentation of biomass and increases the gaseous and liquid yield which limits the formation of biomass. Heat transfer through biomass in the reactor facilitates the roasting of biomass. The first 20 minutes low heating rate measurement showed that more heat was required to evaporate the moisture of the feedstock. As shown in Table 2, the heating rate in the reactor was varied based on the airflow rate. This heating rate determines the amount of biochar produced and its properties. The maximum heating rate (1.55^{0}c/min) has occurred when both primary and secondary air inlets were opened. Further increase in heating rate has an impact on char production since at a high heating rate the process becomes fast pyrolysis and converts biomass into oil.

Table 2 Experimental results of heating rate during paper and cud biochar production

Heating rate (^{0}c/min) during waste paper biochar production			
Primary air inlet open	Secondary air inlet open	Both inlets closed	Both inlets open
0.6	0.75	1.2	1.7
1.25	1.4	0.3	1.15
0.6	0.5	0.6	1.05
0.5	0.7	0.75	1.55
Heating rate (^{0}c/min) during cud biochar production			
0.3	0.75	0.15	0.7
0.5	0.85	0.25	0.95
0.45	0.35	0.35	0.75
0.95	0.9	0.9	1.45

A high heating rate increases temperature and leads to the formation of gaseous and liquid. But slow pyrolysis requires low temperature and longer residence time to produce the char.

The heating rate distribution through the reactor also determines the charred quality and removal of moisture content below 10%. Part of this energy released during the combustion of biomass at the ignition point is usually used to heat the feedstock for pyrolysis. However, after the biomass has been dried by heating rate, the airflow rate should be much reduced to obtain more biochar yield.

3.5 Effect of temperature on biochar yield

The heat generated by the torch on the biomass during the pyrolysis process was transferred to the bottom parts of biomass. The ignition side of biomass heat is more and produces biochar first. However, the other side far from the starting side dries until the flame reaches and provides less biochar product. The temperature and time affect the biochar roasting process in the reactor. Figure 7 showed the temperature and biochar yield counter plots at 0.35, 0.65, 0.95, and 1.25kg/s air flow rate. It can be seen that during pyrolysis, temperature trends increase as the airflow rate increases within the limited values. However, the biochar yield reduces as a pyrolysis temperature and airflow rate increase. This provides a non-uniform pyrolysis profile, where the bottom of the feedstock was the last region to pyrolyze. Different heating zones also appear inside the particle because of its structural development as well as heat transfer conditions. The highest heating rate regions were near to the surface of the reactor where the biomass ignites first and the biochar forms quickly and its residence time is short and those particles without decomposing produce more biochar. Increasing the temperature in pyrolysis affects the biochar yield negatively as shown in figure 7.

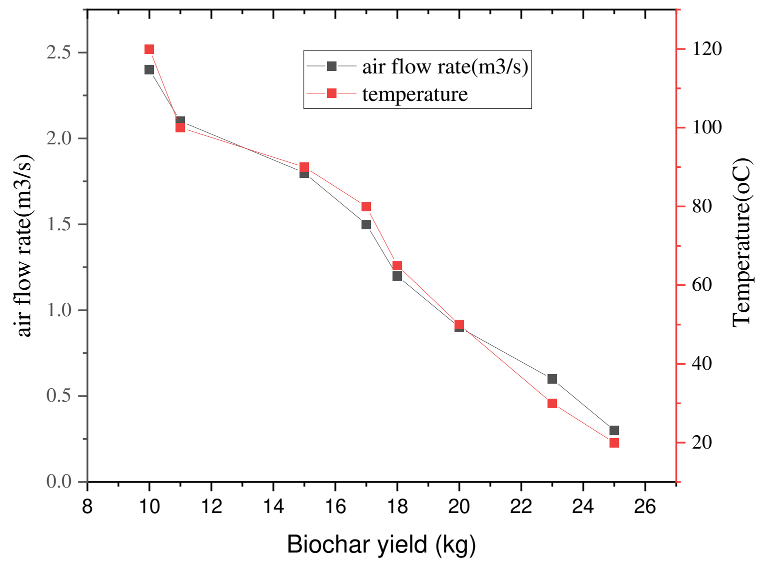

Figure 7 Effects of temperature on biochar yield

As it can be seen that at a high airflow rate, the temperature is high but there is less biochar yield. Energy exchange is high in the reactor at high temperatures. The pyrolysis experiment was conducted at atmospheric pressure and vacuum at the top of biomass. Conducting at atmospheric pressure is simple and economically noble. As shown in Figure 7, the pyrolysis temperature is negatively correlated with the biochar product. As the temperature increases further in the reactor, the thermal cracking of molecular weight in biomass feedstock may increase and reduce the biochar yield. With an increase of temperature from 30 to 167^{0}C, correspondingly, the biochar yield decreases to 9kg. While at low temperatures, the yield of biochar was found to be high. As the temperature of the pyrolysis process increases above 167^{0}C, the biochar yield becomes ash. In a similar study of wood pellets and grass straw, the temperature has the opposite effect on the biochar production between the temperature ranges 350 -600^{0}C[31], and as Browsort, Peter has studied, higher temperature gives less char in all types of the pyrolysis process. With a higher temperature, more volatile material is forced out of the biomass (feedstock), and therefore the number of char decreases[32].

4. Conclusions and recommendations

In this paper, the pyrolysis process experiment was conducted to produce biochar at different temperatures and airflow rates. The main factor that affects the production of biochar is the temperature, type of feedstock used, airflow rate, and moisture contents. The more amount of airflow rate makes the process fast pyrolysis and gives less biochar yield. During the experiment, drying feedstock (less moisture) reduces the period of biochar produce and airflow rate into the reactor. The densely accumulated feedstock (cud) requires molding and internal secondary airflow rate to improve the char product. It is possible to predict the flue gas constitutes and the reaction that occurs during char production in the reactor using the ultimate and proximate values of the feedstock.

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Highlights

In this study, the effect of parameters on composite char production was investigated.

- ✓ the effects of primary and secondary air on composite char yield was examined
- ✓ the maximum temperature of $167^{0}C$ was used to produce the char.
- ✓ Energy exchange in the reactor during char production at maximum air flow rate was analyzed.
- ✓ 11kg- 25kg of biochar yield was obtained in the reactor from 30kg of feedstock.
- ✓ the corresponding air flow rate and temperature was included in the text for every biochar yield result

Author Contributions: The authors contributions of this research work is as follows; "Conceptualization of cud biochar production , methodology, soil modification using cud biochar, Pyrolysis analysis, investigation, resources, writing original draft preparation writing— review and editing. All authors have read and agreed to the published version of the manuscript."

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Conflicts of Interest: The author declares that there are no conflicts of interest regarding the publication of this paper.

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