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GENERATION OF BIO-CHAR FROM CROP RESIDUES

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ABSTRACT

The studies were undertaken to generate bio-char from crop residues using two different types of heating systems, namely external and internal, of pyrolysis. Char from different crop residues like, pigeon-pea, cotton and soybean residues were produced and characterized. For experiments on pyrolysis of crop residues at different temperature, an externally heated vertical cylinder bio-char reactor was developed. The effects of temperature on the yield and the stability of the char were investigated. It could be established that the stability of the char is positively correlated with the pyrolysis temperature; higher pyrolysis temperature gives more stable bio-char. Pigeon pea stalks were found as better bio-material for bio-char generation than the cotton stalk and soybean straw. The carbon contents of the char from the pigeon pea stalk and soybean straw were similar. The pyrolysis process temperature was found appropriate in the range of 350 to 450 °C for obtaining the stable char to act as bio-char. The stability of bio-char was found maximum for bio-char prepared at temperature 450°C. The gain of carbon in soil due to incorporation of soybean char was found as 91 % higher in comparison to add the raw bio-material. This gain was highest for soybean straw char amongst three crop residues studied. Analysis revealed that approximately 0.89 tonnes per year CO_2 can be reduced by converting each tonne of crop residues in bio-char.

Keywords: pyrolysis, bio-char, carbon sequestration, recovery, Iodine value

1. INTRODUCTION

Bio-char is produced by pyrolysis of bio-materials such as crop residues, forestry waste, industrial by-product, municipal waste and animal manure, in a zero or a low oxygen environment [1]. At present, the use of bio-char for improving the soil health is getting attention. Application of bio-char in soil, results in good fertility and significant increase in crop yield due to addition of macro & micro nutrient from carbon rich source in form of char [1]. The carbon sequestration is the most important consideration which not only improves the soil climate but also reduces the CO_2 emission which may generate if the bio-material is burnt, otherwise. Incorporation of the bio-char in soil which is one form of carbon sequestration helps to mitigate the GHG emission making it carbon negative process. By charring the organic material, much of the carbon becomes fixed in a more stable form.

There are mainly two methods for bio-char generation viz., slow pyrolysis and fast pyrolysis. Slow pyrolysis is applicable mainly for bio-char generation due to longer heating duration and slow heating rate.

The influences of pyrolysis temperature and retention time were studied for the oil palm stones pyrolysed in a stainless-steel reactor. The optimum condition of pyrolysis was found as pyrolysis temperature of 800 °C for a retention time of 3 hours [2]. The highest bio-char yield of empty fruit bunches was found as 41.56 % at an optimum pyrolysis temperature of 300 °C using fluidised fixed bed reactor [3]. The higher pyrolysis temperature resulted in bio-char with lower surface charges but higher surface areas, pH and much lower H and O contents [4]. After incubation in the Norfolk soil, the bio-char produced at the higher pyrolysis temperature increased soil pH value.

During pyrolysis, the process temperature and the retention time are the important parameter that needs to be studied for the pyrolysis of different bio-materials because of variability in constituents of bio-materials. Engineering intervention for production of bio-char demands the investigation on generation of significant quantum of bio-char with maximized C-content in it with maximum level of stability. The heat flow method to pyrolysis unit is also important. The present study tries to compare the two systems of heat supply for pyrolysis process.

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For application of bio-char in soil, the stability of char in soil environment is most critical. For better carbon sequestration, the carbon should remain for a long time in soil. This can be obtained by adding the stable carbon in the soil. The stability of bio-char can be represented by iodine value. In fact, iodine value is a measure of activation levels of absorbents; high iodine value points to high activation level. The low activation level means the bio-char is less active towards foreign material indicating stability of material. Iodine number was used to study physico-chemical and surface characterization of absorbent prepared from groundnut shell [5]. The effect of various activation conditions like, time, temperature, and $Zncl_2$ / char ratio on the % yield of products and adsorption efficiency was studied in terms of iodine number [6].

This paper discusses the pyrolysis conducted in two types of heating systems, external heating and internal heating. Pyrolysis process conditions were varied and the bio-char products obtained were characterized.

2. MATERIALS AND METHODS

2.1 Charring System

For conducting the charring process, two methods of heating, external (electrical heating) and internal (self heating), were experimented. In external heating, the radial flow of heat was planned and a vertical cylinder bio-char unit was designed and fabricated. In internal heating, self heating was used and charring kiln (developed earlier [7] by Central Institute of Agricultural Engineering (CIAE), Bhopal) was adopted wherein part of the raw material is burnt just before the charring process to attain the requisite thermal environment for charring. Three types of biomass namely pigeon pea stalk, soybean straw and cotton stalks were selected for study. All three materials were experimented with an internal heating charring system whereas to understand the effect of pyrolysis temperature on charring the pigeon pea stalk was used with external heating system.

A. Charring through external heating using vertical cylinder bio-char reactor

An experimental level reactor (Fig.1) was developed to study the effect of different pyrolysis process parameters on conversion of biomass into the bio - char. The reactor has a mild steel vertical cylinder (diameter 360 mm; height 500 mm; thickness 2 mm) having a volume of 50 litre. This reactor has an electrical heating facility. For this purpose, electrical heating coil of 6 kW was wrapped externally throughout the reactor body. The system was designed in such a way that the heat to raise the desired temperature was supplied from the periphery of vertical reactor and heat flows radial.

Fig.1. Vertical cylinder bio-char reactor equipped with external electrical heating systems

Prior to pyrolysis, collected biomass were analyzed for their moisture content, ash content, true density, bulk density. Stalks of size (length 250 – 300 mm and diameter 3 – 8 mm) were selected for the experimental purpose. In externally heated (electrically) vertical cylinder bio-char reactor, the pyrolysis was conducted at different temperature regulating methods and the bio-char obtained were characterized. For charring, the material was fed into the reactor and the temperature was raised from ambient to predefined temperature (250, 300, 350, 400 and 450 °C). These experiments were done to find out the appropriate temperature to obtain the best quality bio-char from available crop-residues. After attaining the defined temperature, the pyrolysis process was continued at constant temperature for 1 h and then the unit was electrically disconnected for cooling. After cooling, the reactor was opened at ambient temperature and the pyrolysed biomass from the reactor transferred to another closed vessel. The obtained char were analyzed for their output such as recovery, carbon content and iodine value.

B. Charring through internal heating using CIAE charring kiln

For studies on charring through internal heating, the charring kiln (Fig. 2) developed by Central Institute of Agricultural Engineering, Bhopal was adopted [7]. This charring kiln can take a charge of 100 kg crop residues in one run yielding about 35-40 kg of char. The kiln consists of a metallic cylinder having a diameter of 800 mm and a length of 1100 mm. Both ends of the cylinder are closed. A transverse rectangular lid of 550 mm x 450 mm is provided on its side to serve as the feed inlet. The crop residues get converted into char in about 2-4 h [9]. In this system, charring of biomass is done at a low rate of heating requiring sufficient time for the reaction.

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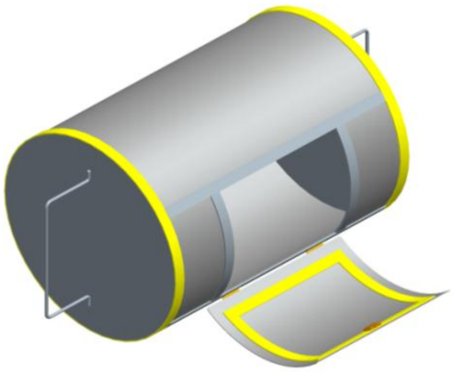

Fig.2. Charring Kiln (developed by CIAE, Bhopal)

2.2 Bio-char Analysis

Characterization of the material includes proximate analysis, carbon content, and recovery and iodine value (ASTM D 4607-94, 2006) [6] and pH [4, 8]. The carbon of residues and bio-char was determined by using Total Organic Carbon analyzer (Make: SHIMADZU, Solid sample module, SSM 5000A). The properties studied for the bio-material includes moisture content (ASTM D4442 - 07), ash content, bulk density and true density.

2.3 Carbon dioxide Reduction

Analysis was done to estimate the potential of CO_2 reduction, which can be achieved by converting the crop residues in bio-char and then by incorporating the bio-char in soil for carbon sequestration. The quantum of bio-char was computed multiplying the biomass quantum with bio-char conversion efficiency (biomass in tonnes × bio-char recovery percentage). Further, total potential carbon was calculated by multiplying of quantity of bio-char and carbon content of bio-char (bio-char in the tonnes × carbon content of bio-char). Finally, carbon dioxide reduction was estimated by multiplication of total potential carbon, carbon stability (80 %) and fraction of 44÷12 [9].

3. RESULTS AND DISCUSSION

Properties of raw residues and char were determined. It was found that the ash content of raw bio-material due to charring increased. It was due to the removal of moisture and volatiles from the raw bio-material. The ash content of the pigeon pea stalk was 3.0 % which increased for pigeon pea char as 15.5 %. In case of the cotton stalk, the ash contents of raw bio-material and its char were 4.0 and 10.5 %, respectively. The bulk densities of the raw pigeon pea stalk, raw cotton stalk, char from the pigeon pea stalk, and char from cotton stalks were 288, 250, 239 and 203 kg/m^3, respectively. The true densities of the raw pigeon pea stalk, raw cotton stalk, char from the pigeon pea stalk, and char from cotton stalks were 553, 466, 610 and 577 kg/m^3, respectively.

3.1 Charring through External Heating using Vertical Cylinder Bio-char Reactor

The pigeon pea stalk was charred by controlling the charring process. The results of experiments conducted at different pyrolysis temperatures are shown in Fig. 3, highlighting the effect of temperature on recovery, i.e., bio-char yield. For the selected temperature ranging from 250 to 450 °C, the bio-char yield varied from 40 to 21 %. The range of carbon content in char was found from 71 to 77 %. With an increase in pyrolysis process temperature, there is a decrease in the yield of bio-char. The pH of bio-char was found to increase with increase in pyrolysis process temperature. The pH value increased from 9.44 to 9.85 when the process temperature was increased from 250 to 450 °C. Thus, the char can be used to reclaim the acidic soil.

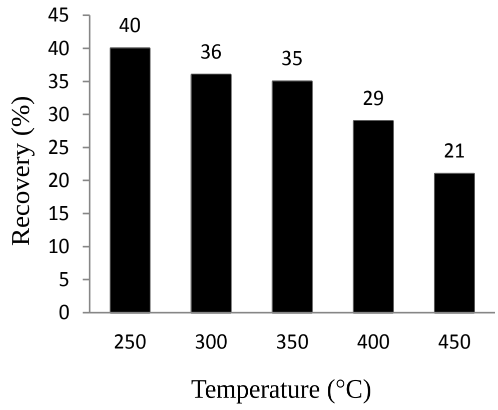

Fig.3. Bio-char recovery from pigeon pea stalk

3.2 Charring through Internal Heating using CIAE Charring Kiln

Charring of crop-residues such as pigeon pea stalk, cotton stalk and soybean straw was done. The increase in carbon content of charred material as compared to raw bio-material was observed (Fig. 4) as the process of charring expelled the moisture and volatiles of biomass and the remaining matter (char) left contained high carbon content. The maximum rise in carbon content was noticed for soybean straw. The pH of char from all three crop residues was measured to be higher than 9.0. The bio-char recovery was obtained in the range of 27-30 %. The lower recovery of charring in case of internal heating as compared to external heating was due to the fact that some amount of raw material was burnt initially to obtain the energy for charring. The carbon content of char obtained reaches up to 90-94 % (Process maximum temperature 380 °C). The higher carbon percentage may be due to condensation of bio-oil on the char surface.

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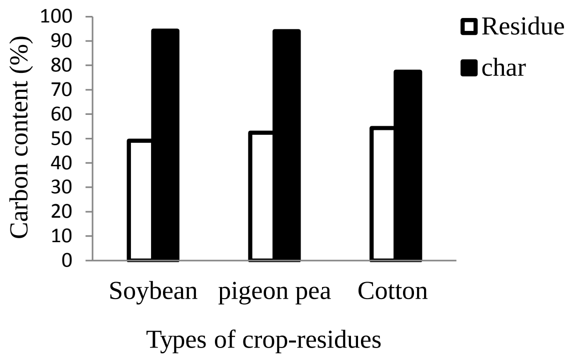

Fig. 4. Carbon content for selected agro- residues

The char obtained can be used for carbon sequestration in soil. An estimate of carbon added to the soil by incorporating char in comparison to the raw bio - material is given Table 1. For the convenience of comparison, the assumption was taken that 1 tonne of material / ha is to be incorporated into the soil.

Table 1: Comparison for C incorporation in soil using different crop residues and their char

Particulars	Incorporation of C in soil		
	Pigeon pea stalk	Cotton stalk	Soybean straw
Raw crop residue (kg/ha)	520	540	490
Char (kg/ha)	940	770	940
Gain of C in soil for C-sequestration using char, (%)	80	42	91

3.3 Comparison of Charring Systems

The higher char recovery was obtained using externally heating systems as the process temperature conditions can suitably be regulated. The radial heat flow (vertical cylinder bio-char unit) has uniformity in temperature distribution of material undergoing through charring process. The carbon content of char obtained in the internal heating (self–heating) system were higher as compared to the carbon content of char obtained from charring using the external heating system. However, the char obtained from the internal heating system is relatively not appropriate for carbon sequestration in soil because this char has subsistent amount of condensed volatiles over its surface. Besides, the total quantity carbon for carbon sequestration which can be obtained from a particular quantity of biomass is higher in case of external heating system due to its higher char yield despite the lower level of carbon content in char.

3.4 Carbon dioxide Reduction from Atmosphere

Using the results of charring of pigeon pea stalk in both types of charring systems, analysis was done to estimate CO_2 reduction potential. The comparison is shown in Fig 5. Bio-char recovery and carbon content of the char was used for calculation of CO_2 reduction. For ease of computation, the conversion of unit quantum (i.e., 1 tonne of residues per year) of biomass to char was assumed. This analysis gave factors that can be used for extrapolating the CO_2 reduction potential for vast biomass potential of our country. Analysis revealed that 0.89 and 0.71 tonnes of CO_2 can be reduced per tonnes of crop residues using charring through external and internal heating systems, respectively.

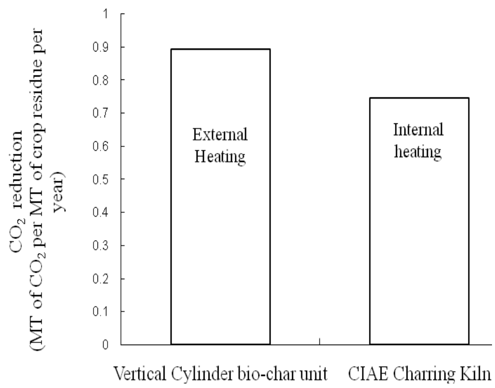

Fig.5. Comparison between two charring systems used in the study for CO_2 reduction

3.5 Stability of Char

The stability of char generated was ascertained by determining the iodine value of char samples with the hypothesis that the activeness of char is inversely proportional to the stability; for bio-char the stability must be higher therefore the activeness must be lower. At process temperature of 250 °C, 300 °C, 350 °C, 400 °C, 450 °C, the iodine values were determined as 316, 285, 258, 206, 196, respectively, for pigeon pea char obtained through charring by external heating. In case of internal heating, pigeon pea char showed the lowest iodine value of 192 in comparison with other material such as soybean char (337) and cotton char (200). It indicated that pigeon pea is the best material for making bio-char than the cotton stalk and soybean stalk, and the process temperature should be kept in the range of 350 to 450 °C for obtaining the stable char to act as bio-char. If only the carbon content is considered, the pigeon pea and soybean bio-char were at par. The activation level of char was found lower when the char was prepared at higher temperature. It indicated that the stability of char is positively correlated with the pyrolysis temperature.

4. CONCLUSIONS

Charring process was experimented using two types of heating systems, internal and external. Char obtained from the external heating system was having higher char yield and lower carbon content in char as compared to char generated in the internal heating system. Pigeon pea stalks are better material for making bio-char than the cotton stalk and soybean straw, and the process temperature should be kept in the range of 350 to 450 °C for obtaining the stable char to act as bio-char.

If only the carbon content is considered, the pigeon pea and soybean char were at par. The char can be used for reclamation of acidic soil; the pH of bio-char being higher than 9.0. The gain of carbon in soil for carbon sequestration was highest (91 %) for soybean straw char as compared to the char obtained from other crop residues. The external heating reactor had potential to reduce 0.89 tonne per year CO_2 from the atmosphere by producing the bio-char from each tonne of crop residues and adding the generated char in soil for carbon sequestration.

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