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PYROLYSIS OF AGRICULTURAL RESIDUE FOR BIO-CHAR PRODUCTION

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Abstract: A horizontal bio-char reactor system was developed for preparation of bio-char from agricultural residues. The reactor was made up of mild steel of 2 mm thickness having diameter of 300 mm; length of 1500 mm. In this reactor, electrical heating element of 6 kW was wrapped externally throughout the reactor body to raise the temperature from room temperature to predefined set temperature. The study was conducted at three levels of predefined temperature of 450, 500 and 550°C and residual time duration of 60, 120 and 180 min for optimization of temperature for obtaining the better quality of bio-char. In the present study char was prepared from pigeon pea stalk. The average recovery of bio-char prepared from pigeon-pea stalk was found to be 40.30%. Total carbon (TC), total organic carbon (TOC), and total inorganic carbon (TIC) of pigeon-pea stalks of sized $\phi \leq 5$ mm (D_1), $\phi = 5$ to 7 mm (D_2) and $\phi \geq 7$ mm (D_3) was found in the range of 45.1 to 45.8, 41.6 to 42.3 and 2.6 to 4.1%, respectively. Similarly, these value were determined at three temperature levels of 450, 500 and 550°C and found to be 68, 67.03 and 3.5%; 81.51, 69.11 and 6.5%; 68.4, 65.18% and 6.7%, respectively. The pH value of bio-char prepared at 450, 500 and 550°C was found in the range of 6.1 to 6.8, 7.7- to 8.5 and 7.7 to 9.5, respectively.

Keywords: Pigeon pea stalk, bio-char and reactor

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INTRODUCTION

Bio-char is commonly defined as charred organic matter, produced with the intent to deliberately apply to soils to sequester carbon and improve soil properties (Blackwell *et al.*, 2008). The only difference between bio-char and charcoal is its utilitarian intention; charcoal is produced for other reasons (e.g. heating, barbeque, etc.) than that of bio-char (Mchenry, 2009). In a physicochemical sense, bio-char and charcoal are essentially the same material. It could be argued that bio-char is a term that is used for other purposes than scientific, i.e. to re-brand charcoal into something more attractive-sounding to serve a commercial purpose. However, from a soil science perspective it is useful to distinguish any charcoal material and those charcoal materials where care has been taken to avoid deleterious effects on soils and to promote beneficial ones. Research in India showed that pigeon-pea helped to reduce bulk density of the soil, helping to increase the root volume and root weight of the crop in the rotation (Zwieten *et al.*, 2009). Top-growth stalk production has been reported as high as 35 tons of fresh weight green matter per acre. Dry matter top growth production is about 2.5 tons/acre, contributing about 25 kg of nitrogen per ton of dry matter (Singh *et al.*, 1992; Sukiran and Kheang, 2011). Keeping in mind the importance of the bio-char a horizontal bio-char reactor system was developed for preparation bio-char from agricultural residues.

MATERIAL AND METHODS

The experiment was planned using three independent parameters namely diameter of stalks, charring temperature and duration. The levels of diameter were selected less than 5 mm, 5mm and greater than 5mm (D_1 , D_2 and D_3). The levels of charring temperature in the reactor were fixed as 450, 500 and 550 °C (T_1 , T_2 and T_3). The levels of residual time for charring in the reactor were set at 60, 120 and 180 min (Du_1 , Du_2 and Du_3). For efficient application of the system the physical properties of the pigeon-pea were studied. The physical properties such as bulk density and true density were determined (Downie *et al.*, 2009). Size reduction of pigeon pea stalks were needed to fulfill the requirements of rapid heating and to achieve bio-char yields and it was made by bio-mass cutter. The pigeon-pea stalks were selected and cut down to 80-100 mm in length. The cut pieces were separated in three different diameter sets as $\phi \leq 5$ (D_1), $\phi > 5 - 7$ (D_2), $\phi \geq 7$ mm (D_3). Temperature of reactor chamber was set at three levels such as 450 °C, 500 °C and 550°C. The recovery of the bio-char was determined by using following equation.

$$\text{Bio-char recovery, (\%)} = \frac{\text{Bio-char mass}}{\text{Bio-mass}} \times 100 \text{-----(Eq.1)}$$

The reactor was made up of mild steel of 2 mm thickness having diameter of 300 mm and length of 1500 mm. Electrical heating element of 6 kW capacity was wrapped externally throughout the reactor body to raise the temperature from room temperature to predefined set temperature. The experimental set-up of the horizontal bio-char system is shown in Fig. 1. For charring, the material was fed into the reactor and the temperature was raised from ambient to predefined temperature (450, 500 and 550°C). These experiments were carried out for different residual time ranging viz., 60, 120 and 180 min to find out the optimum temperature and time to obtain the best quality bio-char from pigeon-pea crop-residue. Material selected for the study include pigeon pea stalk of different diameters. Properties of bio-char such as moisture content, volatile matter, ash content, iodine value, pH, and true density, bulk density were determined in laboratory.



Fig.1. Experimental set-up of horizontal bio-char reactor System

Results and discussion

Recovery of bio-char

The recovery of bio-char at charring temperature 450, 500, and 550°C of 27 samples of pigeon pea stalk were evaluated in bio-char reactor. The recovery of bio-char of 27 samples is shown in Fig. 2 and 3. Less percentage of bio-char production may be due to presences of some un-charred raw material in experiment condition due to temperature regime inside the reactor. There was possibility that complete fast pyrolysis could not take place. The recovery in different experiments varied from 33 to 60%. The average bio-char recovery was found to be 40.36 %.

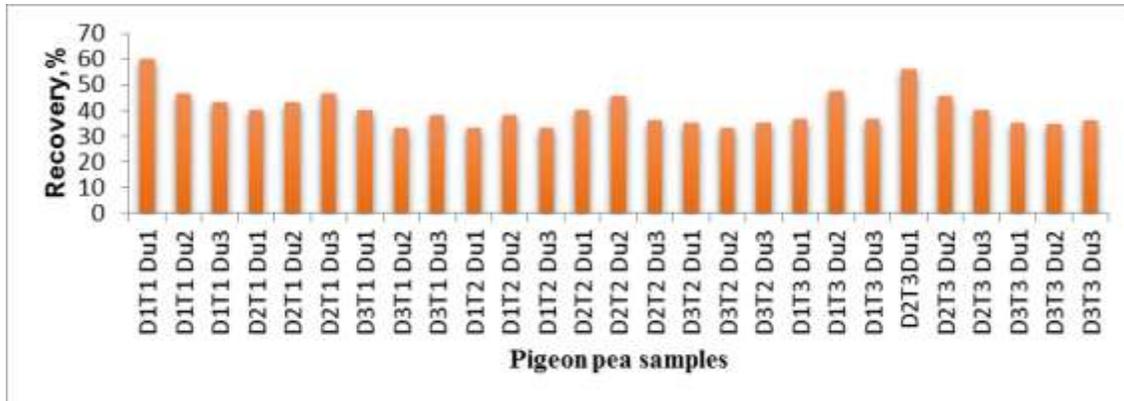


Fig. 2 Recovery of bio-char of 27 samples of pigeon pea



Fig. 3 Bio-char obtained from pigeon pea stalks

Effect of size of pigeon-pea on moisture content, ash content, fixed carbon and volatile matter

The effect of sizes of pigeon-pea stalks on its moisture content, volatile matter, ash content and fixed carbon, is shown in Fig.4 to Fig. 7. The moisture content, volatile matter, ash content and fixed carbon was found to be in the ranged of 4.1 to 4.9 %, 59.10 to 65.12 %, 1.8 to 2.54 % and 22.6 to 33.6 %, respectively. No remarkable variation was observed in moisture content, fixed carbon, ash content, volatile matter and fixed carbon of pigeon-pea stalk samples and bio-char samples.

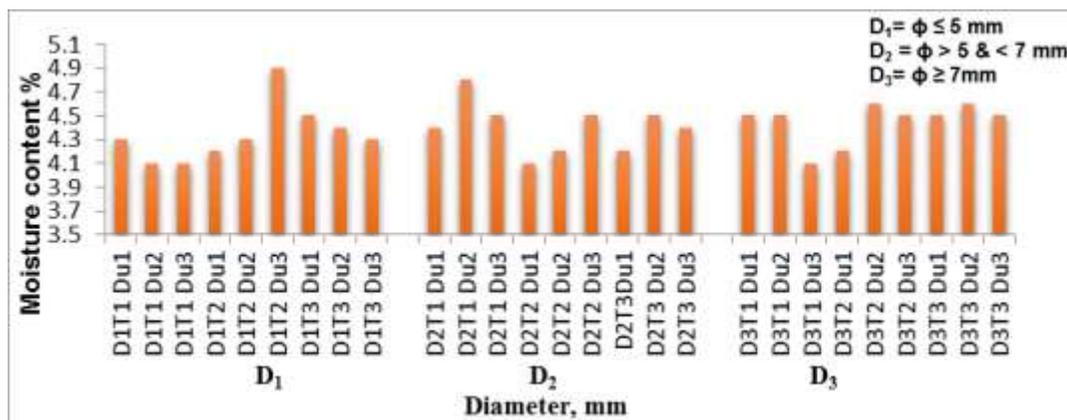


Fig. 4 Effect of sizes of pigeon pea on its moisture content

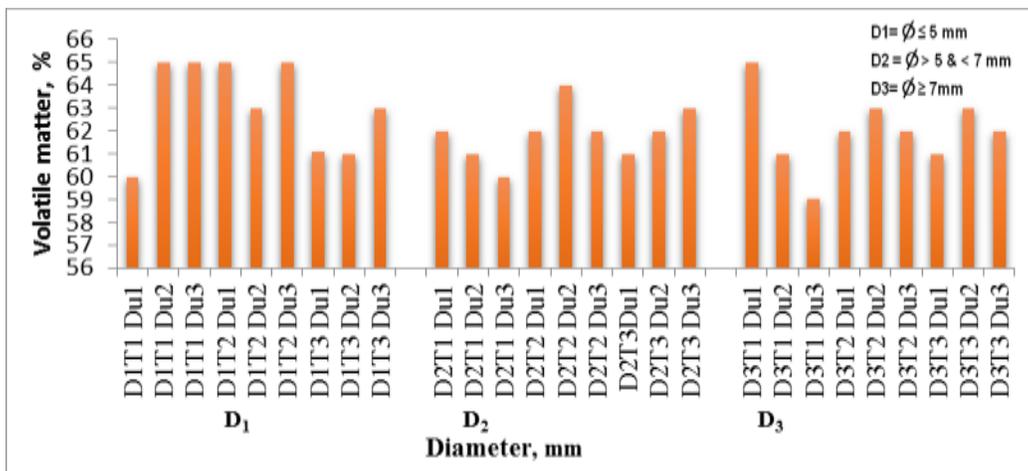


Fig. 5 Effect of sizes of pigeon pea on volatile matter

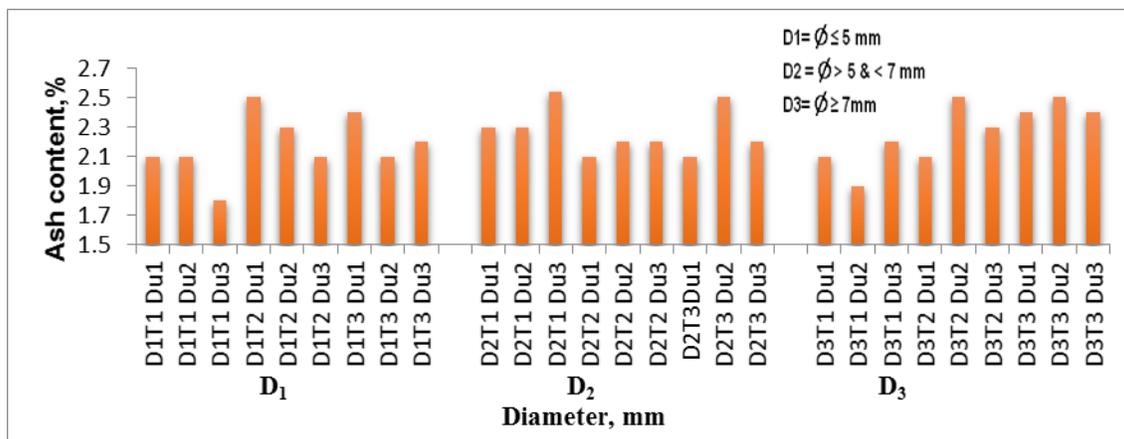


Fig.6 Effect of sizes of pigeon pea on ash content

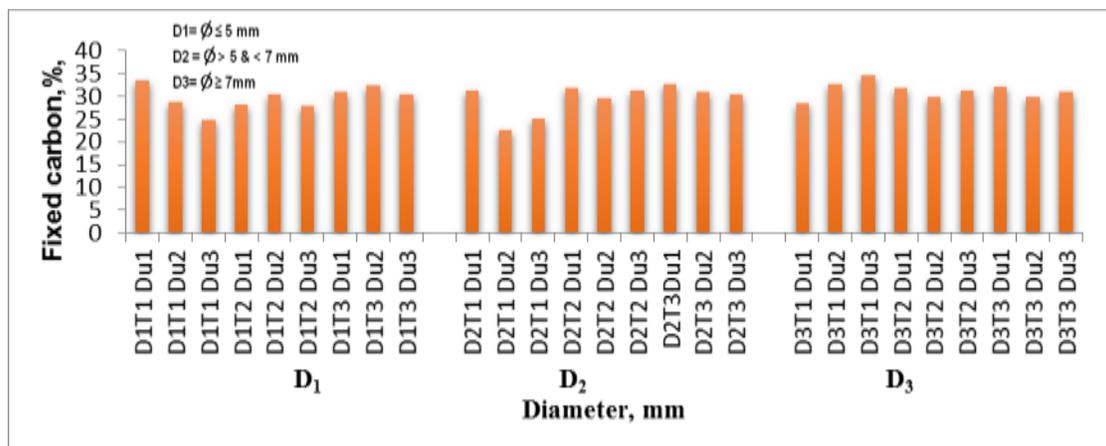


Fig 7 Effect of sizes of pigeon pea on fix carbon

Iodine value of pigeon-pea stalk was measured and found in the range 201 to 298. The standard deviation of their value was 29.26. Similarly, pH value was also determined and found in the range of 4.1 to 5.1. The total carbon

(TC), total organic carbon (TOC) and total inorganic carbon (TIC) of stalk of D₁ D₂ and D₃ were found out and presented in Table 1 and Fig.8. The range of total carbon was found to be 45.1 to 45.8 %, TOC ranged from 41.6 to 42.3 % and TIC ranged from 2.6 to 4.1 %. The average value of TC, TOC and TIC of pigeon-pea stalk of D₁ size were found to be 45.18, 42.35 and 2.83 %, respectively. Similarly for D₂ it was 45.14, 42.45 and 2.69 % and for D₃ it was 45.83, 41.64 and 4.19 respectively. Very minor variation was observed in D₁ D₂ and D₃ size of pigeon-pea stalks.

Table 1 Total carbon percentage in pigeon pea stalks

Stalk diameter	TC (%)	TOC (%)	TIC (%)
D ₁	45.18	42.35	2.83
D ₂	45.14	42.45	2.69
D ₃	45.83	41.64	4.19

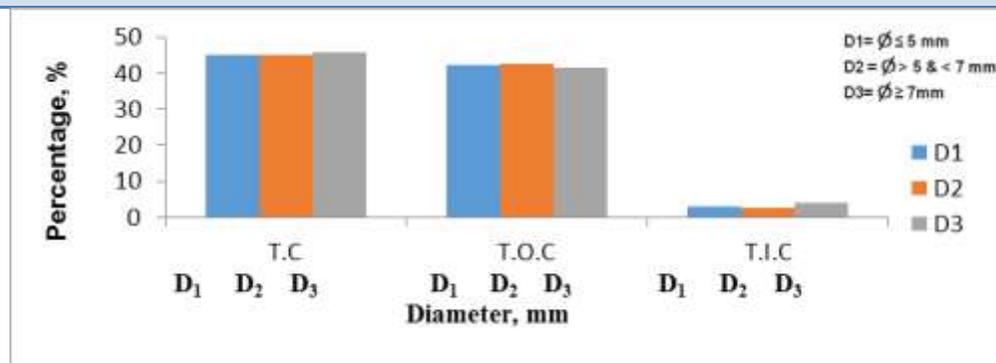


Fig. 8 Effect of sizes of pigeon pea stalk on TC, TOC and TIC

Effect of diameter of bio-char on bulk density

The average value of bulk density of bio-char of size D₁, D₂ and D₃ charring at 450 °C was found to be 230.6, 587.3 and 636.3 kg/m³, respectively. Similarly, the average value of bulk density of size D₁, D₂ and D₃ charring at 500 °C was found to be 547, 590 and 284.3 kg/m³, respectively and it was 548, 579 and 284.6 kg/m³ when charred at 550 °C (Fig. 8).

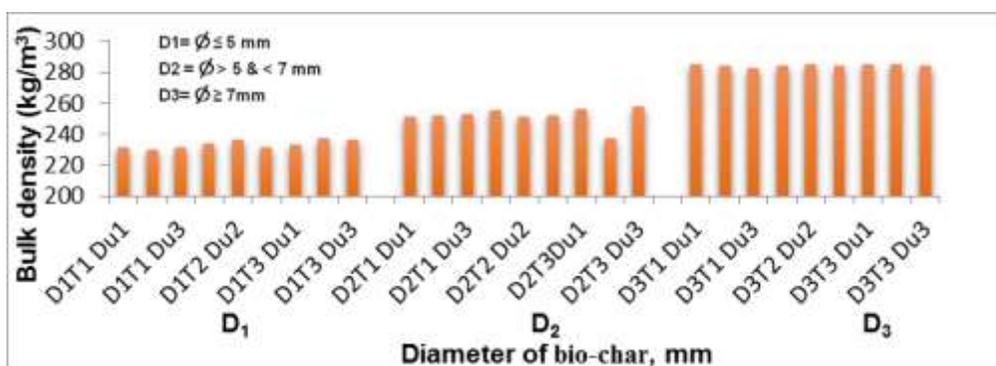


Fig. 8 Effect of diameter of bio-char on bulk density

It is clear from the Fig. 8 that as the diameter of stalk increased the bulk density also increases and the bigger sized produced layered size char. Similarly, the true density of D₁, D₂ and D₃ size of pigeon-pea stalk bio-char was determined and found to be 452.2, 453.6 and 454.4 kg/m³.

Comparison on pigeon-pea stalk and its bio-char

The parameters of pigeon-pea stalk and bio-char was studied and compared in Table 2.

Table 2. Comparison on pigeon-pea stalk and bio-char

Sr. No.	Parameters	Average value	
		Stalk	Bio-char
1	Moisture content ,%	4.45	2.1
2	Volatile matter,%	63.48	42.03
3	Ash content,%	2.23	1.4
4	Fixed carbon,%	29.78	54.30
5	pH value	4.6	7.5
6	Iodine value, mg/gm	253.51	757.6
7	Bulk density, kg/m ³	271.66	256.40
8	True density, kg/m ³	543.03	459.44
9	Total carbon,%	45.39	75.77
10	Total organic carbon (TOC),	42.14	65.54
11	Total inorganic carbon (TIC), %	3.24	5.61

It was observed that about 50 % moisture contents different was observed in pigeon-pea stalk and its bio-char. Similarly, it was seen from the Table 3 that around 30 % different in volatile matter of stalk and its bio-char was observed. Fixed carbon in bio-char was found to be 80 % higher than that of its stalk. Around 40% of total carbon was found higher in bio-char than that of the pigeon pea stalks.

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