ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 07, Issue, 09, pp.15214-15216, September, 2017

ORIGINAL RESEARCH ARTICLE

Open Access

HORIZONTAL REACTOR FOR BIO-CHAR PRODUCTION

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ARTICLE INFO

Article History:
Received 16th June, 2017
Received in revised form
27th July, 2017
Accepted 22nd August, 2017
Published online 29th September, 2017

Keywords:

Crop Residue,
Bio-Char and Horizontal Reactor.

ABSTRACT

A reactor horizontally oriented was developed for bio-char for preparation from agricultural crop residues. 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. 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 $Ø \leq 5$ mm (D_1), Ø = 5 to 7 mm (D_2) and $Ø \geq$ 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.

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Citation: Dere, A.J., Kamble, A. K. and Sandip Gangil. 2017. "Horizontal reactor for bio-char production.", *International Journal of Development Research*, 7, (09), 15214-15216.

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.

MATERIALS AND METHODS

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 in reactor 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. The experiment was planned using three independent parameters namely diameter of stalks, charring temperature and duration. 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.

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

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

RESULTS AND DISCUSSION

Recovery of bio-char

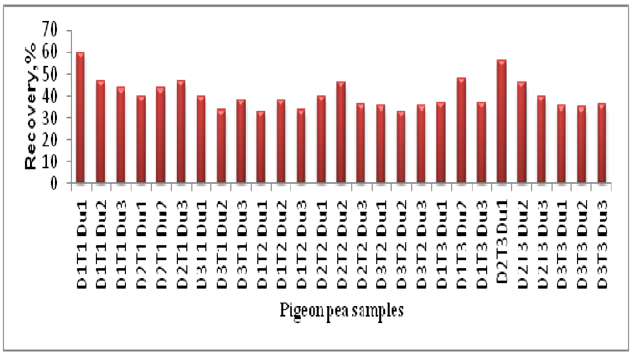

Fig. 2 Recovery of bio-char of 27 samples of pigeon pea

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.

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 %.

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.3 to Fig. 6. 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 remarkeble variation was observed in moisture content, fixed carbon, ash content, volatile matter and fixed corbon of pigeon-pea stalk samples and bio-char samples.

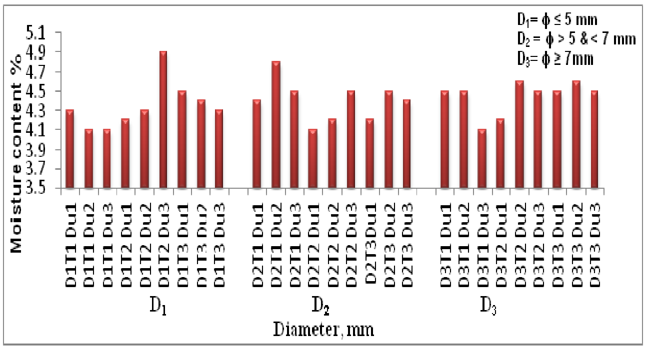

Fig. 3 Effect of sizes of pigeon pea on its moisture content

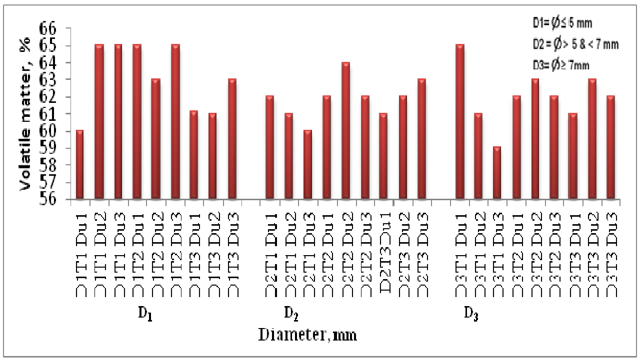

Fig. 4 Effect of sizes of pigeon pea on volatile matter

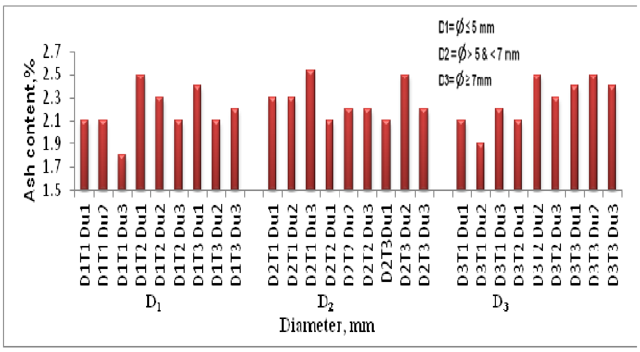

Fig.5 Effect of sizes of pigeon pea on ash content

Iodine value of pigeon-pea stalk was measured and found in the range 201 to 298.

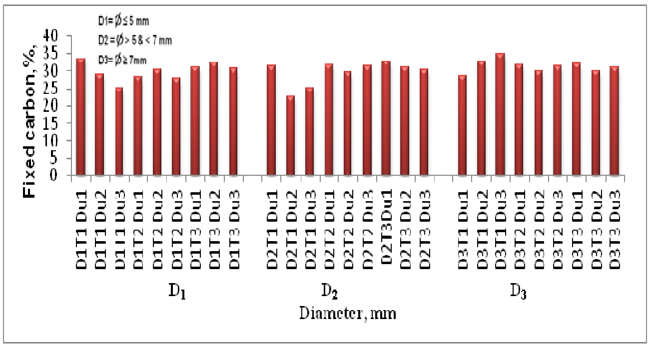

Fig 6. Effect of sizes of pigeon pea on fix carbon

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 D_1 D_2 and D_3 were found out and presented in Fig.7. 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 D_1 size were found to be 45.18, 42.35 and 2.83 %, respectively. Similarly for D_2 it was 45.14, 42.45 and 2.69 % and for D_3 it was 45.83, 41.64 and 4.19 respectively. Very minor variation was observed in D_1 D_2 and D_3 size of pigeon-pea stalks (Table 1).

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

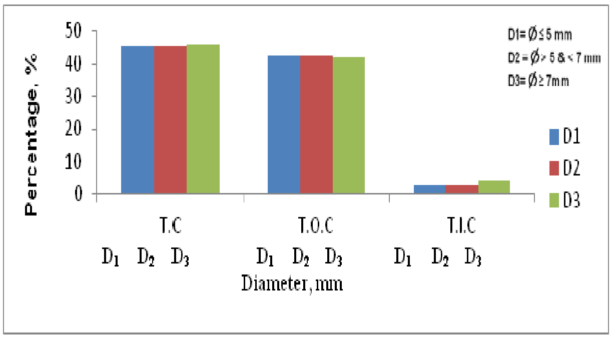

Fig. 7. Effect of sizes of pigeon pea stalk on TC, TOC and TIC

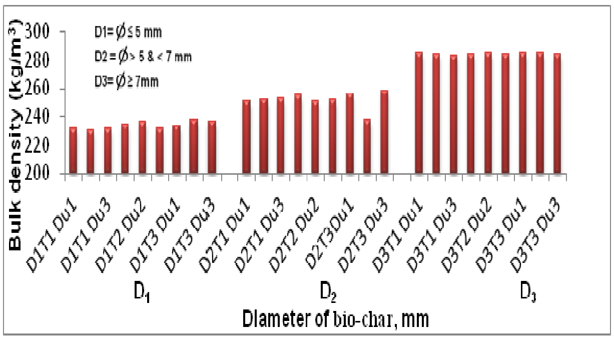

Fig. 8 Effect of diameter of bio-char on bulk density

Effect of diameter of bio-char on bulk density

The average value of bulk density of bio-char of size D_1, D_2 and D_3 charring at 450 °C was found to be 230.6, 587.3 and 636.3 kg/m^3, respectively. Similarly, the average value of bulk density of size D_1, D_2 and D_3 charring at 500 °C was found to be 547, 590 and 284.3 kg/m^3, respectively and it was 548, 579 and 284.6 kg/m^3 when charred at 550 °C (Fig. 8). 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 D_1, D_2 and D_3 size of pigeon-pea stalk bio-char was determined and found to be 452.2, 453.6 and 454.4 kg/m^3. The analysis of pigeon-pea stalk and its bio-char was studied and compared in Table 2. 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.

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

Sr. No.	Parameters	Average value	
		Pigeon pea Stalk	Bio-char of pigeon pea stalks
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

Conclusion

The recovery of bio-char from horizontal bio-char reactor was varied from 33 to 60 % and on an average it was found to be 40.36 %. Fixed carbon in bio-char was found to be 80 % higher than that of its stalk and around 40% of total carbon was found higher in bio-char than that of the pigeon pea stalks.

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