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Development and optimization of pyrolysis unit for producing charcoal

Gitanjali Jothiprakash[1*] and Venkatachalam Palaniappan[2]

[1]Department of Bioenergy, AEC&RI, Tamil Nadu Agricultural University, Coimbatore-641003, India
[2]Department of Agricultural Engineering, AC&RI, Tamil Nadu Agricultural University, Madurai-625104, India

*Corresponding author: jogitanjali@gmail.com

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Abstract

The Developed system is designed to produce the charcoal from biomass samples like Jatropha seed husk, *Melia Dubia* and *Prosopis juliflora.* The technology adopted is hybrid by combining both direct and indirect method of heating the biomass based on pyrolysis. The temperature is in the range of 300 °C to 500 °C. In results of the proximate analysis showed the fixed carbon content is increased in this pyrolysis unit charcoal whereas biomass sample and existing pyrolysis unit charcoal showed lower fixed carbon content. The charcoal yield efficiency is 34.84% whereas in conventional method of charcoal making the charcoal yield efficiency is about 20%. The mass and energy closure were found to be 72.72% and 80.30%.

Highlights

- Pyrolysis unit is first of its kind in using semi in direct heating method
- Creating an economic value and local opportunity to create and use charcoal as charcoal yield is 34% which is higher than conventional method (20%)
- Charcoal was produced with the use of biomass displaces fuel oil and natural gas in domestic heating applications
- It promotes distributed local agriculture productivity and energy production

Keywords: Pyrolysis, charcoal production, charcoal yield efficiency, mass balance, energy balance

Biomass represents the renewable resource with the largest potential to affect energy-related greenhouse gas emissions. The problems caused by solid and liquid waste can be significantly mitigated through the adoption of environmentally waste to energy technologies such as biomethanation, combustion, pyrolysis etc. (Sarbjeet *et al.,* 2013) There are many possible scenarios by which biomass could influence the current energy consumption options and this analysis will attempt to put those options in perspective (Urmila *et al., 2013*). In general, biomass can replace fossil fuels in energy consuming applications (electrical generation, transportation, heating), where the biomass fuel is considered "carbon-neutral", but the overall application is actually "carbon-negative" if one includes the fossil fuels displaced (Lehman *et al*., 2006).

Charcoal is a carbon product derived from biomass that can enhance soils, sequester or store carbon, and provide useable energy. Charcoal presents the ability to produce usable energy during its production while concurrently creating a solid carbon product, which has many value-added uses. (Lehmann, 2007). When biomass is burnt in the absence of oxygen, pyrolysis occurs and the biomass can be turned into

Pyrolysis Unit

Inner view of pyrolysis unit

Figure 1. Pyrolysis Unit and Inner view of pyrolysis unit

a liquid ('bio-oil'), a gas and a high-carbon, fine-grained residue: Charcoal. Charcoal has been made from jatropha husk, *Melia dubia* and *Prosopis juliflora*. However, experimentation with Charcoal has typically been on wood because of its consistency as a material and its relatively low ash content (Spokas *et al.*, 2009)

Materials and Methods

Carbonization procedure (Pyrolysis unit)

This developed pyrolysis unit follows semi – indirect heating method. This pyrolysis unit consists of the black coated cylindrical drum equipped with a removable wire meshed structure of pore size 5 mm, a chimney and a removable lid. The known weight of ignited charcoal is fed in the annular space of the double jacket and the inner wire mesh cylindrical drum which has cone shaped structure at the bottom is filled with known weight of biomass which has to be turned into charcoal. The pyrolysis unit is covered with the air tight lid to complete the reaction and the time is noted and it is termed as reaction/residence time. The temperature of the process is found to be in the range of 300 to 500°C. To cool down and to stop the reaction the lid surrounded by water holding provision is filled with water for one to two hours. After letting out the water, the lid is opened and charcoal is taken and weighed. The pyrolysis unit with the inner view is showed in Figure 1.

The optimization of energy input in terms of charcoal weight is done taking Jatropha husk, *Melia dubia* and *Prosofis juliflora* as a feed material and trials with replication is done.

Characterization of Biomass and charcoal

Jatropha Husk, *Melia dubia* and *Prosopis juliflora* were used in charcoal production. Characteristics of these materials and its charcoal were analyzed as per ASTM standards and given in the table 1. The procedures followed were given as follows. The moisture content of the samples was carried out in a hot air oven at 103 ± 2°C upto the arrival of standard weight. The volatile matter (ASTM-E 872) was found out using the dried biomass/charcoal in a muffle furnace at 650°C for 10 minutes. The ash content (ASTM-E 830) of the biomass/charcoal was determined in muffle furnace at 750°C for 2 hours. The fixed carbon content was found from the weight difference. Calorific value was determined by bomb calorimeter (Jain and Jain, 1991). The mass and energy balance of the pyrolysis unit was calaculated by considering the mass and energy flow along with the loss at each stage (Charles *et al.,* 2010).

Characterization of Biomass and charcoal

Proximate Analysis of Biomass and Charcoal

Results and Discussion

The selected biomass i.e. Jatropha Husk, Melia dubia and Prosopis juliflora used for preparation of charcoal the pyrolysis unit. The selected biomass and its charcoal are showed in Figure 2. The comparative study between biomass and their charcoal with their performance is discussed under characterization of biomass and charcoal, charcoal yield efficiency, mass and energy balance.

Antal and Gronli (2003) stated that moisture content can have different effects on pyrolysis product yields depending on the conditions. The high moisture levels lead to reduced charcoal yields as a greater quantity of biomass must be burnt to dry and heat the feed. Thus the moisture content of biomass various from 7 to 10% moisture content which is well suitable for pyrolysis and coincides with the result of Jeguirim and Trouve (2009). The fixed carbon content of charcoal is found to be increased from initial biomass as referred by Yin (2011) This system yields more carbon content charcoal compared to the existing conventional one by 4 to 5%. The carbon content in the condensate is in the order of 18% for the current method as compared to 13.9% in the direct traditional process due to less exhaust and carbon enrichment inside the kiln. (Rondon *et al*., 2009). The ash content of the charcoal produced found to be in the range of 3 to 4% in case of Jatropha husk and *prosofis julifera* and for *Melia dubia* was 11.65% which was found to be less than the traditional or conventional charcoal (Ogawa *et al.,* (2006).

Figure 2. Selected Biomass and It's Charcoal

Table 1. Proximate analysis

Parameters	Jatropha Husk		Melia Dubia		Prosopis Juliflora	
	Biomass	Charcoal	Biomass	Charcoal	Biomass	Charcoal
Fixed Carbon,%	15.24	37.2	21.07	47.95	28.72	51.25
Volatile Matter,%	70.38	56.3	56.03	36.7	59.57	43.5
Moisture Content,%	9.95	3.1	8.07	3.7	7.29	1.4
Ash Content, %	4.43	3.4	14.83	11.65	4.42	3.85

Table 2. Calorific value Thermal Characteristics - Calorific Value

No.	Feedstock's	Calorific value, MJ kg^{-1}
	Jatropha seed husk – biomass	19.11
	Jatropha seed husk - Charcoal	36.74
	Melia dubia– Biomass	18.26
	Melia dubia - Charcoal	32.64
	Prosopis Juliflora – Biomass	22.31
	Prosopis Juliflora- Charcoal	46.60

Table 3. Optimization trails of selected biomass in charcoal production

Material	Ratio (Ignited charcoal: biomass)	Weight of ignited Charcoal, Kg	Weight of remaining (Ash), Kg	Weight of biomass, Kg	Weight of Charcoal (un burnt), Kg	Reaction time, hours
Jatropha seed husk	0.5:10	0.5	0	10	1.5(3)	1.45
	1.0:10	1	0.1	10	3.5(0)	1.30
	1.5:10	1.5	0.1	10	2.5(0)	1.25
Melia dubia	0.5:10	1	0	20	5(4.4)	1.50
	1.0:10	2	0.05	20	7.49(0)	1.30
	1.5:10	3	0.6	20	6.2(0)	1.25
Prosopis juliflora	0.5:10	1.5	0.1)	30	7.5(3.7)	1.35
	1.0:10	3	0.1	30	11.5(0)	1.20
	1.5:10	4.5	0.4	30	8(0)	1.30

Parikh *et al.* (2005) analyzed the higher heating value of biomass would be 16-22 MJ kg^{-1} The calorific value of biomass was found to be in the range of 18.26 to 22.31 MJ kg^{-1} with the results of Parikh *et al.* (2005). The calorific values of charcoal's came in the range of 32.64 to 46.60 MJ/kg and matches with the results of (Erol *et al.,* 2010), which is more when compared with the calorific value of biomass sample. It shows that to enhance the energy in the biomass; the biomass can be converted into charcoal.

Optimization Trials

From Table 3 it is found the ratio for producing charcoal is 1:10 yields good result and the charcoal yield also increased. There by the traditional charcoal production method can be replaced by a more energy

efficient and environmental friendly process. This process can be used in industries where charcoal production is carried out using electricity.

Charcoal Yield Efficiency

The charcoal yield efficiency of the pyrolysis unit is calculated as follows.

Mass of charcoal produced = 11 to 12, i.e 11.5 Kg

Mass of ignited charcoal used = 3 Kg

Mass of biomass taken = 30 Kg

Charcoal Yield efficiency = (11.5/(30 + 3)) x 100
= 34.84 %

This efficiency is found to be increased when compared with the traditional method of producing

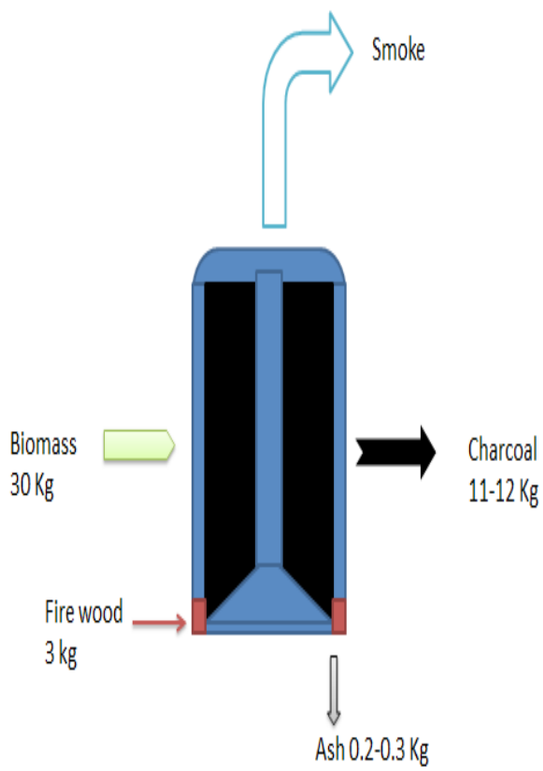

Figure 3. Mass balance pictorial representation

charcoal and pictorial representation is represented in the Figure 3.

Mass Balance and Energy Balance

Mass balance closure was found out to represent the accuracy of the system and methodology adopted.

Mass input = Mass of Biomass + Mass of Ignited charcoal = 11 kg

Mass output = Mass of charcoal + Mass of Ash + Mass of Flue gas + Mass of Unburnt = 8 kg

Mass closure, per cent = 72.72

Thus the mass closure for the pyrolysis unit is found to be 72.72%.

An energy study makes an attempt to critically evaluate the studies to make a breakthrough in agricultural sector (Murugan, 2011). Energy balance closure was found out to represent the efficiency of the system and methodology adopted.

Energy input = Energy content in Biomass + Energy content in ignited charcoal = 132 MJ

Energy output = Energy content in (Charcoal + Ash + Flue gas + Un burnt) = 106 MJ

Energy closure, per cent = 80.30

Thus the energy closure for the pyrolysis unit is found to be 80.30%.

This mass closure and energy closure efficiency coincides with the result of Chew and Doshi (2011). As he stated that pyrolysis is a thermal treatment of biomass typically in the temperature range of 200 - 300°C with reactor residence time from 15 minutes to 3 hours. The process typically retains 70% of the mass closure and 85% of energy closure efficiency. The mass lost during pyrolysis are high oxygen content and low energy content compounds, which improves the fuel quality of the biomass.

Conclusion

The present study was undertaken to preparation of charcoal from the Jatropha seed husk, *Melia Dubia* and *Prosopis juliflora* with 3 kg of ignited charcoal as energy input. Selected biomass dried in the solar tunnel dryer developed by Tamil Nadu Agricultural University. Reduced the moisture content of biomass

at optimum level and utilized to make charcoal. During this work different characteristics such as proximate analysis and thermal property are studied. These characteristics were studied with the help of these instruments such as muffle furnace, bomb calorimeter and hot air oven.

Conclusions are as following,

(1) In results of the proximate analysis showed the fixed carbon content is increased in developed pyrolysis unit charcoal whereas biomass sample showed lower fixed carbon content.

(2) Calorific values of charcoal's came in the range of 32.64to 46.60 MJ/kg, which is more when compared with the calorific value of biomass sample.

(3) Charcoal yield efficiency is increased from 19.69 (conventional method) to 34.84% (developed unit).

(4) The mass and energy closure were found to be 72.72% and 80.30%.

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