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Physico-chemical and thermal properties of different biomass material selected for thermal gasification

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ABSTRACT : Agricultural and forest biomass material were reported to be the potential feedstock for gasification by various researchers. The physical, chemical and thermal properties of biomass material play very important role in order to characterize the feedstock for energy conversion process. The physical properties (moisture content and bulk density), chemical properties (volatile matter content, ash content and total carbon content) and thermal properties (calorific value) of selected agricultural and forest biomass *viz.*, pigeonpea stalk (*Cajanus cajan*), cotton stalk (*Gossypium hirsutum*) and vilaytee babool (*Prosopis juliflora*) for different length of sizes ranging from 25-50, 50-75 and 75-100 mm were determined using standard procedures. The moisture content of pigeonpea stalk, cotton stalk and vilaytee babool were found to be 3.28, 6.98 and 9.45 per cent, respectively. While the bulk density of these feed stock were reported to be 501, 465 and 556 kg m^{-3}, respectively. The volatile matter content, ash content and total carbon content of pigeonpea stalk were 80.67, 1.39 and 17.94 per cent, respectively. While for cotton stalk these were 80.20, 1.43 and 18.37 per cent. Whereas, vilaytee babool these were 80.81, 1.83 and 17.36 per cent, respectively. The calorific value of 16.44, 16.05 and 17.49 MJ kg^{-1} was observed for pigeonpea, cotton stalk and vilaytee babool, respectively. The results obtained from the study indicated that the selected agricultural and forest biomass material were found to be potential for thermal gasification.

KEY WORDS : Ash content, Biomass material, Bulk density, Calorific value,Total carbon content, Volatile matter content

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Biomass is the term used for materials or derivatives left behind by the organic living things of both terrestrial and aquatic variety and generate their energy from the sun through photosynthesis. Biomass is considered as renewable energy source with the highest potential to contribute to the energy needs of modern society for both the developed and developing countries world- wide for reducing the greenhouse gases emissions and to the problems related to climate change.

The demand for energy sources to satisfy human energy consumption continues to increase. Prior to the use of fossil fuels, biomass was the primary source of energy for heat via combustion. With the introduction of fossil fuels in the form of coal, petroleum and natural gas, the world increasingly became dependent on these fossil fuel sources. The use of plastics and other chemicals which are derived from these fossil fuels also have increased (Fischer and Schrattenholzer, 2001). Although it is not known how much fossil fuel is still available, it is generally accepted that it is being depleted and is non-renewable. Given these circumstances, searching for other renewable forms of energy sources is reasonable. Other consequences associated with fossil fuel use include the release of the trapped carbon in the fossil fuels to the atmosphere in the form of carbon dioxide which has led to increased concerns about global warming (Faaji, 2001 and Parikka, 2004). Also, fossil fuel resources are not distributed evenly around the globe which makes many countries heavily dependent on imports.

The generation of electricity from biomass, no doubt this concept is certainly not new, humans have been burning wood for cooking and heating for thousands of years. It is difficult to say for certain how extensive the use of biomass is as an energy source today because some of the more traditional and non-commercial uses tend to be hard to account accurately or go unreported. Worldwide, biomass is the fourth largest energy resource, providing 14 per cent of the world's energy needs approximately (Mishra *et al.*, 2010). In developing countries, usage of biomass accounts for approximately 35 per cent of the energy used and in the rural areas of these nations, biomass is mostly the only accessible and affordable source of energy (Tomar, 1995). Biomass can be converted into liquid, solid and gaseous fuels with the help of some physical, chemical and biological conversion processes.

In India, potential availability of biomass is 500 million metric tonnes (MMT). In the same way, the Karnataka state has potential availability of 39.1 MMT of different biomass. The surplus agro-residue availability in Karnataka is about 7.15 million tonnes (MT) with power production potential of about 930 MW (Kumar *et al.*, 2015).

Agricultural and forest biomass material were reported to be the potential feedstock for gasification by various researchers. The physical, chemical and thermal properties of biomass material play very important role in order to characterize the feedstock for energy conversion process.

Rao *et al.* (2004) analysed physico-chemical properties of biomass material for counter current fixed-bed gasification. The moisture content was observed in wood chips was 9.55 per cent and length of wood chips varied from 40-60 mm and the volatile matter content, ash content and fixed carbon content of wood chips were 83.20, 1.30 and 15.50 per cent, respectively.

Khardiwar *et al.* (2014) analysed physical and chemical properties of briquettes for gasification. The results showed that length of soybean briquette, pigeonpea briquette and mixed briquette was varied from 60-85, 65-90 and 65-80 mm, respectively, whereas, the diameter of briquette of soybean, pigeonpea and mixed briquettes was 60, 30 and 60 mm, respectively were as bulk density of soybean briquette, pigeonpea briquette and mixed briquette was 618, 675 and 518 kg m^{-3}, respectively.

Garge and Sharma (2013) analysed chemical properties of biomass material for running gasifier engine system using different feed stocks. The results showed that volatile matter content of sawdust pellets, pine wood pellets, sal wood pellets, eucalyptus wood pellets and popular wood pellets was 82.77, 80.29, 78.7, 79.76 and 72.3 per cent, (d. b), respectively, whereas, the ash content was 17.13, 19.16, 20.30, 19.92 and 17.20 per cent, respectively. The fixed carbon content of sawdust pellets, pine wood pellets, sal wood pellets, eucalyptus wood pellets and popular wood pellets was 0.10, 0.55, 1.00, 0.32 and 1.20 per cent, respectively.

Keeping the above parameters, the present investigation was conducted to evaluate the physical, chemical and thermal properties selected biomass material *viz.*, pigeonpea, cotton stalk and vilaytee babool for thermal gasification.

■ METHODOLOGY

Selection of biomass materials for gasification :

The selection of biomass material is one of the important parameters in the gasification experimentation. The biomass material selected for the gasification should have lesser moisture content, high bulk density, lower calorific value, low percentage of ash and nitrogen contents.

In the present study, the biomass materials were selected keeping the above properties in view and their ease of availability. Also, the biomass material selected should be of low price and these materials should help in increasing the useful life of the gasifier.

The biomass material selected for the study were, pigeonpea stalk (*Cajanus cajan*), cotton stalk

(*Gossypuim hirsutum*) and vilaytee babool (*Prosopis juliflora*).

Size of samples :

The physical dimensions *viz.*, length and diameter of biomass material play very important role in gasification. The optimum length of the gasifier feed material is about 25-100 mm depending on the capacity of gasifier. The required cotton stalk, pigeonpea stalk and vilaytee babool woods were collected from the Main Agricultural Research Station (MARS), University of Agricultural Sciences, Raichur, Karnataka. These biomass materials had higher length and diameter. Hence, there was a need to reduce the length of cotton stalk, pigeonpea stalk and vilaytee babool wood. The biomass material were cut into required length of 25-100 mm by a wood cutter machine as suggested by Ladan *et al.* (2006).

Moisture content :

Moisture content of sample (wet basis) is defined as the ratio of mass of water in the sample to the mass of dry matter contained in it. Moisture content plays an important role in the process of gasification as water is required for a number of reactions in the process. It was computed using ASTM D3173-11 test procedure (Ahmad *et al.,* 2013). The optimum moisture content required for gasification is about below 10 per cent. The raw stalk collected had higher moisture content which needs to be reduced to required levels (less than 10 %) of moisture content. This level was achieved by drying in open sun for about 5-7 days in case of cotton stalk, pigeonpea stalk and 8-10 days for vilaytee babool. The moisture content was determined using the procedure as explained below.

A known weight of feed material sample was kept in a aluminium container and kept in a hot air oven at 105^0 C for 24 hours (Plate A). The sample was taken out and placed in desiccators for one hour. After this the initial and final weight of the sample was recorded using a digital balance. This procedure was repeated thrice for each sample and the moisture content was computed using the following formula and the average values were repeated.

$$\mathbf{M.C.(\%)} = \frac{(W_1 - W_2)}{(W_1 - W_3)} \times 100$$

where,

Plate A : A view of hot air oven for determining the moisture content of different biomass material

W_1 = Weight of aluminium box with sample before drying, g

W_2 = Weight of aluminium box with sample after drying, g

W_3 = Weight of empty aluminium box, g

Total solids :

The total solids play a vital role in determination of bulk density of material, which is important from the point of gasification. The per cent of total solids calculated using the formula as given below.

Per cent total solids = 100 - moisture content

Bulk density :

The bulk density of biomass material is another important factor in achieving the higher calorific values. The bulk density was computed using the method as suggested by Shinde and Singarvelu (2014).

A vessel of standard volume was filled with biomass material sample. The weight of the sample was measured in a precision electrical balance with an accuracy of 0.1 g. The bulk density was calculated as the ratio of weight of the material to the volume of the vessel. The procedure was repeated thrice for each sample and average values were recorded.

$$\text{Bulk density, kg m}^{-3} = \frac{\text{Weight of sample}}{\text{Volume of vessel}}$$

$$\text{B.D.} = \frac{(W_2 - W_1)}{V}$$

where,

W_1 = Weight of empty aluminium box, kg

W_2 = Weight of aluminium box with sample, kg

V = Volume of the vessel, m^3.

Volatile matter :

The volatile matter content of biomass was determined using ASTM D/3175-11 test Birwatkar *et al.* (2014). One gram of oven dry sample of biomass was weighed, placed in a silica crucible and kept at 600^0 C for a period of six minutes in a muffle furnace. These samples were kept at 750^0 C for another six minutes in the same furnace and final weight was recorded. The initial and final weight due to the loss of volatile matter was calculated to be as volatile solids of the sample. The same procedure was repeated thrice for each sample and average values were recorded (Plate B).

Plate B : A view of muffle furnace for determining the chemical properties of different biomass material

$$\text{Volatile matter (\%)} = \frac{(W_2 - W_3)}{W_1} \times 100$$

where,

W_1 = Initial weight of sample, g

W_2 = Weight of sample along with crucible before ashing, g

W_3 =Weight of sample along with crucible after ashing, g

Ash content :

Ash content of a biomass represents amount of residue left after complete combustion of biomass. The ash content of the sample was determined using ASTM [illegible] *et al.*, 2004). A known mass of dried biomass sample was taken in silica crucible and heated gradually in a muffle furnace at 750^0 C for two hours till a constant weight was reached. The weight of the residue left in crucible represents the ash content of the sample. Final weight of the sample was recorded using digital balance. The same procedure was repeated thrice for each sample and average values have been tabulated.

$$\text{Ash content (\%)} = \frac{W_2 - W_3}{W_1} \times 100$$

where,

W_1 = Initial weight of sample, g

W_2 = Weight of sample along with crucible before ashing, g

W_3 =Weight of sample along with crucible after ashing, g

Fixed carbon content :

Fixed carbon content was determined by subtracting the summation of ash, volatile and moisture content from 100 (Rao *et al.*, 2004).

Fixed carbon (%) = 100 - (Ash content + Volatile matter)

Calorific value :

An isothermal oxygen bomb calorimeter confirming to the requirements of Indian standards (IS: 1359; 1959), British standards (BS: 1016; Part 5: 1967) and the institute of petroleum (IP: 12/63T) was used to determine the calorific value of biomass material Birwatkar *et al.* (2014) (Plate C). The procedure used for determination of calorific value is explained below.

Initially, the cleaned and dried crucible was weighed and one gram of test sample was kept in the crucible. A piece of fuse wire made of platinum was tied across the two electrodes such that the tip of the wire was just above the surface of the sample. A cotton thread of 150 mm length was rounded over the fuse wire. Two ml of distilled water was poured in the bomb. The lid of the bomb was tightened by hand and bomb was charged by oxygen without replacing the inside air until pressure gauge indicated a value 25 kg cm^{-2}. The charged bomb was checked for leakage and placed inside the calorimeter vessel, which was then placed in the calorimeter bucket. A known amount of water was poured in the vessel until the bomb was completely submerged except its terminals. Bomb materials were

Plate C : A view of bomb calorimeter for determining the calorific value of differentbiomass material

connected to the ignition through firing unit of the calorimeter and cover plate. This unit was placed with thermometer and a stirrer which was rotating at 600 rpm.

The vibrator and magnifier units of the calorimeter were set and apparatus was kept idle for 10 minutes. The charge filled in the bomb was fired by closing the circuit and temperature was measured for every one minute interval. The temperature was measured until the rate of change of temperature becomes constant. The test procedure was repeated for three times for each test sample and average values were tabulated. The calorific value of test samples were calculated as follows:

$$CV = \frac{W \times T}{M}$$

where,

CV = Calorific value of test sample kcal kg^{-1}

W = Water + water equivalent of the calorimeter assembly, kcal $^{o}C^{-1}$

T = Rise in temperature, ^{o}C

M = Mass of the test sample burnt, kg

RESULTS AND DISCUSSION

The results pertaining to different physical properties of biomass material like; diameter of sample, moisture content, bulk density and total solidsof three different feed stock materials are presented in Table 1. The diameter of cotton stalk, pigeonpea stalk and Vilaytee babool wood varied from 6-18, 5-16 and 11-48 mm, respectively for 25-100 mm length of feed stock material. The moisture content was maximum (9.45%) for vilaytee babool wood material followed by cotton stalk (6.98%) and minimum of 3.28 per cent for pigeonpea stalk. The total solid was maximum for pigeonpea stalk (96.72%) followed by cotton stalk (93.02%) and minimum of 90.55 for vilaytee babool. The maximum bulk density of 556 kg m^{-3} was observed for vilaytee babool, followed by pigeonpea stalk (501 kg m^{-3}) and minimum of 465 kg m^{-3} for cotton stalk.

The chemical and thermal properties of biomass material *viz.*,volatile solid content, ash content, fixed carbon and calorific value of three different feed stock materials are presented in Table 2. The maximum volatile solids content of 80.81 per cent was observed for vilaytee babool followed by pigeonpea stalk (80.67 %) and a minimum of 80.20 per cent for cotton stalk. The maximum ash content of 1.83 per cent was observed for Vilaytee babool followed by cotton stalk (1.43 %) and a minimum of 1.39 per cent for pigeonpea stalk. The maximum fixed carbon content of 18.37 per cent was observed for cotton stalk followed by pigeonpea stalk (17.94 %) and a minimum of 17.36 per cent for vilaytee babool. The maximum calorific value was observed for vilaytee babool (17.49 MJ kg^{-1}) followed by pigeonpea stalk (16.44 MJ kg^{-1}) and a minimum of 16.05 MJ kg^{-1} for cotton stalk.

Conclusion :

Physico-chemical and thermal properties of feedstock material play a very important role in

Table 1 : Physical properties of selected biomass material

Sr. No.	Types of biomass material	Size of biomass material (mm)	Diameter (mm)	Moisture content (%)	Total solids (%)	Bulk density (kg m^{-3})
1.	Pigeonpea stalk	25-50	6-10			
		50-75	6-14	3.28	96.72	501
		75-100	6-18			
2.	Cotton stalk	25-50	5-10			
		50-75	6-13	6.98	93.02	465
		75-100	6-16			
3.	Vilaytee babool	25-50	11-18			
		50-75	18-26	9.45	90.55	556
		75-100	18-46			

Table 2 : Chemical and thermal properties of selected biomass material

Sr. No.	Types of biomass material	Size of biomass material (mm)	Volatile matter (%)	Ash content (%)	Total carbon content (%)	Calorific value (MJ kg^{-1})
1.	Pigeonpea stalk	25-100	80.67	1.39	17.94	16.44
2.	Cotton stalk	25-100	80.20	1.43	18.37	16.05
3.	Vilaytee babool	25-100	80.81	1.83	17.36	17.49

gasification. Hence, physico-chemical and thermal properties of selected biomass material were analysed for thermal gasification. The moisture content was maximum 9.45 per cent for vilaytee babool and a minimum of 3.28 per cent for pigeonpea stalk. The bulk density of (501, 465 and 556 kg m^{-3}) was observed for pigeonpea stalk, cotton stalk and vilaytee babool, respectively. The maximum volatile solids content of 80.81 per cent was observed for vilaytee babool followed by pigeonpea stalk (80.67 %) and a minimum of 80.20 per cent for cotton stalk.The ash content of pigeonpea stalk, cotton stalkand vilaytee babool were found to be 1.43, 1.39 and 1.83 per cent, respectively. The total fixed carbon content was maximum (18.37 %) for cotton stalk and a minimum (17.36 %) for vilaytee babool. The maximum calorific value was observed for vilaytee babool (17.49 MJ kg^{-1}) followed by pigeonpea stalk (16.44 MJ kg^{-1}) and a minimum of 16.05 MJ kg^{-1} for cotton stalk. Vilaytee babool as the highest calorific value and bulk density compared to other biomass material. Among the three-selected biomass material, the vilaytee babool has great potential compared to pigeonpea and cotton stalks, respectively.

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