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RESEARCH ARTICLE

Physical and thermo-chemical characterization of agricultural residues and municipal waste

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ABSTRACT: Characteristics of crop residues such as size, angle of repose, colour and density, calorific value, percentage of moisture content and chemical composition affect the production of bio-fuels. These properties also affect drying and handling of biomass and the design of thermal conversion systems. These characteristics can vary noticeably from waste to waste. In this study, four local varieties of rice straw (Nabina, Tamapasara, Swarnaand NuaAchharmati), sugarcane bagasse, coconut coir and vegetable waste were characterized. Study revealed that the sugarcane bagasse has the darker color, higher particle density (384.66 kg.m^{-3}) compared to others tested biomass. Sugarcane bagasse contained highest percentage 82.7% of volatile matter followed by coconut coir, vegetable waste and rice straw. Rice straw variety Nabina has shown the highest calorific value 22.98 MJ/kg compared to Tamapasara, Swarna and NuaAchharmati and can be utilized for biofuel production.

1. INTRODUCTION

Agricultural residues are the organic matter which is available in the environment. These biomass remains underutilized and most of the agricultural crop residues are burnt in the field that creates environment pollution, destroys essential micro-organisms and degrades the soil fertility. Biomass is an important source of energy generation through thermo-chemical conversion process. Municipal solid wastes include wastes generated from domestic, commercial, industrial, and construction activities. In India, biomass energy potential is approx. 16000 kW and total production of crop residues is approx. 650 million tonne/annum. The municipal solid waste potential of India is about 1,45,626 million tonne/day. Biomass is the only naturally occurring energy-containing carbon resource that is large enough in quantity to be used as a substitute for fossil fuels. Energy can be produced by biomass from different conversion processes like direct combustion, co-firing, thermo-chemical(gasification, and pyrolysis) and biochemical (anaerobic digestion, fermentation and esterification) processes. Biomass is bulky, loose, and dispersed in its natural form. Hence, they are difficult to handle during utilization and do not present economical, efficient transportation and storage characteristics due to low bulk density of bales 40-200 kg.m^{-3}(Tabil 1996; Sokhansanj *et al.*, 2005; Sokhansanj *et al.*, 2006; Mani *et al.*, 2006; Adapa *et al.*, 2009).The conversion efficiencies are as low as 40% with widespread of air pollution in the form of very fine particulate matters (Grover and Mishra 1996; Granada *et al.* 2002; Kaliyan and Morey 2009).

The studies on different physical and thermo-chemical properties of agro residues and municipal solid waste (MSW) has been conducted by Barmina *et al.* (2012) and Geyer *et al.*(1994). They have studied particle size, shape, angle of repose, density (bulk density and true density), colour (engineering properties) moisture content, calorific value, proximate analysis (volatile matter and ash content), ultimate analysis (C,H,N,O,S). A deep perception of biomass physical properties and their parameters for characterizing are required for safe processing and utilization. These properties are also highly affecting the design of handling and transportation systems, feeding in combustion process, storage in hoppers, bins and silos, and fuel conversion methods. Therefore, in this study physico-thermo-chemical characterization of selected agricultural

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residues and municipal solid wastehas been conducted aiming to commercial level utilization of biomass for biofuels production.

2. MATERIAL AND METHODS

2.1. Materials

In the present study four local varieties of rice straw namely as *Tamapasara*, *Swarna*, *Nabina*, *Nua Achharmati* and other agricultural residue sugarcane bagasse, coconut coir and vegetable wastes as municipal solid waste, has been selected for the experiments**.** Sugarcane bagasse and coconut coir were collected locally from the vendors of Bhubaneswar. Vegetable waste was collected from a local hostel. During the experiment, the samples were kept for drying under the sun for 8 hours continuously for 3 days. The dried samples were analyzed for their properties and there were five replicas for the experiments.

2.2. Engineering Properties of Biomass

2.2.1. Particle size distribution

Particle size distribution of the samples were assessed by sieve analysis following ASTM El1-95 standard method (Jillavenkatesa *et al.*, 2001). The sieves used were 212, 180,150,106, 0.075 and 0.063 mm. The sample size of 150 mm of biomass was used in the experiment.

2.2.2. Angle of repose

Angle of repose was determined by the laboratory setup as shown in Fig. 1. The sample was filled into the funnel and allowed to pile on the retainer plate. The pile height and diameter of the retainer plate was measured through the meter scale and the angle of repose was measured by using the equation (1).

$$\text{Angle of repose } (\alpha) = \tan^{-1}\left(\frac{h}{r}\right) \quad \ldots(1)$$

Where α is the angle of repose in degree; h is the pile height (cm) and r is the radius of the retainer plate (cm).

Fig. 1. Angle of repose measuring setup.

2.2.3. Colour

The colour of biomass was measured by the colorimeter CR-20 (Konica Minolta, INC, Japan). The colour of biomass with the range of different degree for thermal treatment was measured by the colorimeter. The variation in colour coordinates was calculated as the difference between the measured values for L^*, a*, and b^*coordinates for the untreated and treated biomass, Where the colour coordinates L^*, a^*, and b^* (lightness, redness/greenness, and yellowness/blueness) were determined for each sample. The differences are expressed in percentage of the initial treated and untreated value.

$$\Delta L = \left(\frac{L^*_{treated} - L^*_{untreated}}{L^*_{untreated}}\right) \times 100 \quad \ldots(2)$$

$$\Delta a = \left(\frac{a^*_{treated} - a^*_{untreated}}{a^*_{untreated}}\right) \times 100 \quad \ldots(3)$$

$$\Delta b = \left(\frac{b^*_{treated} - b^*_{untreated}}{b^*_{untreated}}\right) \times 100 \quad \ldots(4)$$

2.2.4. Density

A 50 g biomass sample was filled into a 100 mL graduated cylinder. Volume of the sample was noted with gentle tapping and the bulk density was calculated by using the equation (5).

$$\text{Bulk density } (\rho_b) = \left(\frac{weight\ of\ the\ sample}{volume\ of\ the\ sample\ in\ graduated\ cylinder}\right) \quad \ldots(5)$$

Particle density was measured using pycnometer. The weights of empty pycnometer without sample and with sample were recorded. Then the pycnometer was filled with toluene and the total weight was recorded. The particle density was calculated by using equation (6).

$$\text{Particle density } (\rho_p) = \left(\frac{Total\ weight\ of\ sample\ in\ pycnometer}{Total\ volume\ of\ sample\ in\ pycnometer}\right) \quad \ldots(6)$$

2.3. Calorific Value

The calorific value of samples was measured by using a bomb calorimeter. One gram of the sample was taken in a nichrome crucible. A 15 cm long cotton thread was kept over the sample in the crucible to facilitate ignition. Both the electrode of the calorimeter was connected by a nichrome fuse wire. Oxygen gas was filled in the bomb at a pressure of 25 to 30 atm. The water (2 litter) taken in the bucket was continually stired to keep homogenous temperature. The sample was ignited by switching on the current through the fusing wire and the rise in temperature of the water is automatically recorded. The following equation was used to determine the calorific value of the sample.

Calorific value = $\left(\frac{2520 \times \Delta T}{\text{weight of sample}}\right)$ – heat relased by cotton + heat released by fuse wire …(7)

2.4. Proximate Analysis

2.4.1. Moisture content

Moisture content was determined using hot air oven at 104°C for 24 h to obtain over dry weight as per standard of ASTM, E871.

$$\text{Moisture content, \% (w.b.)} = \frac{(W_2 - W_1) - (W_3 - W_1)}{(W_2 - W_1)} \times 100 \quad \ldots(8)$$

Where, W_1 - weight of crucible, g; W_2 - weight of sample + crucible, g; W_3 - weight of sample + crucible after oven drying, g.

2.4.2. Volatile matter

The oxidized sample was measured into a known weight of crucible with lid. The crucible was kept into a high-temperature muffle furnace set at 950°C and heated for 7 minutes as per standard of ASTM, E872. Then the crucible was taken out from the furnace and allowed to cool down in the desiccators. The weight of the sample was determined again when it reached the room temperature, both initial (W_i) and final (W_f) weights were recorded. Volatile matter percentage has been determined by using following equation

Volatile matter percentage (VM %) =

$$\frac{(W_i - W_f)}{W_i} \times 100 - \%\, MC \quad \ldots(9)$$

2.4.3. Ash content

One gram of sample was put into known weighted crucible without a lid. The sample was heated in a high-temperature muffle furnace set at 600°C for 4 hours. Then, the crucible was taken out from the furnace and it was cooled in the desiccator until it reaches room temperature, both initial (W_i) and final (W_f) weights were recorded (ASTM D1102).

$$\text{Ash content (AC)} = \frac{W_f}{W_i} \times 100 \quad \ldots(10)$$

2.4.4. Fixed carbon

The fixed carbon (FC) indicates the calorific value of the biomass. This was obtained by subtracting the percentages of moisture, volatile matter and ash content from 100.

FC = 100 – (% MC + % VM + % AC) …(11)

2.5. Ultimate Analysis

It is the process of predicting the chemical composition of biomass such as carbon, nitrogen, oxygen, hydrogen, and sulphur. During the experimentation, the sample was burned in a crucible in presence of oxygen to convert the sample into carbon dioxide and water. Elemental composition (C, H, N, and S) of the ash sample was measured using a micro elemental analyzer (UNICUBE, maximum furnace temperature 1200°C, combustion point furnace temperature 1800°C, precision > 0.1% absolute, analysis time ≥ 7 minutes). The recorded data were downloaded from the elemental analyzer to PC using windows® based UNICUBE® operating software.

3. RESULTS AND DISCUSSION

3.1. Engineering Properties of Biomass

The colour L*, a* and b* coordinates measured for selected biomass is presented in Fig. 2. Colour property is important for quality control and a quick estimation of fuel properties (e.g., heating value). Darker biomass produces more heat and efficient energy. Vegetable waste has shown the darker colour followed by bagasse and coconut.

The observed angle of reposes is shown in Fig. 3. In powder form, coconut coir and sugarcane bagasse showed a different texture and consequently posed significant difference in angle of repose. The data of angle of repose is used as design parameter of hopper design and for easy handling.

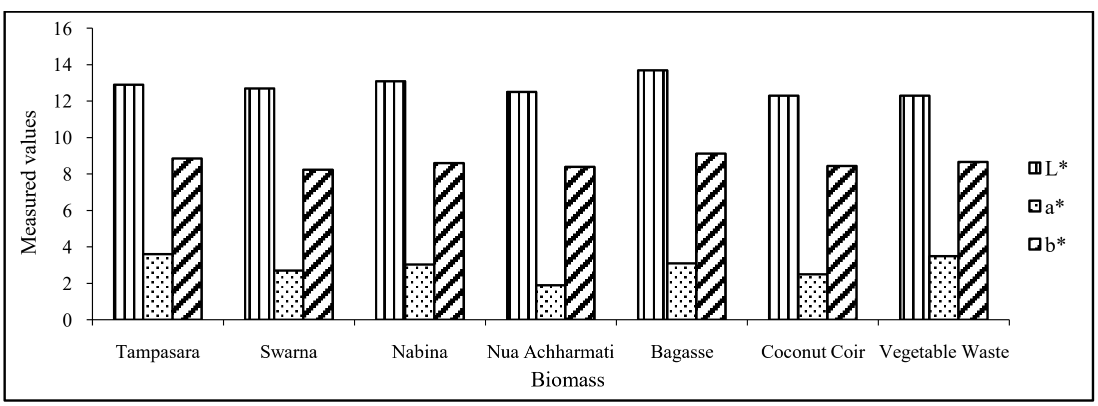

Fig. 2. Colour values of different biomass.

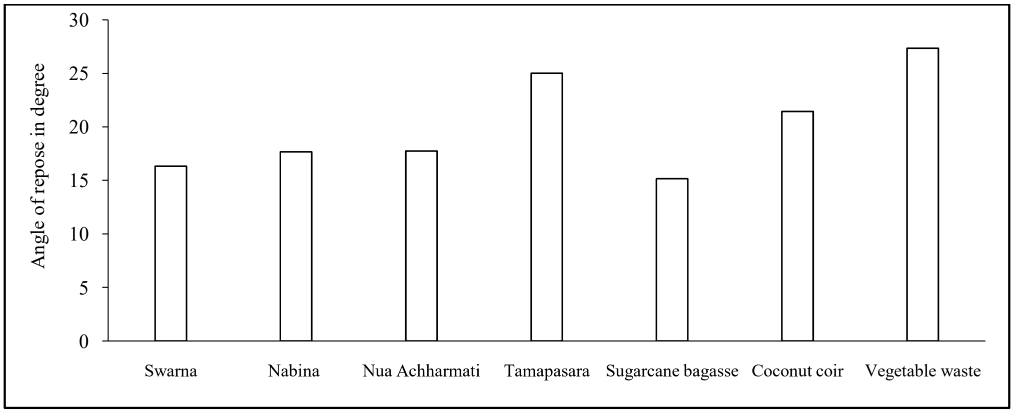

Fig. 3. Angle of repose of biomasses.

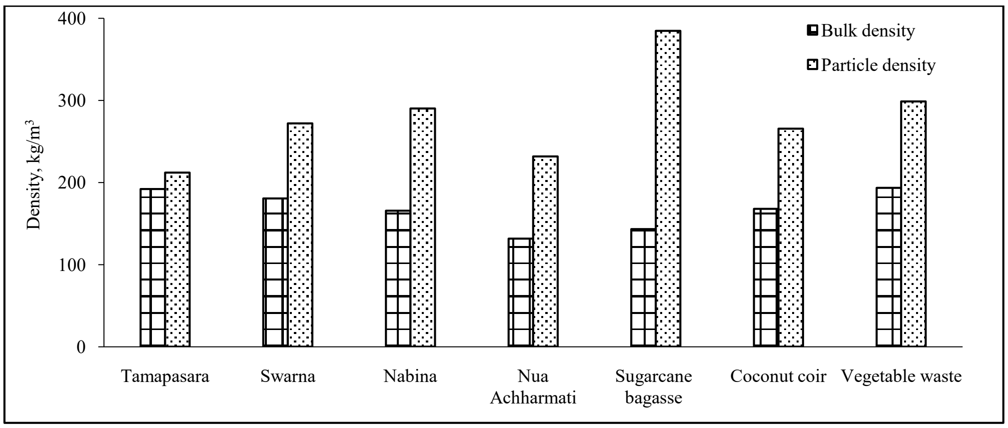

Fig. 4. Bulk and particle density of biomasses.

Density is used for supply logistics, transportation, and storage of biomass in different forms: chips, logs, ground particles and pellets, *etc*. *Swarna* (rice straw) has more density as compared to other biomass (Fig. 4). It is evident from Fig. 4, the bagasse has more particle density as compared to tested biomass.

Moisture content is important as design parameter for drying and thermal conversion process. Moisture in the range of 12-18% is acceptable for conversion process (Gagliano, 2018). Higher moisture content is responsible for water activity, which supports the microbial activity and contaminant the process (Wihersaari, 2005). Moisture content values for selected four varieties of biomass are shown in Fig. 5. Moisture content in the range of 9 to14 % was observed for the selected biomass. *Nua Achharmati* has the higher moisture content as compared to other materials. The coconut coir has the lowest moisture content (Fig. 5).

3.2. Calorific Value and Composition

The calorific value has been found highest in *Nabina* variety of rice straw 22.98 MJ/kg among of all selected samples (Fig. 6). Calorific value is a key for heating property and energy recovery efficiency. Sample with higher calorific value is good for gasification process. Proximate analysis data is used for estimation of the potential risk of slagging and fouling issues during biomass conversion process. It is found that, *Nabina* has acceptable physical and thermal properties (Fig. 6 to 8). Presence of nitrogen and sulphur in samples are responsible for tar and pollutant production. It can be observed from Fig. 8 that, vegetable waste has more nitrogen and sulphur content reflecting the fact that vegetable waste can cause more pollution and harmful.

The results observed in the study are in agreement with the observations made by Chaney (2010). He reported that the analysis of biomass for gas production has the energy constituents comprising of 30% and 50% of the dry matter and 30% to 50% oxygen. Hydrogen is the third main constituent as 5 - 6%, and nitrogen and sulphur normally accepted less than 1% of dry biomass.

4. CONCLUSIONS

Four local varieties of rice straw (*viz. Nabina, Tamapasara, Swarna* and *Nua Achharmati*), sugarcane bagasse, coconut coir and vegetable waste were characterized for physical,

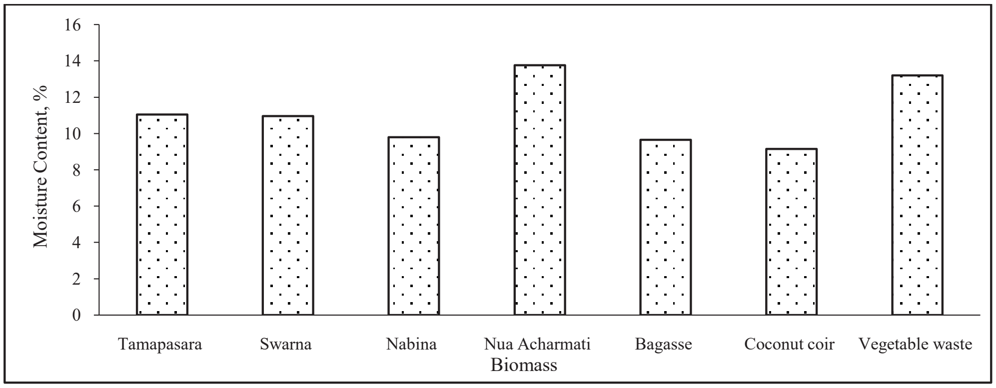

Fig. 5. Moisture content of selected biomass.

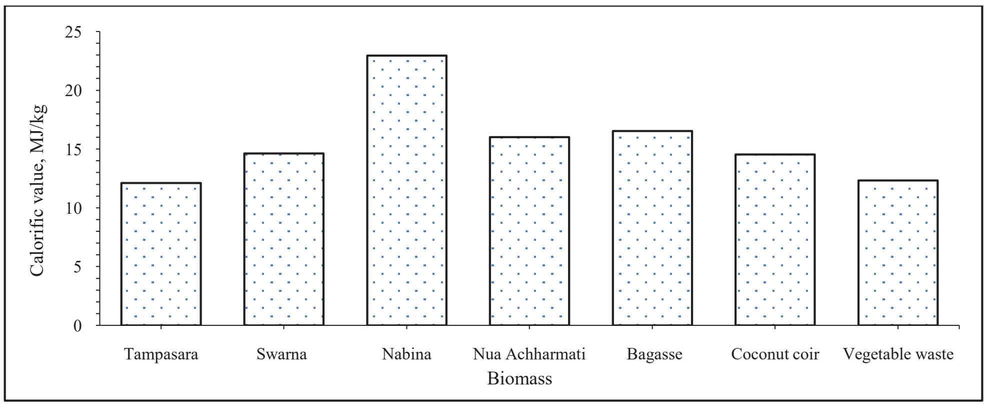

Fig. 6. Calorific value of biomasses.

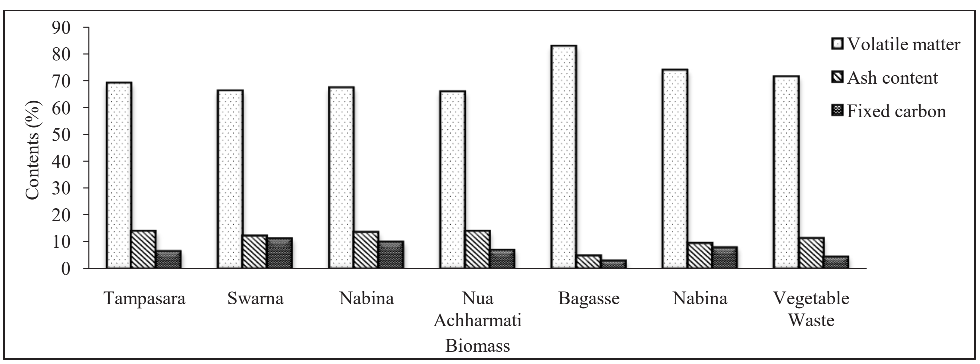

Fig. 7. Proximate analysis of biomasses.

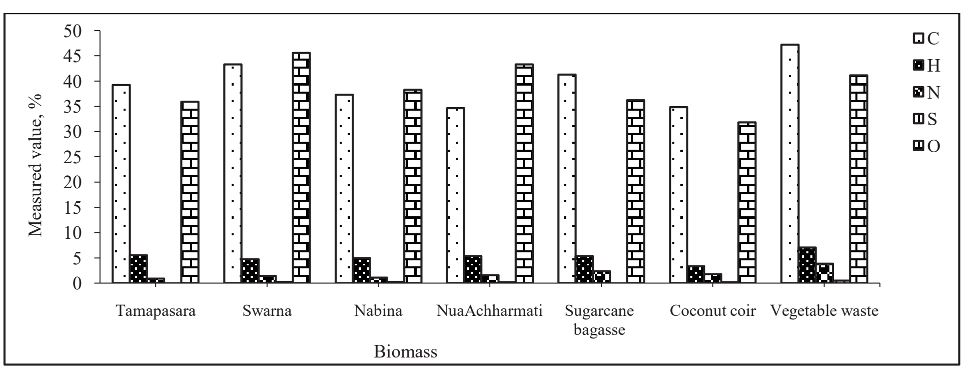

Fig. 8. Ultimate analysis of biomass.

chemical and thermal properties for their utilization. Sugarcane bagasse showed darker colour (colour value 13.7) than others biomasses indicating its higher energy value compared to coconut, vegetable and rice straws. The higher particle density in sugarcane bagasse (384 kg.m^{-3}) revealed that it has the higher energy value per unit mass than the tested biomass. Sugarcane bagasse contained highest percentage 82.7% of volatile matter followed by coconut coir, vegetable waste and rice straw. Engineering and physical and thermal properties of sugarcane, bagasse, coconut coir, vegetable residue and rice straw varieties *Tamapasara, Swarna, Nabina* and *NuaAchharmati* has shown that these biomass has enormous scope and can be important source of energy for commercial production of bio-fuels in future. Also these biomasses can be utilized for generation of electricity in existing gassifier based power plants.

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