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Physical Characteristics Studies of Biocoal from Waste Tender Coconut

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ABSTRACT: A study was conducted to develop a suitable practice/technology for the effective utilization of one of the most neglected agro-residues i.e. waste tender coconut (husk and shell) for its safe disposal and deriving energy out of it. Carbonization of waste tender coconut in raw form (10-14 % moisture contents) and then densification of the produced char are followed to obtain the briquetted char, known as biocoal which possesses the coal-like properties for widening its application as an energy rich and high density solid biofuel especially in domestic and industrial sectors. The loose char obtained from the carbonization process was densified by hand press method using cheaply available binding materials such as cow dung, kitchen waste, food waste, waste paper slurry and grass to prepare biocoal for assessing its physical characteristics. From the study, it was revealed that biocoal with cow dung as binder exhibited highest quality and durability (durability index is 86 %) followed by the kitchen waste (durability index is 78 %).

Keywords: Tender coconut wastes, bioenergy resource, biocoal, carbonization of biomass, briquetting.

INTRODUCTION

Tender coconut after consumption of juice and copra is usually thrown away here and there or is dumped as the waste biomass comprising of its husk and shell. Improper throwing away of tender coconut wastes (husks and shells) results in poor sanitation, air pollution and blockage of roadside drains that facilitate the breeding of mosquitoes and other harmful micro-organisms (Obeng *et al.*, 2020). This waste is the most neglected and underutilized biomass in the state of Odisha, India and no initiative is being taken either at Govt. level or non-Govt. level for developing suitable technology to derive energy out of it. This waste is seen to be enormous along the road sides of villages, cities and nearer to the temples, railway tracks, bus stands, hospital complex, market places as well as tourist's locations. The demands of tender coconut are increasing day by day among the people for the consumption of its juice because of several health benefits (Anonymous, 2018). The usage of tender coconut is also immense in temples and ceremonies. The husk of tender coconut is not as well suitable for coir industry due to the delicate and soft nature of husk and immature shell along with high moisture content. Handling and transportation of this agro-residue is difficult due to its low bulk density and irregular sizes. Adequate processing is required to convert waste tender coconut into a valuable clean fuel. Hence, effective utilization of this abundantly available and neglected waste, particularly in the coconut growing areas is a major concern for its safe disposal and efforts to derive energy out of it. Preparing high density and energy concentrated compact solid fuel i.e. biocoal is one of the viable and attractive options to utilize this waste as a substitute of fossil coal and facilitating its thermal applications especially in domestic and industrial sectors (Ghosal *et al.*, 2016). High energy content and coal-like properties of biocoal make it attractive fuel for heat and power generation in the existing coal-fired power plants, boilers for heat and steam, food processing industries for bakeries, drying, hotels and restaurants, fuels for gasifiers, domestic cooking and water heating, brick kilns etc. (Mwampamba *et al.*, 2013). Studies have revealed that biocoal as a compressed block of charred organic waste material exhibits about 20 % more of the combustion properties and emitting one-fifth and one-tenth of NO_x and SO_2 respectively than that of the coal (Chen, 2015).

Biocoal is the briquetted char produced by the densification of char obtained through the process of carbonization, one of the stages in the route of pyrolysis next to drying and torrefaction of biomass feedstock (Oladeji, 2015). In recent years, the so-called biocoal (or green coal) has received at lot of attention in the energy sector (Cheng *et al*., 2020). Biocoal, as the name implies, is a substitute of fossil coal and is produced from renewable biomass resources. It is considered to be the substitute of coal because it can be handled and combusted in the same way as fossil coal and possessing coal-like physical properties (Agar and Wihersaari, 2012). Carbonization entails conversion of the biomass into carbon rich product i.e. char or more specifically biochar by following the pyrolysis process in which the biomass is subjected to the temperatures in the range of 300-400°C in an oxygen-starved or inert environment conditions (Tumuluru *et al.*, 2011). Depending on the ranges of process temperatures, carbonization is divided into two classes. At temperatures between 200 and 300°C, the process is called torrefaction (Basu 2013) and the solid product is the torrefied biomass. In temperatures above 300°C and within 450°C, the biocharis formed (Wang and Sarkar 2018). Torrefied biomass and biochar are produced with the same method in the torrefaction and carbonization process respectively, the main differences lie in the process temperatures and the yield of the solid product (Patel *et al*., 2011) (Fig. 1). During torrefaction, the yield of solid product is around 90 % and with the increase of the process temperatures in the further step of torrefaction i.e. during the carbonization, the yield of solid product decreases to about 40 % with higher content of carbon. The aim of torrefaction is to remove only the chemical bonded water and less volatile compounds avoiding carbonization reactions whereas in carbonization, the fixed carbon of the solid product is maximized and volatile components are minimized (Onuegbu *et al.,* 2012). The purpose of torrefaction is to upgrade the fuel characteristics of biomass such that it can be co-combusted with coal or used as an independent fuel by being pelletized and stored with little or no microbial degradation and converting it into a hydrophobic product, not prone to biological decomposition. Hence, biocoal is produced by compacting carbon rich product (biochar), produced mostly in the carbonization step of the pyrolysis process. However, there are currently two methods in use for densification of biomass to produce briquettes. One option is the briquetting and then carbonization and second one is the carbonization and briquetting. The first one is the direct extrusion type, where the biomass is dried and directly compacted with high heat and pressure. The first method therefore requires high heat and pressure, creates dusty environment when in use and difficult to ignite (Roy, 2018). It is in the light of this problem, it is preferable to go for carbonization and then briquetting. The purpose of biocoal is to improve the density, burning time, and calorific value (per unit volume) of raw biomass thereby facilitating the easy handling and transportability of biomass. The present study therefore focusses on the durability and stability of the prepared biocoal from waste tender coconut. The important quality parameters for this are basically Compressive strength, abrasion resistance, impact resistance, moisture absorption, and density (Sunday *et al.*, 2020).

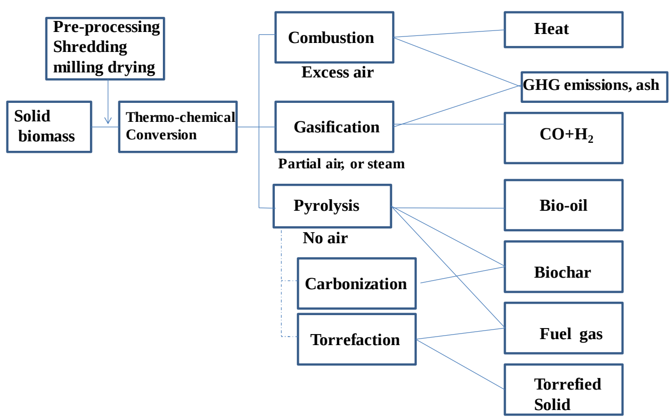

Fig. 1. Common thermo-chemical conversion pathways of biomass feedstock.

No studies have so far been conducted for the preparation of biocoal from waste tender coconut shell and husk in order to assess its heating value for using it as an effective substitute of cooking fuel (Kingshuk 2018). An attempt has therefore been made in this paper to study the physical characteristics of biocoal from waste tender coconut for its easy storage and transport. The various steps followed to prepare the biocoal are presented in the Fig. 2.

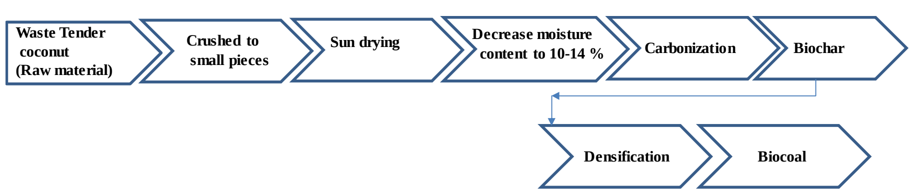

Fig. 2. Steps to prepare biocoal from waste tender coconut.

MATERIALS AND METHODS

The present study on the preparation of biocoal from waste tender coconut was carried out in the College of Agricultural Engineering and Technology, OUAT, Bhubaneswar during the year 2017-18. The raw tender coconuts after their uses were collected from different places in the city of Bhubaneswar, Odisha, India. The collected raw tender coconuts were cut into small pieces and dried in the sun for 5-6 days in order to reduce the moisture content in the range of 10-14 percent, preferable for better carbonization process to occur. The ash content of biomass affects its slagging behaviour in the charring reactor. The biomass feedstock having ash content less than 4 % is preferred for briquetting. (Grover and Mishra 1996). The moisture contents and proximate analysis of raw tender coconut were carried out before feeding into the charring drum. The details of the procedure for preparing char from the raw tender coconut using charring drum are mentioned in the research paper by the author (Ghosal *et al.,* 2016). The briquettes were prepared by hand press method using five different binding materials of easy and convenient availability such as cow dung, grass, kitchen waste, paper slurry and food waste. Various tests such as degree of densification, durability index following tumbling method, resistance to water penetration, shatter index for determining the hardness of the briquettes and compressive strength for withstanding breakage during transportation etc. were conducted to assess the physical characteristics of the biocoal from waste tender coconut. Bulk density of the briquettes was determined by dividing the mass of the briquettes by volume. Water absorption of a briquette was determined by immersing the briquette completely in water for 30 s at room temperature. The per cent gain in weight of the briquette was calculated and recorded as percentage of water absorbed. Shatter resistance was measured by subjecting the briquettes to 10 repeated drops from 1 m height on to a concrete surface. Mass of the briquettes decreased due to shattering/disintegration. The per cent original mass retained by the briquettes was recorded as the shatter resistance. Compressive strength of the biocoal having diameter of 50 mm and length of 50 mm was determined by using Universal Testing Machine (UTM) density of the briquette to density of the raw material.

RESULTS AND DISCUSSIONS

The data relating to the physical characteristics of the biocoal from waste tender coconut were presented by calculating the following parameters using various binding materials and their comparisons have been made to find out the suitable binder with respect to its easy, convenient and cheap availability for preparing briquettes fulfilling the desired quality and durability.

Degree of densification. Degree of densification is defined as percent increase in the density of biomass due to briquetting and is expressed as, Degree of densification (DD)=$\frac{\text{Density of briquette}}{\text{Density of raw material}}$. The data of DD is mentioned in Table 1 below.

Table 1: Degree of densification of biocoal prepared by hand press method.

Methods of briquetting	Density of raw char(kg/m^3)	Density of briquetted char (kg/m^3)	Degree of densification
Hand press	0.40	1.12	2.8

The results are in agreement with the findings of the previous work of Mahapatra and Rout (2010).

Tumbling test. Tumbling test has been conducted to calculate the durability index which indicates the impact resistance of biocoal. More is the value of durability index, more is the convenience for handling and transportation of the material.

$$\text{Durability Index}\ \ DI = \frac{M_2}{M_1} \times 100$$

where, M_2 = weight of material retained above the sieve and M_1 = weight of material before tumbling. The tumbling test is carried out with the help of a durability test unit which is made of a rectangular stainless-steel container with inner dimension of 300 mm × 300 mm × 125 mm. The rotation speed is adjusted to 50 rpm and the rotation time is 5 minutes and 100 g of the sample is used for the test. The rotated sample is sieved using round screen holes of 2.75 mm.

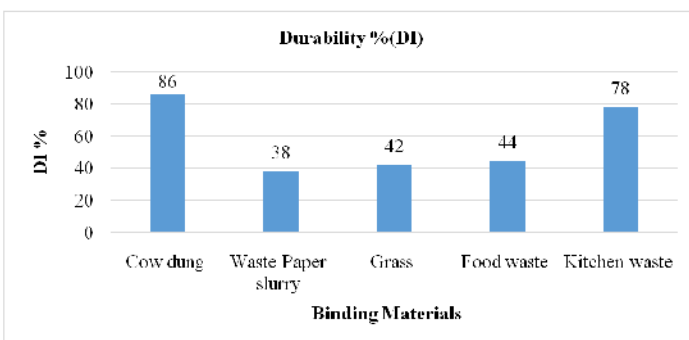

Fig. 3. Durability index of biocoal with different binding materials.

The percent of briquettes remained unbroken to total sample weight is reported as durability index. The result of the durability index of biocoal with different binders is shown in Fig. 3. The starch and water-soluble fibers act as a good binding agent to increase the bonding of biomass in the briquette.

Resistance to water penetration

It is measured by the percentage water absorbed by a briquette when immersed in water. Each briquette was immersed in the water at 27°C for 30 seconds. The percent water gain was then calculated and recorded by using the formula i.e. % water gained by briquette

$= \frac{W_2 - W_1}{W_1} \times 100$, where, W_1 = Initial weight of briquette, W_2 = Final weight of briquette, % Resistance to water penetration = 100 - % water gain

The result of the resistance to water penetration with different binders is shown in Fig. 4.

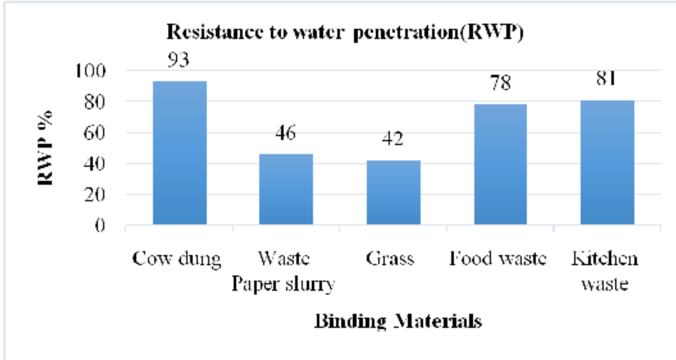

Fig. 4. Resistance to water penetration (RPW) (%) of biocoal with different binding materials.

The briquettes with cow dung as binding material were observed to be highest i.e. 93 %, followed by the briquettes with kitchen waste (81%), food waste (78 %), waste paper slurry as a binder (46 %), grass (42 %). It may due to gelatinization of starch during the mixing process, contributing good binding properties and thus reduces the void between the briquette causing decrease in the water absorbing capacity.

Shatter index. The shatter index is used to determine the hardness of briquettes by following the drop test as mentioned in the Materials and Methods section. It is calculated by using the following formula and its results are presented in the Fig. 5.

% Shatter resistance = 100 - % weight loss and percent weight loss $= \frac{W_1 - W_2}{W_1} \times 100$

where, W_1 = weight of briquette before shattering and W_2 = weight of briquette after shattering

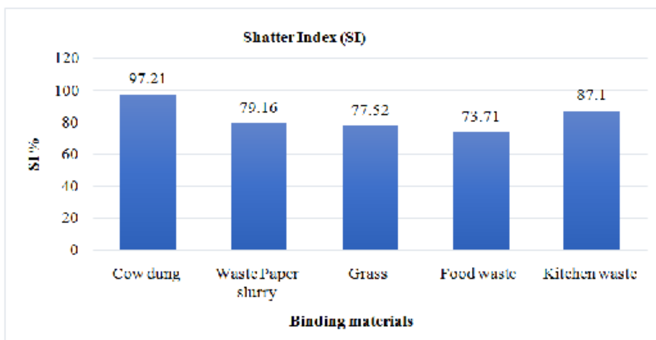

Fig. 5. Shatter index (%) of biocoal with different binders.

Shatter index percent of biocoal was found to be highest (97.21 %) in case of cow dung as binding material, followed by the same with kitchen waste (87%), waste paper slurry (79.16 %), food waste (73.71 %), grass (77.52 %) as binders. It may be due to the presence of starch and water-soluble fibres in the binding material which help to increase the SI because of more bonding of biomass particles (adhesiveness) in the briquettes.

Compressive strength. Compressive strength (or crushing strength) is the maximum compressive load a pellet/briquette can withstand before cracking or breaking. Compressive strength of the densified products is determined by Universal Test Machine (UTM). The sample of biocoal having diameter of 50 mm and length of 50 mm was found to be highest (657 kPa) in case of cow dung as binding material followed by the same with kitchen waste (644 kPa), waste paper slurry (490 kPa), grass (472 kPa) and food waste (350 kPa) as the binding materials at about 12.5 percent moisture content. It is only due to the decrease of void and removal of moisture from the particles of the sample during compaction, resulting in to the reduction of intra particle distance. This causes the increase of both cohesive and adhesive forces among the particles and thereby increasing the bulk density and strength of the material. The results are in agreement with the findings of the previous work of Ghosal *et al*., (2016).

CONCLUSIONS

Carbonization and densification of waste tender coconuts is a simple and low-cost technology for their effective utilization in order to produce a solid biofuel of high density and energy concentrated biocoal for easy handling, safe storage and convenient transportation compared to raw and unprocessed biomass. Not much studies have been so far conducted for preparation of bio-coal from waste tender coconut (husk and shell) for assessing its physical characteristics to produce solid biofuel of desired quality and durability. The findings of the study would provide right information to the coconut growers, vendors, entrepreneurs, environmentalists etc. about the practice for waste to energy. From the study, the following conclusions have been drawn.

1. The density of biocoal is increased by about 2.8 times than that of its loose char by following hand press method of compaction.

2. Briquette prepared from the char of waste tender coconut with cow dung as binding material was found to be most durable (durability index is 86 %), followed by the briquettes with kitchen waste (durability index is 78 %).

3. The biocoal with cow dung as the binding material were found to be the highly water resistant followed by the briquettes with kitchen waste and can be stored for a longer period.

4. Impact strength of the biocoal was found to be highest in case of cow dung as binding material (shatter index of 97.21 %), followed by the same with kitchen waste (shatter index percent of 87%).

5. It was found that biocoal with cow dung as binding material exhibited more compressive strength followed by the same with the binding material of kitchen waste.

Considering all the parameters related to the quality and durability of the biocoal prepared from the waste tender coconut, the briquettes with cow dung as the binding material exhibit highest physical characteristics followed by the kitchen wastes as compared to the other binding materials (food waste, waste paper slurry and grass) considered in this study.

The practice adopted in this study can be made applicable to other unutilized agricultural residues for their effective disposal, environmental protection and deriving useful biofuels. The same technology can be extended to the pyrolysis process resulting into the yield of bio-oil and syngas in addition to biochar. With further improvement, the potential user may go for adopting microwave pyrolysis to optimize the process conditions and to obtain good quality of the biofuels (solid, liquid and gaseous products) for enhancing their physical and fuel characteristics.

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Conflicts of Interest. The results furnished in this paper are from our own research and there are no any conflicts from other research scholars or scientists.

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