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Heating Performance and Pollutant Emissions in Burning Biocoal Prepared from Waste Tender Coconut

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ABSTRACT: A study was conducted to assess the heating performance and pollutant emissions from burning of biocoal (briquetted char) prepared from waste tender coconut. Heating performance with respect to calorific value, cooking efficiency and burning rate of biocoal, possessing coal like properties has been investigated. A solar powered forced draft cook stove was used to evaluate the heating performance and emissions of gases such as CO_2, CO and HC while burning the biocoal in it. The biocoal was prepared from waste tender coconut through the process of carbonization and then densification of char with the use of five different binding materials such as cow dung, kitchen wastes, food waste, grass and waste paper slurry because of their easy and cheap availability. The loose char obtained from the carbonization process was densified by hand press method. From the study, it was revealed that the calorific value of the charred tender coconut waste is about 38% higher that of the uncharred raw tender coconut waste. Cooking efficiency of the cook stove in case of biocoal with cow dung binder was highest (33 %) followed by the other binders such as kitchen waste, food waste, paper slurry, grass and raw dried tender coconut. The biocoal with cow dung as binding material was observed to emit less pollutant gases compared to other binding materials and hygienically suitable for in-door domestic cooking.

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

INTRODUCTION

Biocoal, the briquetted char, produced from the carbonization of biomass and then its densification has been considered not only a clean and energy rich solid biofuel for thermal applications in domestic cooking/heating and industrial sectors but also a scope to utilize the surplus agricultural residues in an agricultural based region for their safe and effective disposal sustainably along with reducing environmental pollution (Cheng *et al*., 2020). Biocoal, as the name implies, a substitute of fossil coal, is produced from renewable biomass resources and possesses the coal-like properties to handle and use it in the same way as the commercially available coal (Agar and Wihersaari, 2012). Despite the availability of various agricultural residues in an agrarian society, the waste tender coconut (husk and shell) is one of the most neglected and underutilized biomasses especially in the coconut growing areas due to its abundant availability and efforts have not so far been made for properly utilizing it as an energy resource because of its high moisture content, bulky volume and irregular sizes causing several difficulties in storage, transportation and thermal applications. The husk of tender coconut is also not suitable for coir industry due to the delicate and soft nature of husk and immature shell along with its higher percentage of moisture. The usual practice is the improper throwing away of the tender coconut here and there by the consumers as well as the vendors after consumption of its juice resulting into poor sanitation and blocking of the roadside drains that facilitate the breeding of mosquitoes and many harmful micro-organisms (Mahapatra and Rout 2010). The waste tender coconuts either remain dumped long time in open areas till their decomposition, burned openly or local people collect some of them and dry in the sun for a number of days to reduce the moisture content for using in domestic cooking through direct combustion. As the demands of tender coconut are increasing day by day among the people for the consumption of its juice because of several health benefits and immense usage in the temples and public ceremonies (Anonymous, 2018), proper conversion of these huge amount of the neglected agricultural residues into clean and energy rich solid fuel, particularly in the coconut growing areas, needs to be explored at the point of availability and as per the convenience of the users in order to provide a promising substitute in domestic cooking purposes. The direct burning of the raw and unprocessed tender coconut waste in traditional cook stoves emits a lot of harmful pollutants, giving rise to increased health risks and cause tremendous environmental problems (Maxwell *et al.,* 2020). Household cook stoves are not likely to be replaced in many areas in the near future due to limited economic conditions and living habits (Shinde *et al.,* 2017). In the light of the problems of improper dumping, difficulties in storage and transportation and poor sanitation caused by the waste tender coconuts, it is preferable to go for carbonization and then briquetting them to produce a densified product for improving the calorific value (per unit volume) and burning time of raw biomass thereby facilitating their easy handling and transportability (Grover and Mishra 1996). During carbonization, most of the volatile materials are removed and the biomass is converted into a carbon rich solid product, called char, leading to an increase in the calorific value, thus improving the significant contribution of its burning characteristics (Tumuluru *et al.,* 2011). Studies have also 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).

The process of carbonization, which is a mild pyrolysis process, has been well studied and results in the loss of almost all the hemicellulose, up to 75% of the cellulose (depending on the process conditions) and a few percentage of the lignin during thermal cracking (Li *et al*., 2015), leading to the formation of a less smoking (smokeless) fuel (Mitchell *et al.,* 2016). Moisture is also reduced during the process and the product is usually more consistent (Yuliansyah *et al.,* 2019). The calorific values of the raw uncharred and charred coconut wastes have been studied by the researchers and it has been reported that the average calorific value of the charred coconut wastes is about 40% more than that of the uncharred coconut wastes (Obeng *et al.,* 2020). The moisture content of the raw uncharred coconut wastes influences relatively the low calorific value. High moisture content of biomass results in poor ignition and reduces the combustion temperature, which in turn affects the combustion of the products and quality of combustion (Huda *et al.,* 2014). The implication is that with relatively high calorific value and lower smoke emission, the charred coconut wastes can be considered to be a better fuel than the raw uncharred materials that can be burned as domestic fuel, particularly in the rural areas of the coconut growing regions where this feedstock is abundantly available (Roy, 2018). As water is evaporated gradually from the raw uncharred coconut wastes during the combustion process, CO emissions is generally decreased to a level considered to be within the WHO recommendations (Wang and Sarkar 2018). This suggests that charred coconut wastes would likely produce less CO pollutant emissions than the raw uncharred coconut wastes. Therefore, to effectively utilise the tender coconut wastes as a bioenergy resource in the form of biochar briquette fuel (biocoal), there is the need to produce biochar in the carbonization process and then to prepare briquettes, called biocoal, for maximising the calorific value and minimising the smoke emissions. The present study therefore focusses on the heating performance and pollutant emissions of biocoal from waste tender coconut while using it in an improved cook stove. The important quality parameters for this study are the calorific value, burning rate, thermal efficiency of the used cook stove and pollutants emissions. There is thus the need for the continuous research in this direction in order to gain insight into the effective conversion of waste tender coconut into an energy resource and mitigating environmental pollution. No studies have so far been conducted to evaluate the heating value and emissions of pollutants while using biocoal prepared from the waste tender coconut (shell and husk) (Kingshuk 2018) and hence, attempt has been made in this present investigation to assess these parameters for providing useful information regarding its suitability and user-friendliness as a domestic cooking fuel.

MATERIALS AND METHODS

The present study on the preparation of biocoal from waste tender coconut and its heating performance along with harmful emissions during burning was carried out in the College of Agricultural Engineering and Technology, OUAT, Bhubaneswar during the year 2018-19. The raw tender coconuts after their uses were collected from different places in the city of Bhubaneswar, Odisha, India. The collected waste raw tender coconuts were cut into small pieces and dried in the sun for 5-6 days in order to reduce their moisture content in the range of 10-14 percent, preferable for better carbonization process to occur. The details of the procedure for preparing char from the dried raw tender coconut using charring drum and making biocoal with five different binding materials 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. The calorific values of the biocoals from various binding materials used under this study were determined with the help of bomb calorimeter. The average calorific value of each biocoal with specific binding material under study were reported on the basis of five sets of experiments. The heating performance (cooking efficiency and burning rate) and emission studies (release of harmful gases such as CO_2, CO and HC) were undertaken by using prepared biocoal in a low cost forced draft solar powered cook stove (Fig. 1).

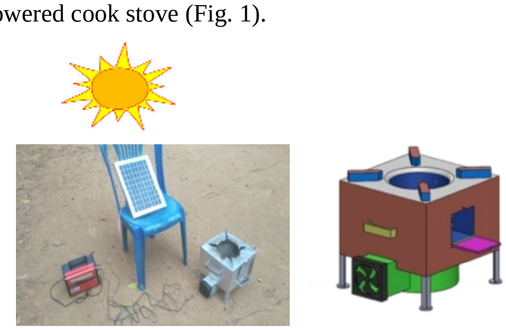

Fig. 1. Photograph of solar powered forced draft cook stove.

Water boiling test (WBT) has been followed to evaluate the cooking efficiency and burning rate of the used biocoal.

Cooking efficiency. Cooking efficiency is defined as the ratio of energy used to heat the water or food materials versus the energy content of the fuel consumed. A known quantity (2 liters) of water was heated for a period of one hour in WBT. The temperature of the water was continuously monitored. In order to calculate the efficiency of the stove, the initial temperature of water, the volume of water remaining after the one-hour test, and the remaining weight of wood at end of each cooking session was measured. The stove efficiency or cooking efficiency (η) is the useful energy delivered divided by the fuel energy, which was calculated using the following formula (Vaccari *et al*., 2012).

$$\eta = \frac{M_w C_{pw}(T_b - T_i) + M_{we} L_v}{M_f H_f}$$

where M_w is the initial mass of water in the cooking vessel (kg), C_{pw} is the specific heat of water (kJ/kg°C), T_b is the temperature of boiling water (°C), T_i is the initial temperature of water (°C), M_{we} is the mass of water evaporated (kg), L_v, is the latent heat of vaporization (kJ/kg), M_f is the net mass of fuel used (kg), and H_f is the calorific value of fuel (higher heating value, kJ/kg). The first term in the numerator represents the energy required to heat the water from the initial temperature to boiling, the second term in the numerator represents the energy required to boil off the evaporated volume of water, and the denominator represents the energy content of the spent fuel.

Burning Rate. Burning rate is the amount of biomass fuel (biocoal in the present study) used during the time of bringing the food material to boil. It is the ratio of fuel consumed (g) to time (min) to boil the food material (Vaccari *et al.*, 2012). It is expressed in the unit of g/min.

Emission Test. One of the objectives of preparing bio coal i.e. a briquetted char is to reduce the emissions of harmful gases and particulate matter during direct combustion of unprocessed raw biomass. Emissions resulting from biomass combustion are characteristic of the material composition. During combustion, gases such as CO, CO_2 and NO_2, and CH_4 are emitted. The composition of the emissions depends also on the nature of the combustion i.e. complete or incomplete. These emissions can have an impact on human health. Emission tests were conducted with the help of exhaust gas analyser in order to determine the reduction in the emissions of harmful pollutants during the burning of prepared bio coals under study and to recommend its use as a clean domestic fuel against pollution for in-door and open fire cooking in the domestic sector, using loose biomass. During the test, 200 g of each of the bio coal and dried raw tender coconut was burnt in the same solar powered forced draft biomass improved cook stove with an attachment of chimney. The emissions of gases such as CO, CO_2, and HC were recorded with the help of a gas analyser (Fig. 2) and compared with those of the values for the dried raw tender coconut.

Fig. 2. Gas emissions recording in gas analyser from biocoal burning in cook stove.

RESULTS AND DISCUSSIONS

The data relating to heating performance and emissions of harmful gases during burning of biocoal prepared from waste tender coconut with different binding materials used in this study were presented. The comparative study of tender coconut char having different binding materials are shown in the Fig. 3.

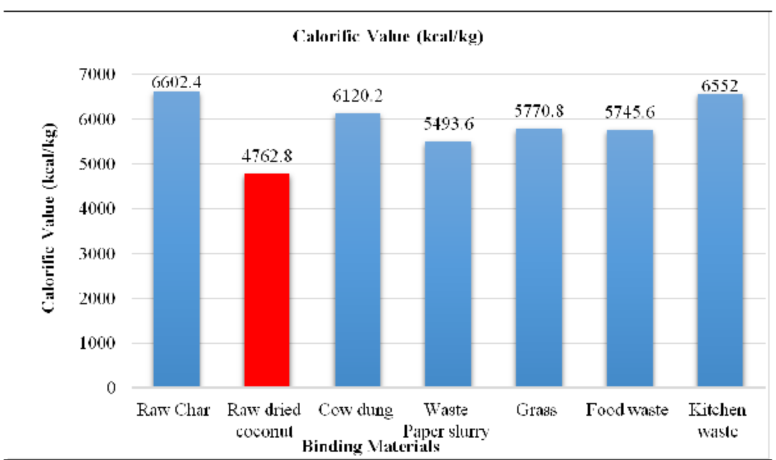

Fig. 3. Calorific value of raw dried tender coconut and its char with different binders.

The bomb calorimeter used in this study conforms to ASTMD 5865 standard. The specifications of the bomb calorimeter include analysis time of 11 min and oxygen gas requirement of 99.5% purity. The calorific values of the raw sun-dried tender coconut wastes along with its biocoal from different binding materials were analysed and the results are shown in Fig. 3. The results indicated that the calorific value of biocoal with kitchen waste as binding material was found to be highest i.e. 6552 kcal kg^{-1}, followed by the briquettes with the other binders cow dung (6120 kcal kg^{-1}), grass (5770 kcal kg^{-1}), food waste (5745 kcal kg^{-1}), waste paper slurry (5493 kcal kg^{-1}). This may be due to the presence of more amount of cellulose (21.81%) in kitchen waste compared to (8%) in waste paper slurry. These values are generally consistent with the results that were obtained from the study (Obeng *et al.*, 2020). From the results, the calorific value of the charred tender coconut waste is about 38% higher than the calorific value of the uncharred tender coconut waste because of the increased amount of the fixed carbon content.

The performance of biocoal with respect to cooking time, fuel consumption, burning rate and cooking efficiency of solar forced draft cook stove during boiling of 1 litre of water under WBT at cold start as well as hot start was studied and compared with raw dried tender coconut. The average values of the tests are presented in Table 1.

Table 1: Comparison of cooking time, fuel consumption and cooking efficiency of biocoal with different binding materials under study in boiling of 1 litre of water. Initial temp. of water=31.5°C.

Sr. No.	Material used	Average boiling/cooking time (minutes) for cold start	Average boiling/cooking time (minutes) for hot start	Average fuel consumption (g)	Cooking efficiency (%) (solar powered forced draft cook stove	Average burning rate (g/min) for hot start
1.	Dried coconut (without binding)	11.00	6.50	200	26.30	30.76
2.	Biocoal with cow dung binder	9.30	4.30	200	33.70	46.51
3.	Biocoal with waste paper slurry binder	10.50	6.20	200	29.60	32.25
4.	Biocoal with grass binder	10.00	5.40	200	29.30	37.03
5.	Biocoal with food waste binder	14.00	8.5	200	30.10	23.52
6.	Biocoal with kitchen waste binder	9.50	4.40	200	31.20	45.46

The data mentioned in the table above revealed that cooking efficiency in case of biocoal with cow dung binder was highest followed by the binders such as kitchen waste, food waste, paper slurry, grass and raw dried tender coconut. This may be due to the higher calorific values and variations in the moisture contents of the biocoals used in the study.

Similarly, cooking time was found to be lowest and burning rate was calculated to be highest in case of biocoal with cow dung binder. This may be due to the faster burning and thus higher release of thermal energy of biocoal with cow dung binder having more porous in nature compared to the other binders and therefore easy entry of air into the fuel mass for facilitating quick combustion. The results of the emission of carbon mono oxide, carbon dioxide and hydrocarbon gases while burning the tender coconut char with different binders are shown in the Figs. 4-6 respectively.

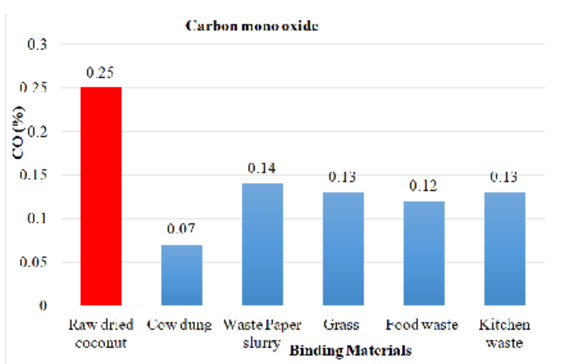

Fig. 4. Emission of carbon mono oxide of tender coconut char with different binding materials.

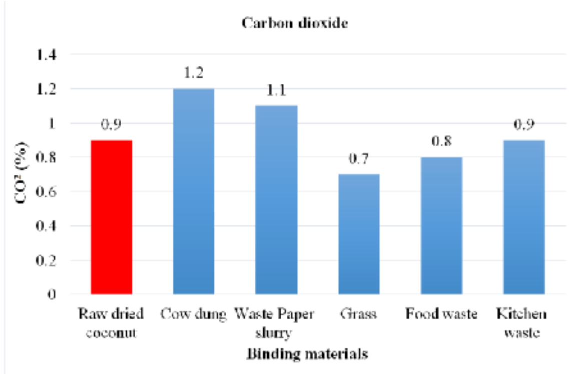

Fig. 5. Emission of carbon dioxide of tender coconut char with different binding materials.

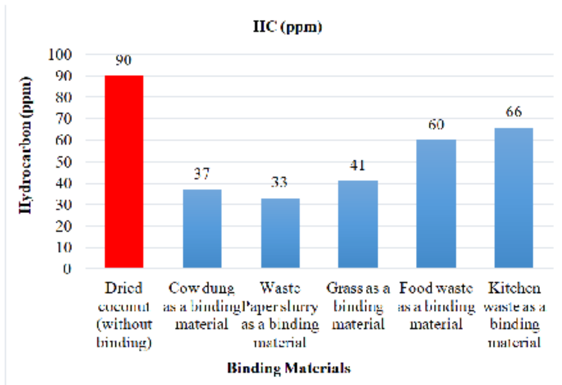

Fig. 6. Emission of hydrocarbon of tender coconut char with different binding materials.

It was found that the briquettes from the cow dung as binding material emit less harmful pollutants compared to others and under the safe limit of emission for human being in case of CO, CO_2, and HC are respectively. Carbon monoxide emission in case of raw dried tender coconut is found to be higher compared to the biocoals of different binders under study due to the effect of more moisture in raw biomass. However, carbon dioxide emission was found to be comparatively higher in case of biocoals of different binders due to the more amount of fixed carbon in the char resulting into complete combustion and increased CO_2 emission. From the safe limit point of view, it was observed that briquettes prepared from the char of tender coconut with cow dung as binding material are healthier followed by the binding materials i.e. kitchen and food waste and can be used as domestic fuel without causing any indoor air pollution. However, the briquettes from raw dried tender coconut without binding materials emits more harmful pollutants causing health hazards for the woman involved in domestic cooking and may not be safe hygienically for use as a domestic fuel.

CONCLUSIONS

Waste tender coconuts which are one of the abundantly available agro-residues in the coastal regions are the most neglected biomass and simply dumped here and there after the consumption of their juice. Hence their efficient utilization is crucial for providing bio-energy, releasing risk of environmental pollution and substituting the domestic cooking fuel in rural areas. Carbonization and then densification may be one of the important utilization routes for them. People are quite ignorant of the fact that husks of the tender coconut have the potential of converting into energy-rich bio fuel because of their low ash content (Purohit *et al.*, 2006). That’s why, they simply throw them as waste material causing subsequently the negative impact on the local environment. These are normally being used as fuel after drying and direct burning resulting into providing a very less heating value. These residues have low heating value per unit volume and high transportation as well as storage costs due to the bulkiness of the husk. Carbonization and densification of waste tender nuts is a simple and low-cost technology to prepare high density and energy concentrated briquetted char (biocoal) in situ. The objective of this paper is therefore to explore the feasibility of biocoal from waste tender coconut as a substitute for domestic cooking fuel from heating performance and pollutant emissions points of view. Not much studies have so far been conducted in preparation of bio-coal from waste tender coconut and assessing its heating performance and pollutant emissions during burning for thermal applications. Hence, the present investigation has been undertaken to study the feasibility of utilizing biocoal from waste tender coconut as a sloid biofuel in domestic and industrial sectors along with its cleanness in emitting harmful gases in burning and the following conclusions have been obtained from the study.

1. The calorific value of the charred tender coconut waste is about 38% higher than the calorific value of the uncharred tender coconut waste

2. Calorific value of briquette prepared from the char of tender coconut with kitchen waste as binding material was found to be highest (6552 kcal kg^{-1}), followed by the briquettes with cow dung (6120 kcal kg^{-1}), grass (5770 kcal kg^{-1}), food waste (5745 kcal kg^{-1}), waste paper slurry (5493 kcal kg^{-1}).

3. Cooking efficiency in case of biocoal with cow dung binder was highest followed by the other binders in this study, such as kitchen waste, food waste, paper slurry, grass and raw dried tender coconut

4. Cooking time was found to be lowest and burning rate was calculated to be highest in case of biocoal with cow dung binder

5. The briquette prepared from the char of tender coconut with cow dung as binding material emits less pollutant gases compared to other binding materials

The findings of the study would provide right information to the coconut growers, vendors, entrepreneurs, environmentalists etc. about the practice for waste to energy. Considering all the parameters related to the heating performance and cleanness in harmful emissions of the biocoal prepared from the waste tender coconut, the briquettes with cow dung as the binding material exhibit both better heating performance and lower emissions of the pollutants followed by the kitchen wastes and 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 clean and energy rich biofuels. The same technology can be extended to the pyrolysis process resulting into the yield of other biofuels such as bio-oil and syngas in addition to biochar. With further improvement, the potential user may go for adopting microwave pyrolysis to optimize the process condition and to obtain good quality of the biofuels (solid, liquid and gaseous products) for enhancing their both 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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