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Briquettes as an Alternative Fuel to Wood for Circular Economy in Paddy Straw

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ABSTRACT

The study was conducted during *rabi* from November to March, 2019–20 at Department of Renewable Energy Engineering, PAU Ludhiana, Punjab, India to explore the new alternate biofuel for industry and cooking needs. Briquetting is one of the techniques that were not matured as required in the developing countries. Briquettes were prepared from chopped paddy straw, which is considered as waste and generally set on fire for clearing the fields. The aim of the investigation was to utilize field waste for thermal energy source in industry as well as for cooking in farming society. This endeavor could provide a ray of hope for paddy straw management in *ex-situ* application at large scale along with environmental benefits of preventing open burning. Briquettes were prepared on piston type briquetting machine with diameter 70 mm and the resultant fuel was compared with wood for physicochemical as well as thermal properties. It was observed from proximate and ultimate analysis that the paddy straw briquettes have similar properties as compared to the wood. Also, the calorific value of paddy straw briquettes was equivalent to wood and showed insignificant difference statistically. But the ash content of paddy straw briquettes was more than wood. The results showed that the calorific value, bulk density, ash content, and volatile matter of paddy straw briquettes were 15.29 MJ kg^{-1}, 639.22 kg m^{-3}, 23.46% and 64.03%, respectively. The paddy straw briquettes were evaluated in biomass cook stoves using water boiling test.

KEYWORDS: Paddy straw, briquettes, wood, cook stoves, boiling test

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1. INTRODUCTION

Biomass remains by far the dominant fuel used for several domestic activities like cooking in many developing countries which constitutes around 2.7 billion people depending on fuels such as wood, charcoal, agricultural waste and animal dung (Arora et al., 2014). The cooking needs in rural areas through combustion of biomass fulfills in traditional stoves or three stone stoves that burn biomass inefficiently and ultimately causes indoor air pollution that cause detrimental impact on health especially women and children below 05 years (El-Sayed and El-Sammi, 2006). More so, there have been persistent escalating fossil oil prices which demands for producing viable alternatives to kerosene and gas for domestic cooking (Kumar et al., 2020). Rice (*Oryza sativa* L.) is the staple food of many countries worldwide and thus act as major energy source of population diet (Al-Mamun et al., 2013). In addition, there is issue of open biomass burning especially paddy straw that causes not only respiratory problems but leads to accidents during harvesting period of about 20 days as heavy smoke is emitted due to uncontrolled combustion. Inspite of posing bans and fines by the state governments, the paddy straw burning is still a big challenge for the administration. The total area under paddy in Punjab was estimated to be about 31 lakh hectares and paddy straw generation was expected to be around 20 mt in 2023 (Anonymous, 2023). The primary reason for burning rather than incorporation for enriching the soil is absence of any suitable residue management practice (Ali et al., 2016). The management of such a huge amount of waste demands multiple sectors that can aid in reducing field burning. Briquetting is one of such venue through which paddy straw can be effectively managed at large scale by collecting and transforming it into higher density logs for ease in transportation and storage. Compared to fossil fuels, the briquettes produce low net greenhouse gas emissions because the materials used are already a part of the carbon cycle. Secondly, the physical appearance of briquettes is also similar to wood logs but their composition is different. According to an estimate, the adoption of paddy straw as fuel has a potential to consume more than one million tons of waste from 2 lac ha of agricultural land annually (Jain et al., 2015). The waste biomass can be proved as great potential for meeting energy demands in low income countries and shows advantage of volarization to attain the sustainable circular economy (Brunerova et al., 2020). Many researchers tested the biomass briquettes in improved cook stove by utilizing variety of agro residue for briquetting viz. soybean straw, ground nut shells, pigeon pea, sugarcane bagasse etc. (Verma and Shukla, 2019). According to Ibrahim et al. (2020), biomass briquettes from rice husk may be the best alternative energy source to wood fuel. Adoption of biomass briquettes for energy would benefit the economy and could result in creating more job opportunities besides more tax revenue for the government. The briquette burning can also reduce emissions by 20% to 45%. Syed Adam et al. (2021) burnt paddy straw partially and transformed it into charcoal for producing briquettes. The briquettes were prepared by adding corn starch and tapioca starch as binders and the characteristics were studied. Therefore, the literature revealed that the briquettes formation is done by using biomass other than paddy straw and the studies on paddy straw briquettes were either done by its size reduction to powder or recently, by first converting it to charcoal. But the present study was undertaken by preparing paddy straw briquettes made from chopped material and without binder in a piston type briquetting machine and the specific objectives was to study the physicochemical properties of paddy straw briquettes and its evaluation as compared to wood.

2. MATERIALS AND METHODS

2.1. Raw material

Biomass briquettes (B) of size 70 mm were made from chopped paddy straw on high pressure piston type briquetting machine during rabi season from November to March in 2019–20. The waste paddy straw bales were procured from the local market. The paddy straw was chopped (Figure 1a), chopped paddy straw was fed in briquetting machine (Figure 1b), then it was briquetted (Figure 1c). Briquettes were first tested in the laboratory for proximate analysis (moisture content, ash content, bulk density and calorific value) according to standard procedures.

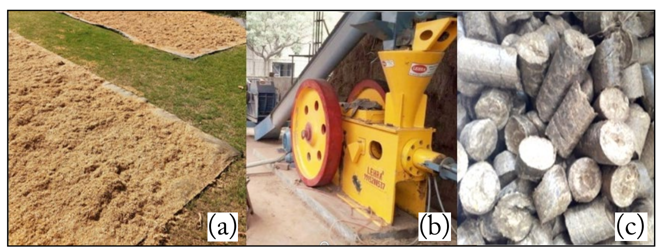

Figure 1: (a) Chopped paddy straw (b) Briquetting machine (c) Chopped paddy straw briquettes

2.2. Moisture content

The moisture content of the burning material before and after sampling was determined using ASAE standard S352.2 involving the use of oven drying methods. The initial weight of the samples was determined (W_1) and placed in a hot air oven at 103°C±2°C for 24 hours. The samples were then removed, cooled and reweighed (W_2). Moisture content of the samples was calculated using the following expression:

$$MC\ (\%)=(W_1-W_2)/W_1\times100$$

MC=Moisture content, (%)

W_1=Weight of sample before drying, (g)

W_2=Weight of sample after drying, (g)

2.3. Calorific value

Calorific value of any biomass represents the amount of energy per kilogram, it gives off when burnt. The calorific value can thus be used to calculate the competitiveness of a processed fuel in a given market situation. The calorific value of wood and paddy straw briquette samples was determined using digital adiabatic bomb calorimeter (Model: MAC MSW-506) at Pathak Energy Laboratory, PAU Ludhiana using ASTM E711-87.

Calorific value (MJ/kg)=[((Trise×w)-(Cvp×Wp)]/(Ws/1000)

T_{rise} =Rise in temperature of water due to burning of sample (°C) in bomb

w=Water equivalent of apparatus=0.0105 MJ/°C

Wp=Weight of Odet Cascedec Bollore (OCB) paper, kg

Cvp=Calorific value of OCB paper=16.11 MJ kg^{-1}

Ws=Weight of sample taken, (g)

2.4. Bulk density

The bulk density of briquettes was determined as per the standard procedure ASTM D6683-19. A square shaped container of 0.02832 m^3 volume was used for its determination. The container was first weighed empty to determine its mass. Then it was filled with the sample and weighed once again. The bulk density was determined by dividing the mass of the material by the volume of the container. The bulk density was calculated by using the formula:

Bulk Density (kg m^{-3})=Mass of biomass, (kg)/(Volume of container (m^3)

2.5. Specific fuel consumption

The specific fuel consumption represents the ratio of the mass of fuel consumed (grams) to the quantity of boiling water (liters). The specific fuel consumption was measured (Olorunisola, 1999) by taking a fixed amount of fuel in the cook stove which was used to boil the water.

2.6. Ash content

Ash content of paddy straw briquette and wood was determined according to the standard ASTM D 1102-84. The oven dried sample was placed in the crucible without lid in a MAC MSW-253 high temperature muffle furnace at 600°C for 2 hours. It was calculated by following formula:

Ash (%)=(Weight of ash (g)/Weight of oven dried sample)×100

2.7. Volatile matter

Volatile matter represents the availability of organic component into the combustible biomass that directly correlates with burning property. It was calculated according to the standard ASTM 1982 in which the sample was put inside the muffle furnace at 950°C for seven minutes with covered lid.

Volatile Matter (VM) (%)=(Weight of sample with lid after heating in muffle furnace/Weight of sample with lid prior to heating in muffle furnace)×100

2.8. Ultimate analysis

Ultimate analysis is the major elemental analysis done for determination of the elements present in the biomass. The ultimate analysis was done using instruments such as Flame Photometer, Spectrophotometer, CHNS Analyzer, Nitrogen Analyzer etc. by following the standard procedures.

2.9. Briquettes' evaluation

Three types of cook stoves (Figure 2) were used to conduct the study for evaluation of chopped paddy straw briquette performance as household fuel. Briquettes and wood blocks were broken into small pieces for ease of loading as fuel in cook stove.

2.9.1. Natural draft cook stove (CS_1)

The cook stove was cylindrical in shape with double wall chamber (Figure 2a). The cook stove was constructed by using mild steel sheet of 16 gauge thickness and had weight of 18.0 kg. A layer of clay soil of 5 mm thickness was applied inside the cook stove so that minimum heat would be transferred to the outer part and handling would be easy. Inner and outer diameter of cook stove was 25.4 cm and 33.5 cm respectively. Height of cook stove from ground was 50 cm and was supported by three legs of height 7.5 cm. At the bottom, the total air flow was controlled by dividing the bottom into eight slits and covering four slits permanently. The air from other four slits can be controlled according to requirement with the help of movable handle. In the present study, the cook stove was used with fully opened four slits.

2.9.2. Conventional cook stove (CS_2)

This type of cook stove (Figure 2b) is mostly used in villages for cooking and heating purpose. It was constructed by using mud and paddy straw. Weight of this cook stove was 12.410 kg. Outer diameter of cook stove was 13.6 inches. Height of cook stove from ground and bottom 9.5 and 7.5 inches respectively. It was closed from three sides and the opened side is used to feed fuel in the combustion chamber.

2.9.3. Forced draft cook stove (CS_3)

The forced draft cook stove was purchased from the local market located in Vidarbha region of north-eastern Maharashtra (India). The cook stove had a small fan which supply air in the combustion chamber and maintain a constant flow of air in chamber (Figure 2c). The cook stove combustion chamber had a square cross section of side 4 inches. The weight of this cook stove was 5.040 kg. The fuel was fed in the combustion chamber from the top and the air was controlled with the help of regulator.

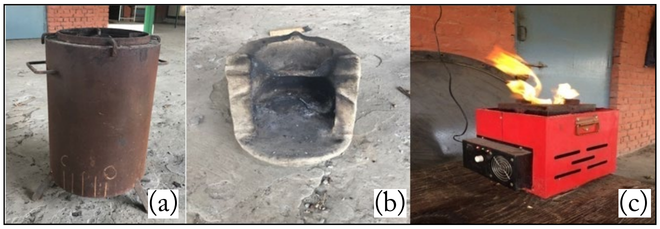

Figure 2: (a) Natural draft cook stove (b) Conventional cook stove (c) Forced draft cook stove

2.10. Burning rate

Before measuring the efficiency of cook stoves, performance testing was done with reference to the BIS standard IS13152 (PART 1): 1991 to determine the fuel burning rate per hour. According to the standard, the cook stove was filled and stacked with the test fuel up to 3/4th of the height of cook stove. Few milliliters of diesel fuel and cotton stalks were used to ignite the fuel. The burning rate of the stoves varies with the fuel used. Initial and final weight of the cook stove with test fuel was measured after half an hour burning as recommended. Burning rate capacity was measured by using the following expression:

$$Br=(Q1-Q2)/T$$

Where,

Br=Burning rate, (kg h^{-1})

Q1=Initial weight of cook stove before burning of briquette, (kg)

Q2=Final weight of cook stove after burning of briquette, (kg)

T=Total burning time, (h)

The thermal efficiency was measured evaluated by using standard water boiling test (WBT).

2.11. Experimental procedure

Thermal efficiency measurement for cook stoves burnt on different fuels was carried out according to the procedure laid down by BIS standards IS.13152:1991. The efficiency of the cook stoves was measured in duplicate. In this procedure, test fuel was taken according to burning capacity rate for one hour. Then the fuel was divided into four equal parts. Firstly, the fuel was stacked in the cook stove and then ignited by sprinkling about 10 ml of diesel fuel. When the fuel started burning, the aluminium vessel filled with five liters of water and covered with lid was kept on cook stove for heating. Feeding of fresh fuel was done after 15 minutes. The water was allowed to warm steadily till it reached a temperature of 80°C. The stirring was started after 80°C to distribute the heat uniformly within the water. The stirring was continued until the temperature of water reaches 95°C. The time taken to heat the water up to final temperature was measured. Then second vessel was loaded on the cook stove and the procedure was repeated by alternatively change of the vessels until whole fuel got exhausted i.e. till there was no visible flame in the combustion chamber of the cook stove. The final temperature of water was noted in the last vessel. The thermal efficiency of cook stove was measured using the following formula:

Thermal efficiency=(Heat utilized/Heat produced)×100

Where,

Heat utilized=(n-1) (W×0.217+w) (t_2-t_1)+(W×0.217+w) (t_3-t_1) kcal.

Heat produced=[(X×C_1)+(x×d/1000×C_2)] kcal.

w=Mass of water in vessel, kg

W=Mass of vessel, kg

X=Mass of fuel consumed, kg

C_1=Calorific value of briquettes, kcal kg^{-1}

x=Volume of diesel consumed, ml

C_2=Calorific value of diesel, kcal kg^{-1}

d=Density of diesel, g ml^{-1}

t_1=Initial temperature of water, °C

t_2=Final temperature of water, °C

t_3=Final temperature of water in last vessel at the completion of test, °C

n=Total number of vessels used. (Specific heat of aluminum= 0.217 cal g^{-1} °C)

3. RESULTS AND DISCUSSION

3.1. Proximate analysis

The proximate analysis of test fuel has been conducted and results are shown in Table 1.

It was observed that the bulk density of paddy straw briquettes was found to be 636.0 kg m^{-3} as compared to

Table 1: Proximate analysis of test fuels

Sl. No.	Proximate analysis	Paddy straw briquettes	Wood
1.	Bulk density (kg m^{-3})	636.0	329.80
2.	Moisture content (%)	9.62	11.63
3.	Volatile matter content (%)	64.03	78.92
4.	Ash content (%)	23.46	2.08
5.	Fixed carbon content (%)	2.88	7.36
6.	Calorific value (MJ kg^{-1})	15.27	16.38

wood which is 329.80 kg m^{-3} (Table 1). The bulk density of briquettes was more than wood which indicated the good compaction achieved during paddy straw briquetting. Similarly, Jittabut (2015) reported the bulk density of paddy straw briquettes to be about 560 kg m^{-3}. The moisture content of paddy straw briquettes was 9.62% as compared to 11.63% of wood. The lower amount of moisture in briquettes was due to removal of moisture from biomass during compaction in briquetting process. The volatile matter in paddy straw briquettes was found to be less than wood which was 64.03% as compared to 78.92%. Vyas et al. (2015) also found the volatile matter of 64.44% in chopped paddy straw briquettes as compared to 76.10% in saw dust briquettes. The ash content in paddy straw briquettes (23.46%) was about 11 times more than wood (2.08%). The calorific value of paddy straw briquettes was 15.27 MJ kg^{-1} as compared to 16.38 MJ kg^{-1} in wood. The calorific value in briquettes was less which might be due to presence of components such as silica (EI-Sayed and El-Samni, 2006) that resulted in more ash content in paddy straw briquettes. Moreover, fixed carbon content in paddy straw briquettes was found to be 2.88%, whereas, it was 7.36% in wood.

3.2. Ultimate analysis

Carbon, Hydrogen, Nitrogen and Sulphur in paddy straw briquettes were found to be 38.8%, 5.2%, 0.9% and 0.1%, respectively (Table 2). The results shows that Nitrogen and Sulphur contents are below 1% which would result in less formation of harmful emissions in the form of oxides and are responsible for formation of ash (Jittabut, 2015). On the other hand, wood had 48.5% of Carbon, 6.4% Hydrogen, 0.7% Nitrogen and 0.04% Sulphur. The silica content in paddy straw briquettes was 16.8% as compared to 1.3% in wood which was due to inherent characteristic of paddy straw. The more silica content in paddy straw results in formation of sodium and potassium silicates during combustion in furnaces. Gilbe et al., 2008 reported that straw-based fuels, which are rich in silicon and alkali and have a relatively lower content of alkaline earth metals showed high slagging tendencies due to the formation of ash containing alkali silicates with relatively low melting temperatures.

Table 2: Ultimate analysis for both the fuels

Material	C	H	N	Na	K	Ca	Li	S	Mg	P	S_1O_2	O
Paddy straw briquettes (%)	38.8	5.2	0.9	0.1	2.1	1.3	0.03	0.1	0.53	0.06	16.8	32.34
Wood (%)	48.5	6.4	0.7	0.3	0.3	0.9	0.00	0.04	0.43	0.08	1.3	42.28

3.3. Thermal efficiency test of cook stoves

The thermal efficiency of both the fuels viz. briquettes and wood were measured by water boiling test (WBT) with help of three different kinds of cook stoves viz. S_1, S_2 and S_3 in duplicate replications of equal weight of feeding fuel for an hour according to the average burning rate of fuels. The thermal efficiency test results for different cook stoves with both the fuels are shown in Table 3. The data showed minimum burning rate for forced draft cook stove with both the fuels. It varied from 0.93 kg h^{-1} for paddy straw briquettes used in forced draft cook stove to 1.53 kg h^{-1} in traditional cook stove and was maximum in natural draft cook stove (1.65 kg h^{-1}). The water boiling test resulted in maximum thermal efficiency of forced draft cook stove was 36.04% with wood fuel and 18.88% with paddy straw briquettes. The thermal efficiency of natural draft cook stove was 13.82% and 28.48% with paddy straw briquettes and wood respectively and it was minimum for traditional cook stove with both the fuels. The thermal efficiency of S_2 was minimum because a large amount of heat was wasted to atmosphere.

3.4. Specific fuel consumption

The specific fuel consumption for different cook stoves with wood and paddy straw briquettes fuels application is given in Table 3. The S_3 cook stove has the minimum specific fuel consumption for wood due to its size difference. The specific

Table 3: Thermal efficiency test cook stoves with paddy straw briquettes and wood

Dependent parameter/variables	Independent parameters/variable					
	CS_1		CS_2		CS_3	
	Paddy straw briquette	Wood	Paddy straw briquette	Wood	Paddy straw briquette	Wood
Burning rate (kg h^{-1})	1.65	1.85	1.53	1.26	0.93	0.95
Thermal efficiency (%)	23.82	28.48	11.71	22.95	18.88	36.04
Specific fuel consumption (kg l^{-1})	0.165	0.123	0.255	0.209	0.190	0.095

fuel consumption for paddy straw briquettes was minimum for natural draft cook stove (0.165 kg l^{-1}) as compared to forced draft that indicated better fuel burning with more air supply as size of forced draft cook stove restricts the movement of more air during combustion.

4. CONCLUSION

The paddy straw briquettes of size 70 mm from chopped material were evaluated as wood replacement in different cook stoves. The study revealed that the calorific value of briquettes is equivalent to wood. The temperature rise per minute was also higher for briquettes (4.26°C) as compared to wood (3.42°C).

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