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Performance Study of Briquettes from Agricultural Waste for Wood Stove with Catalytic Combustor

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Abstract: The study was undertaken to assess the calorific value and to evaluate the performance of briquettes prepared from agricultural wastes such as coconut pith, saw dust and sugarcane waste when fired in modified wood stove with catalytic combustor. All the briquettes were made sun dried, prepared and compressed without addition of any bonding agents. Combustion related properties namely percentage volatile matter, percentage ash content, percentage fixed carbon and calorific value of briquettes were determined. The performance of the modified stove with three different briquettes by conducting water boiling test and cooking test has been investigated. The Test results show that the calorific value of coconut pith briquette, saw dust briquette and sugarcane briquette were 23980.14 kJ/kg, 20371.29 kJ/kg and 18894.94 kJ/kg, respectively. The ash content of sugarcane briquette has lesser value (1.8 %) and the saw dust briquette has higher value (28.13 %). The Efficiency produced by the modified wood stove for coconut pith briquette, saw dust briquette and sugarcane briquette is 63.63%, 61.62% and 53.85% respectively when briquettes were fired in modified wood stove. Thus, the study proves that coconut pith briquette is best suited for firing in modified wood stove with catalytic combustor.
Keywords: .Wood stove, briquette, coconut pith briquette, sawdust briquette, sugarcane briquette.

1. Introduction

Recent estimates state that the total agro-residue availability in India is more than 500 million metric tons per annum. Around 20-25 % of it is used to produce energy. Fossil based technology is the primary source in India that meets the energy requirement in small as well as large industrial applications. Still 2.5 billion people around the world do not have access to modern fuels [1]. Briquetting is a technology for densification of agricultural residues/wastes to increase their bulk density, reduce their moisture contents and make briquettes of uniform sizes and shapes for easy handling, transport and storage. Briquettes can be defined as a product formed from physic-mechanical conversion of loose and tiny particle size materials with or without binder in different shapes and sizes. Commercialization of briquetting technology is essential to know whether the technology is economically viable or not. Therefore, this research work attempts to the utilization of briquettes prepared from coconut pith, sugarcane and sawdust.

Osarenwinda and Ihenyen stated that F.P Veshinakov (a Russian inventor) developed a method of producing briquettes from wastewood, charcoal, hard coal and from directly burning the loose agro waste residues like rice husk, palm kernel shells, groundnut shells in conventional manner which has very low thermal efficiency, loss of fuel and widespread air pollution [2].Briquettes have high specific density ranging from 1100-1200 kg/m^3 and bulk density from 800 kg/m^3 as compared to lose agricultural residues which have bulk density that range from 80 kg/m^3 – 120 kg/m^3 [3]. If these agricultural wastes are compressed into briquettes, these problems can be mitigated, and transportation and storage cost can be reduced and energy production by improving their net calorific value per unit can also be enhanced [4]. Smoke from biomass combustion produces a large number of health-damaging air pollutants including respirable particulate matter, carbon monoxide (CO), nitrogen oxides, formaldehyde, benzene, 1, 3 butadiene, polycyclic aromatic hydrocarbons (such as benzo[a]pyrene), and many other toxic organic compounds. Christophschmidl et al. designed a sampling device and compared the chemical profiles of fine particle emissions from wood stove combustion with various common woods [5]. Murari Mohon Roy suggested that hay and switch grass briquettes can successfully be combusted in domestic wood stoves with similar performance and emissions to that of other woody briquettes [6].Pholoso Malatji et al. stated that the blended briquettes are comparable to pine wood in their performance and the simulation proved that the briquettes could even perform better than pine wood [7]. Emerhi, E.A stated that briquette produced from sample of Afzeliaafricana and Terminalia superba combination bonded with starch had the highest calorific value while briquette bonded with ash had the least calorific value [8].The briquettes produced with glue as a binder perform better than their cassava starch which took less time to reach the boiling stage [9].Bichitra Bikash concluded that decomposition of finely chopped biomass at anaerobic condition is faster and he also stated that keeping biomass materials in heap condition at sun will enhance decomposition [10].

It is commonly known that most of the world's energy demand is not met by fossil fuel mainly coal, crude oil, and natural gas. Fossil fuel, which is non-renewable, provides about 80% of man's energy sources now and this may start to depreciate in future. This has been the major concern of the entire world. Since briquetting operation has not been successful in India and other developing countries, the markets for briquette have not been explored in these areas, as the rural people depend upon utilizing the materials like kerosene and charcoal available more in the local itself. Moreover, the production cost of these materials is also low. Suppose the dependency of the rural people of the globe is shifted from utilizing these non-renewable materials to renewable material like briquette, briquette will have demand in the world market.

2. Experimental

2.1 Modified Wood Stove

The Wood Stove consists of combustion chamber , air vent, ash tray, wood holder, chimney, pot seat 1 and pot seat 2. Combustion chamber is the place where wood is burnt to produce useful heat. Schematic line diagram of wood stove with catalytic combustor and modified chimney are shown in figure 1. The casing of the stove has three layers. The walls of the stove was insulated to decrease heat loss and to increase efficiency. (Thermal conductivity is 1.06 W/mK). The Catalytic combustor was placed in between pot seat 2 and chimney. The inner and outer layer of the stove is made up of mild steel and the chimney is made up of galvanized iron pipe. Ash tray was placed in stove which would collect the burnt out wood ash. Chimney was designed in such a way that it would restrict the flow of excess gas to the atmosphere so as to enhance the heat transfer to the both pots. Also two pots played a vital role in improving efficiency. The photographic view of Experimental set up is shown in Figure 2. One pot was used to absorb the energy from main source and another one was used to utilize the excess energy from the gases passing towards the chimney [11].

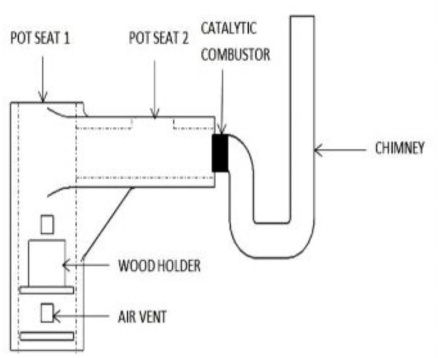

Figure 1. Schematic Line diagram of Modified Wood Stove

Figure 2. View of Modified Wood Stove

2.2 Preparation of briquettes

The coconut pith, sawdust and sugarcane waste were made sun dried for 48 hours. After 48 hours, these briquettes were crushed into fined sizes randomly and then they were compressed using hydraulic press. The prepared briquettes are shown in figure 2.

Figure 2a. Coconut pith briquette Figure 2b.Sugarcane briquette Figure 2c.Sawdust briquette

2.3 Percentage volatile matter

Volatile matter given off by a material as gas or vapor, was determined by definite prescribed methods. In order to determine the percentage volatile matter, 2g of briquettes were placed in the oven. The briquettes were now kept in the furnace at a temperature of 550 ^{o}C for 10 minutes and weighed after cooling and the percentage volatile matter was determined with the following equation.

Percentage volatile matter = (A - B)/A (1)

Where A is the weight of oven dried sample and B is the weight of sample after 10 minutes in the furnace at 550 ^{o}C.

2.4 Percentage ash content

The mass of incombustible material remain after burning a given briquette sample as a percentage of the original mass of the briquette. The percentage ash content was determined by heating 2g of the briquette sample in the furnace at a temperature of 550 ^{o}C for 4 hours duration and weighed after cooling. The percentage ash content is determined as

Percentage ash content = (C/A) * 100 (2)

Where C is the weight of ash and A is the weight of oven dried sample.

2.5 Percentage fixed carbon

Fixed carbon is the solid combustible residue that remains after a coal particle was heated and the volatile matter was expelled. The Percentage fixed carbon was calculated by subtracting the sum of percentage volatile matter and percentage ash content from 100.

2.6 Heating value

The gross or high heating value is the amount of heat produced by the complete combustion of a unit quantity of fuel. This was calculated using the formula:

Heating value = 2.326 (147.6D +144V) (3)

Where D is the percentage fixed carbon and V is the percentage volatile matter (Bailey et al.1982).

Figure 3 Testing of combustion properties of samples in muffle furnace

2.7 Water Boiling Test

The three trails of water boiling test with three different briquettes were carried out to evaluate the modified wood stove. The performance of the modified wood stove with catalytic combustor was evaluated and compared using three different briquettes as fuel material. The experimental apparatus consists of two big size aluminium pots, a weighing balance, an infrared thermometer, two mercury-in-glass thermometers, a stopwatch, water and matches. The tests had been carried out in the open air with the atmospheric condition of 28ºC dry bulb and relative humidity of 65%. These tests were performed in such a way to match the cooking method commonly adopted in rural committees in India.

The modified wood stove was loaded with equal amounts of fuel (briquette). In modified wood stove, two pre-weighed aluminum pots designated as pot A and B were filled with the same quantity of water. The initial temperature of the water was recorded using a mercury-in-glass thermometer before the pots were placed on the stove. The briquette was sprayed with 30ml of kerosene for pilot firing and then it was ignited. The change in temperature up to the boiling point was recorded at two minutes intervals with the two thermometers, permanently inserted in the two opened pots. At boiling temperature the pots were removed from the stoves and weighed. Also the fire was put out immediately and the remaining fuel was weighed.

2.8 Cooking test

One kg of rice with two litres of water was cooked using modified wood stove. The time taken and fuel consumed for cooking rice was recorded. The cooking test results are tabulated in Table 2.

2.9 Thermal efficiency

Efficiency is a measure of proportion of the total energy which is usefully employed in a thermodynamic system. The burn rate and the net calorific value of the fuel were used in the calculation of this parameter as stated

Thermal Efficiency = (Heat used in pot 1 + Heat used in pot 2)/Q_g

$Q_g = W * C$ (5)

Where Q_g is the heat produced by the briquette (dry weight)

W = Weight of the wood burnt during the trails

C = Calorific content of the briquettes.

$Q_u = (W_i - W_f) * C_v + (T_f - T_i) * W_f * C_p$ (6)

Where,

Q_u = sum of heat used in each pot (kJ),

W_i = initial weight of water (g),

W_f = final weight of water (g),

C_v = water vaporization heat (2.23×10^{-3} kJ/kg),

T_i = initial water temperature (^oC),

T_f = final water temperature (^oC),

C_p = water specific heat (0.00418×10^{-3} kJ/kg/^oC).

3. Results and Discussion

3.1 Combustion related properties:

The physical and combustion properties of the briquettes examined in this study were limited to percentage volatile matter, percentage ash, percentage fixed carbon and the heating value. The results were therefore discussed according to the values are obtained in Table1.

Table 1.Combustion properties of briquettes.

Type of briquette	Percentage volatile matter	Percentage ash content	Percentage fixed carbon	Calorific value (kJ/kg)
Coconut pith briquette	71	6.9	22.1	23980.14
Sawdust briquette	60	28.13	11.87	20371.29
Sugarcane briquette	55.5	1.8	42.7	18894.94

3.2 Water boiling test:

The water boiling test results are specified in table (2) which gives the information about the data used for thermal efficiency calculation. The specific heat capacity of water is taken as 4.2 kJ/kg, whereas latent heat of vaporization of water is 2.25 x 10^3 kJ/kg.

Table 2. Water boiling test results of modified wood stove using three briquettes

Parameters		Initial mass of the water (kg)	Water evaporated (kg)	Initial water temperature (°C)	Final water temperature (ºC)	Latent heat of vaporization of water (kJ/kg)	Briquette burned (kg)	Calorific value of briquette (kJ/kg)	Specific heat capacity of water (kJ/kg)
Coconut pith briquette	Pot 1	2	0.65	20	98	2.25 x 10^3	0.5	23980.14	4.2
	Pot 2	2	0.3	20	62				
Saw dust briquette	Pot 1	2	0.7	20	98	2.25 x 10^3	0.6	20371.29	4.2
	Pot 2	2	0.28	20	63				
Sugar cane briquette	Pot 1	2	0.64	20	98	2.25 x 10^3	0.75	18894.94	4.2
	Pot 2	2	0.3	20	62				

The water evaporated in pot 1 was higher than pot 2 because pot 1 absorbed heat from main source and pot 2 absorbed heat from excess gas flowing through chimney. The maximum temperature reached in pot 1 was 98 ºC and in pot 2 was 62ºC. The efficiency of modified wood stove using different briquettes were shown in figure 4. Since the calorific value of coconut pith briquette was high and thus it yields higher efficiency and sugarcane briquette has lower calorific value and thus, it yields lesser efficiency. Therefore calorific value plays a vital role in efficiency of wood stoves.

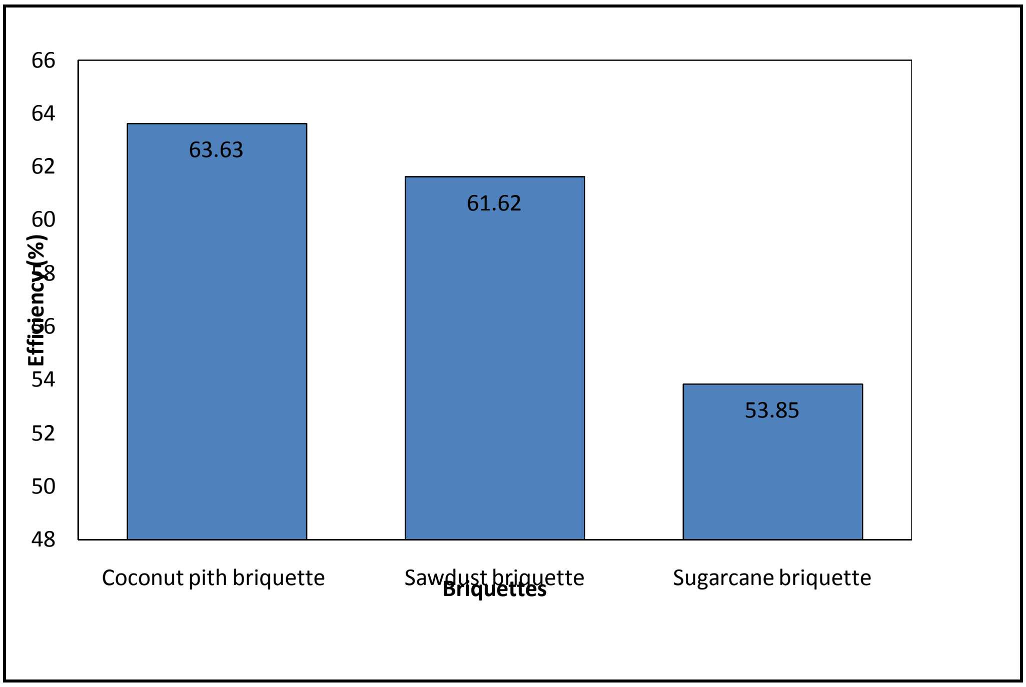

Figure 4. Efficiency of modified wood stove using different briquettes

3.3 Cooking Test:

Cooking test results of modified wood stove for different briquettes has been tabulated in Table 3. From the result it is observed that sawdust briquette is consumed less fuel consumption of 0.9 kg with 26 minutes duration for cooking rice whereas sugarcane briquette consumed high fuel consumption of 1.367 kg for 17.67 minutes. Coconut pith briquette took moderate fuel consumption of 0.967 kg with 19.67 minutes duration. So sawdust briquette is efficient considering fuel consumption but Coconut pith briquette is efficient considering time duration when firing in the wood stove.

Table 3. Cooking test of modified wood stove using different briquettes

No of Trails	Type of Briquette	Fuel Consumed (kg)	Time (Minutes)	Mean values	
				Fuel Consumed (kg)	Time (Minutes)
1	Coconut pith briquette	1.1	21	0.967	19.67
2		0.9	19		
3		0.9	19		
1	Sawdust briquette	0.9	26	0.9	26
2		0.9	26		
3		0.9	26		
1	Sugarcane briquette	1.3	17	1.367	17.67
2		1.4	19		
3		1.4	17		

4. Conclusion:

Generally, briquettes of biomass show a lot of promise as a potential source of fuel. This work was carried out to examine the combustion related properties and efficiency of briquettes when tested in modified wood stove. It was observed that the sawdust briquette has higher percentage ash content of 28.13 % but sugarcane briquette has lesser ash content 1.8%. The Calorific value of coconut pith briquette was found higher than other two briquettes. The coconut pith briquette gave higher efficiency of 63.63% whereas, sugarcane briquette gave lower efficiency of 53.85%.Therefore, the briquetting technology has a great potential for converting waste biomass into a superior fuel for household as well as industrial applications in an affordable, efficient and environment friendly manner. Recycling of biomass can be significantly helpful in alternate fuels.

Thus, briquettes produced out of coconut pith, saw dust and sugarcane would make good supplements to firewood and kerosene.

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