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Development of Cost-Effective Fuel Briquette with Poultry Manure

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Abstract

Biomass can be converted into either heat energy or electrical or energy carriers using both thermo-chemical and bio-chemical conversion. Briquetting is a process where untreated biomass is converted into homogeneous, uniformly sized high density solid blocks. Briquettes are used in boilers, heating plants, thermal power stations and by individual households for heating. Present study focuses on using poultry manure with rice husk and saw dust. Poultry manure mixed with rice husk or saw dust by 60:40 ratio provides comparatively higher bond strength. Calorific value varies significantly with the use of poultry manure and tree leaves as well as its production cost. Pure rice husk contains higher calorific value (HCV) 12.6 MJ/Kg where adding poultry manure reduces its value to 10.3 MJ/Kg and Saw dust shows 10.4 MJ/Kg where pure saw dust has 16.3 MJ/Kg in 60:40 ratios with poultry manure. Addition of 20% tree leaves on weight basis ratio of 40:40:20 with base materials and poultry manure shows 10.5 MJ/Kg and 11.7 MJ/Kg respectively for rice husk and saw dust. Competitive price of briquette for 60:40 ratios with Poultry Manure shows 6 BDT/Kg and 5BDT/Kg when secondary material is added. Moreover, if the machine capacity increases the price is reduced.

Keywords: Briquette, poultry manure, rice husk, saw dust, TGA, HCV.

I. Introduction

Energy is the most important element for economic and social development. It pivots the improvements in living condition of general people. Commercial energy consumption has improved living, but it has also brought up a number of issues. It leads to climate change consequently[1]. A large amount of today's energy is sourced from fossil fuels. Fossil fuel is a non-renewable source of energy. It will be steadily diminished in the future. Oil would be depleted first, followed by natural gas and coal[2]. With the current global energy crisis and accompanying environmental challenges, renewable energy sources are being explored and tested to their utmost potential. The need for energy conservation and the development of alternative energy systems are the two most pressing challenges for this field's researchers[3].

Biomass is a fuel with low density, uneven form, and high moisture content[4]. It is highly challenging to handle, transport, store, and make use of biomass in its natural state. These shortfalls can be improved by Compressing biomass to form briquettes[5]. Briquettes are solid pieces of homogeneous, consistent size formed from loose biomass wastes. High density solid blocks are made from sawdust, straw, or rice husk. Briquettes are a simple fuel source. Briquettes are used as fuel in boiler plants, heating plants, power plants, and thermal power plants[6]. It is also very popular among individual customers for household use[7].

Bangladesh's poultry industry is growing at a rate of 12 to 15% per year. Bangladesh has around 90,000 chicken farms[8]. Bangladesh's animal population is growing, as is manure production. This massive volume of garbage is being disposed of in open spaces, and as a result of inappropriate waste management in livestock and poultry farms, environmental hazards are being created. According to a study, each ton of unutilized poultry manure produces emissions equal to 432 kg CO_2[9]. As a result, a sustainable waste management solution would be a good alternative for farm owners looking to manage their poultry wastes in an effective and sustainable manner. Several research have already addressed the creation of biogas from poultry manure[10-12]. Furthermore, poultry manure can be utilized to make briquettes, which have many applications. Briquettes made from poultry dung are ideal for biomass-based electricity generation and domestic use[13]. Poultry droppings can be recycled by converting into biomass in the form of briquette. In rural areas biomass is mainly used for household cooking. The process is about 8-12% efficient for traditional biomass cookstoves[14]. Processed and good quality briquette can improve the condition of rural cooking where primary and low-quality biomass is used[15]. Despite the fact that there is enormous potential for briquette manufacture in Bangladesh, the sector has gone ignored. For this reason, it's crucial to evaluate the potential and carry out a technoeconomic to spread the technology. In this work briquette is produced by mixing poultry manure in different ratios with saw dust, rice husk and dried leaves. Characteristics of produced briquette is analysed with production cost.

II. Methodology

Processing biomass and shaping it into briquette allows converting organic matter into a standard form of fuel[16]. By

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upgrading as fuel and reforming shape it is transported and used easily. Various types of biomasses are used in production of briquettes.

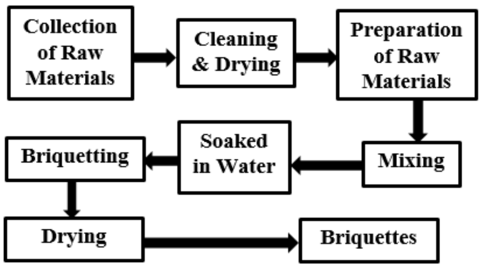

Fig. 1. Briquette production process

Each material has impacts on the physicochemical properties of the final product[17]. In this work following process is mainly followed to produce sample briquettes for testing, data collection and analysis, see Fig.1.Raw materials are collected from sawmill, rice mill and poultry farms. After collection, saw dust is dried in the open sun for four days to remove the moisture content. After Drying unwanted irregular sized particles are separated by screening. A readymade plastic strainer was used with approximate screen size less than 2-4 mm illustrated in Figure 2. The screen size was calculated by measuring the number of openings in the mesh that make up one linear inch of the plastic strainer.

Fig. 2. Screening base materials

After drying and screening, moisture content of the base materials are measured. The measured data are summarized in Table 1.

Table 1. Moisture content of base materials

No	Base Materials	Moisture (Weight basis) %
1	Saw dust	10
2	Rice Husk	9
3	Poultry manure	39

In the experiment, two different base materials, rice husk and saw dust, are used to make briquettes. Two examples were produced with the help of base materials and poultry manure. S6P4 sample comprised 60% saw dust and 40% poultry manure. R6P4 sample contained 60% rice husk and 40% poultry manure. Dry jackfruit leaves were also utilized at a 20% percentage in samples S4P4T2 and R4P4T2, however the proportion of base materials (rice husk and saw dust) was reduced by 20%.

The mould is then lifted using a hydraulic press at the bottom end, and an additional mould with a smaller diameter is fixed to the top plate once the necessary pressure has been reached (see figure 4. Later, the jack's internal pressure is released. After that, the briquette is taken out of the mould. Formed briquettes are taken out and kept inside a solar dryer for four days and used direct solar radiation Shown in fig.3 (a). Briquettes are dried in solar drier fig.3 (b) within a temperature range between 60-70°C. Solar drier is a simple renewable energy application device which is a compartment enclosed by transparent glass with insulation. It traps solar radiation and increases temperature inside the compartment like a greenhouse[18].

(a) (b)

Fig. 3. Drying briquette (a) under sun (b) using a solar dryer

Briquette machine

This briquetting machine was developed at Institute of Energy according to a Nepali model with a load capacity of 2N is shown in figure 4[19].

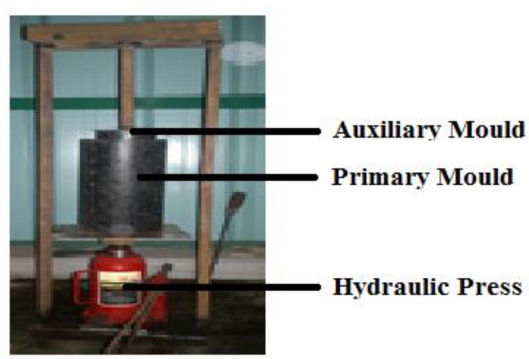

Fig. 4. Briquette machine

A slight modification was made to increase the pressure. In Figure 4, the jack is 10 ton, attached in the base. A rod is attached with the metal plate in the top supported by two rods. It helps to maximize the pressure on the feed placed in the mould. Diameter of the prepared briquette is like the diameter of the dice and is 6 inch. Height of the sample are maintained roughly by 1 inch. It is found that with higher height, the prepared briquette tends to lose compactness. Moreover, several researchers proposed to maintain a lower height for the overall performance of the Briquette[20].

III. Experimental Analysis

Percentage of Moisture content

Weighing the briquette sample (E) and oven-drying it at a temperature between 150 and 200 °C until the mass of the sample was constant allows us to determine the percentage moisture content (PMC). The sample's PMC is then calculated using the following Equation utilizing the change in weight (D):

$$PMC = \left(\frac{D}{E}\right)100 \quad (1)$$

Density Ratio

Density ratio indicates the quality of compressed briquette. It is the ratio between the relaxed density and compressed density (maximum density) of the briquette. The relaxed density of the briquettes is determined in the dry condition. It is calculated as the ratio of the briquette's mass after drying to its volume. This parameter shows how much it deforms from the compressed shape[21].

$$D = \frac{D_r}{D_m} \quad (2)$$

Where, D is the density ratio, D_r is the relaxed density of dried samples and D_m is the maximum density.

Percentage of Volatile matter

The percentage volatile matter (PVM) is determined by Thermo Gravimetric Analysis of Saw dust and Rice husk briquettes respectively with 40% Poultry manure.

The PVM is calculated using the Equation below:

$$PVM = \left(A - \frac{B}{A}\right)100 \quad (3)$$

Here, in equation 3, A is the weight of the dried sample at a temperature more than 200°C. B is the weight of the sample in the furnace at 450-500°C for the three samples.

Percentage of Ash content (PAC)

The percentage ash content (PAC) is also determined by the generated TGA curve respectively for each sample. The PAC is determined using the Equation below:

$$PAC = \left(\frac{C}{A}\right)100 \quad (4)$$

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

Percentage of Fixed Carbon Content

The percentage fixed carbon (PFC) is computed by subtracting the sum of PVM and PAC from 100 as shown in the Equation below:

Percentage volatile matter (PVM) was determined with the formula.

$$PVM = \left(\frac{A-G}{A}\right)100 \quad (5)$$

Where A is the weight of oven dried sample and G is the weight of sample after 10min in the furnace at 550^0c

$$Fixed\ Carbon = 100 - (PAC + PVM) \quad (6)$$

From the analytical test percentage of Carbon (C), Hydrogen (H), Nitrogen (N), and Sulphur (S) are determined. These values are then used to measure theoretical Higher Heating Values (HCV) in KJ/Kg by the following Equations.

$$HCV = 4.18(78.4C + 241.3H + 22.1S) \quad (7)$$

(Dulong Formula)

$$HCV = 4.18\left(78.4C + 241.3\left(H - \frac{O}{8}\right) + 22.1S\right) \quad (8)$$

(Modified Dulong Formula)

$$HCV = 4.18(85C + 270H + 26(S - O)) \quad (9)$$

(Vandralek Formula)

Where C, H and S are the percent of carbon, hydrogen, and sulphur present in a sample respectively.

IV. Results and Discussion

Density Ratio

Table 2 presents the weight, density and density ratio of the sample S6P4 and R6P4. Using the formula no. 1 and 2, 0.88 Kg/m^3 (maximum) and 0.34 kg/m^3 (relaxed) and density ratio 0.39 were found for S6P4 and 0.59 kg/m^3 (maximum), 0.29 Kg/m^3 (relaxed) and density ratio 0.49 were found for R6P4.

Table 2. 60-40 formula briquette properties

Sample	Weight (gm)		Density (Kg/m^3)		Density Ratio
	Wet	Dry	Maximum	Relaxed (Dry)	
S6P4	0.14	0.05	0.88	0.34	0.39
R6P4	0.12	0.06	0.59	0.29	0.49

Table 3 presents the weight, density and density ratio of the sample S4P4T2 and R4P4T2. Using formula 1 and 2, , 0.59 Kg/m^3 (maximum) and 0.0.24 kg/m^3 (relaxed) and density ratio 0.41 were found for S4P4T2 and 0.53 kg/m^3 (maximum), 0.26 Kg/m^3 (relaxed) and density ratio 0.49 were found for R4P4T2.

Table 3. 40-40-20 formula briquette properties

Sample	Weight (gm)		Density (Kg/m^3)		Density Ratio
	Wet	Dry	Maximum	Relaxed (Dry)	
S4P4T2	0.18	0.07	0.59	0.24	0.41
R4P4T2	0.12	0.06	0.53	0.26	0.49

Thermo Gravimetric Analysis (TGA)

The Thermo Gravimetric Analyzer (TGA) is used for sample characterization. Thermo gravimetric Analysis of samples was done in Centre for advanced research (CARS) at University of Dhaka .TGA shows the changes in material's weight in relation to change in temperature. Precise measurement is maintained for weight, temperature and change in temperature for experimented samples. Temperature is presented on the ordinate (Y-axis) while weight percent (%) is displayed on the abscissa (X-axis). Figures 5, 6, 7 and 8 depict the drying time during the first stage, where the temperature is below 200°C, during which light volatiles, primarily water, were released throughout the process. During the thermo-chemical conversion process, de-volatilization takes place. This step is represented by the second stage of decomposition, which occurs at temperatures ranging from 200 to 500 degrees Celsius and exhibits a notable slope of the TG curves (see Figs. 5, 6, 7 and 8). Because fixed carbon indicates the fraction of fuel that burns in solid state, fuels with higher fixed carbon and low volatile matter tend to burn slowly.

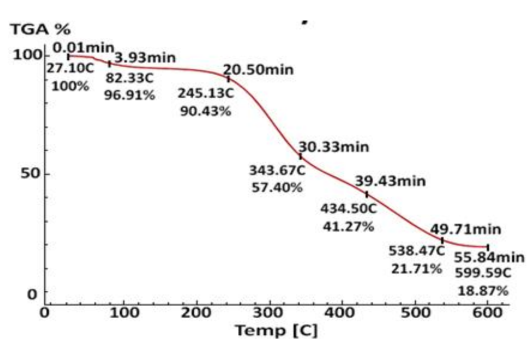

Fig. 5. Thermo Gravimetric curve of R6P4

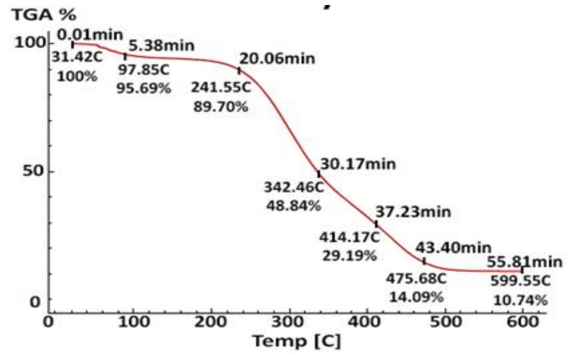

Fig. 6. Thermo Gravimetric curve of S6P4

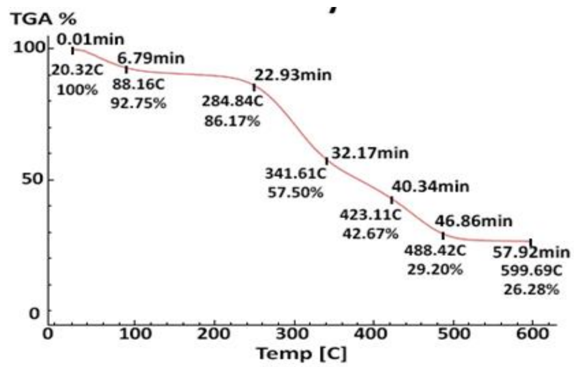

Fig. 7. Thermo Gravimetric curve of R4P4T2

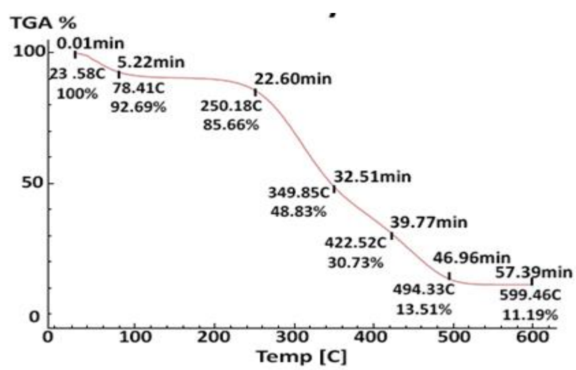

Fig. 8. Thermo Gravimetric curve of S4P4T2

TGA curves for all briquettes changed downward at temperatures over 200°C (see Figs. 5, 6, 7 and 8). It suggests that the volatile matter content of these biomasses is high. All biomasses lost mass in the range of 4-8% due to evaporation of moisture content in the first stage temperature up to 100°C. In the second stage, where temperatures vary from 100°C to 600°C, approximately 70-88% of total mass is utilized for heat production. It denotes the amount of volatile stuff burnt. In this temperature range, the TGA graph abruptly declines. All the volatile matter content is burnt at temperatures ranging from 250°C to 400°C.

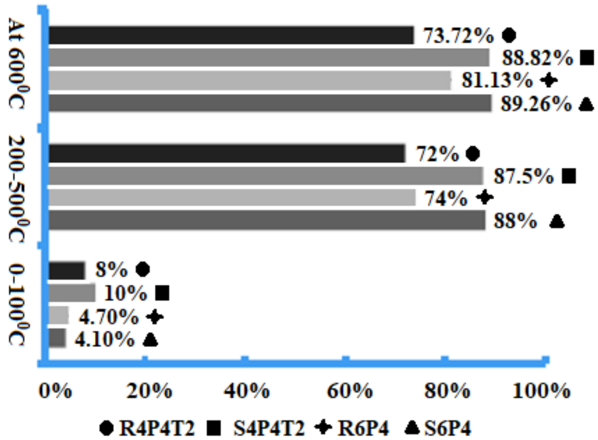

Fig. 9. Weight Loss of prepared samples at various Temperature ranges

Figure 9 presents the weight loss percentage of the briquette sample at different temperature. The results indicate the thermal decomposition of sample briquettes occur within the chosen temperature range. The most significant weight loss 89.26%, 81.13%, 88.82% 73.72% respectively for sample S6P4, R6P4, S4P4T2 and R4P4T2 occurred at 600° C.

Physical Properties of the Briquette

Ash Content

From the TGA graph, figure 5, 6, 7 and 8 last stage is at 600°C temperature which provides the information about residues present in the sample. Residues are non- burning materials. Rice Husk with 40% poultry manure and 20% tree leaves shows higher ash content and saw dust with only 40% manure shows the lowest. After adding 20% tree leaves with saw dust and rice husk, ash content increases as expected (Fig 10). Due to the high ash content R4P4T2 sample is not a recommended one though it has the highest heating value amongst all the tested samples. On the other hand, S6P4, R6P4 and S4P4T2 have lower ash content and significant heating values. If R4P4T2 formula is used higher ash will be produced. As these fuels are meant to be used in rural areas ash can be used as fertilizers and can have monetary values. Ashes are mixed with clay to build mud houses and ash mix bricks can be produced[22-23]. Many other uses of ash are determined now days including embankment, landfill, and gypsum panel production[24].

Volatile Matters

In the second stage of TGA test all biomass lost 65-82% mass. In this stage temperature remains between 200°C-500°C where all volatiles are burnt. This stage specifies the highest temperature needed to burn off the volatile components of biomass[25]. The volatile compounds of each sample are shown in Figure 11.

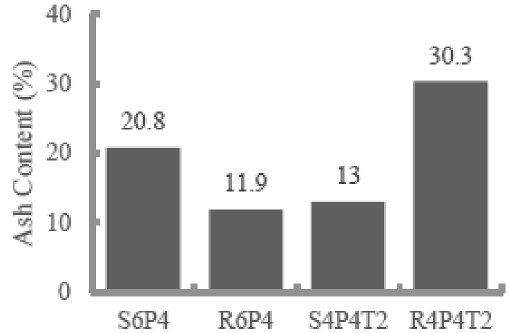

Fig. 10. Ash Content Percentage of the Samples

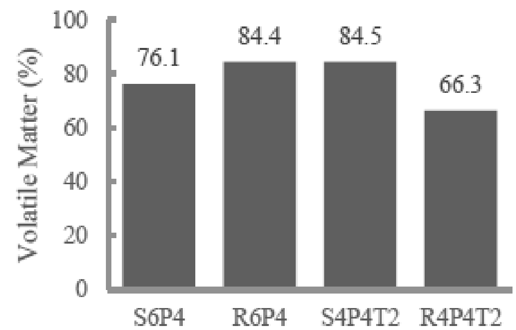

Fig. 11. Volatile Matter Percentage of the Samples

Moisture Content

In the first stage of burning process moisture contents are evaporated. All samples lose their weight in the range of 4-10 %. Rice husk with manure at 60:40 ratios show higher moisture content. Though all the samples show moisture content almost same. It should be noted that these samples are dried in same time length in a solar drier. Figure 12 shows the percentage of moisture content of tested samples.

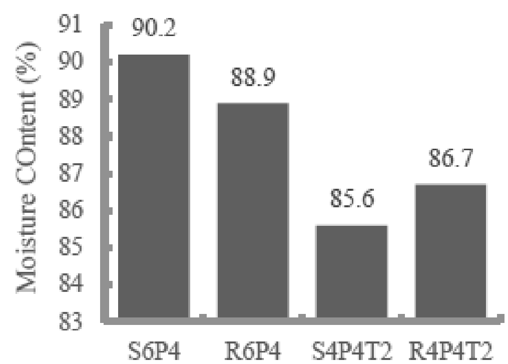

Fig. 12. Moisture content percentage of Samples

Fixed Carbon Content

Fixed carbon content is the percentage of carbon available for char combustion after the release of volatile matter and moisture due to burning of the sample briquette. Fixed carbon content for briquette sample S6P4, R6P4, S4P4T2 and R4P4T2 are 3.1 %, 3.7 %, 2.5% and 3.4% respectively (Fig. 13).

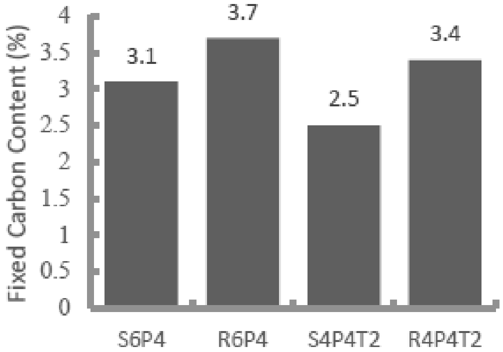

Fig. 13. Fixed Carbon Content of Samples

Elemental Analysis

In this analysis sample is tested to find its composing elements (Table 4). Analysis of samples was done in Centre for advanced research (CARS) at University of Dhaka. It mainly deals with finding percentage of carbon, hydrogen, nitrogen, and sulphur in a sample. Prepared samples are tested, and percentage values of these elements are shown in table 6. These values are later used to find out the theoretical higher heating values (HCVs) for samples. Sample S6P4 contains the highest fixed carbon value and R6P4 contains the lowest. Moreover, Sulphur content is comparatively low in rice husk which implies good for fuel properties.

Table 4. C H N S analysis of the Briquette

Composition	Weight (mg)	%C	%H	%N	%S
R6P4	4.85	27.56	6.663	3.68	0.082
S6P4	3.731	43.02	6.454	3.06	0.083
S4P4T2	3.546	42.12	6.355	4.08	0.088
R4P4T2	3.414	37.92	5.638	4.34	0.11

Calculation of Theoretical and Measured HCV

According to Dulong Formula, Modified Dulong Formula and Vandralek Formula Higher Heating Value is obtained theoretically by using formula 7, 8 and 9 and then compared with tested values. Figure 15 shows calculated HCV values separately. Data shows higher variation between measured and calculated values. This may be resulted from apparatus taken from experimental analysis.

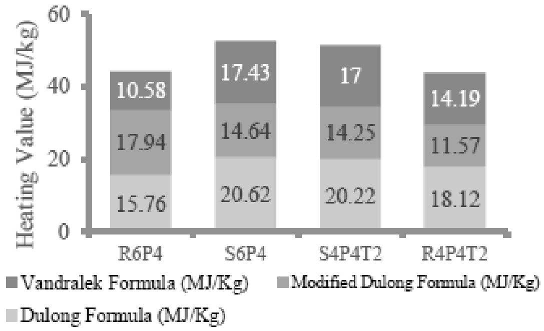

Fig. 14. Analysis of Heating Values of prepared Briquettes

Four samples with 40% Poultry Manure mixture and 20% tree leaves with saw dust and rice husk are tested to determine Calorific Value. Heating value of samples is showed in Figure 15.

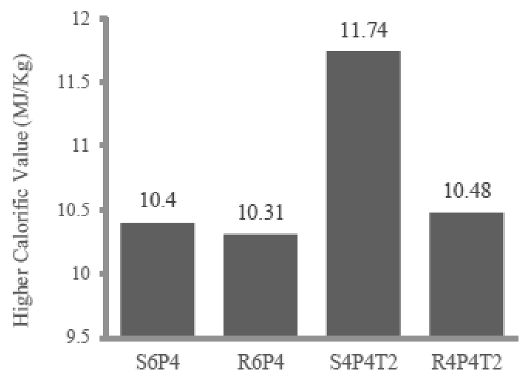

Fig. 15. Measured Higher Calorific Value

It is found that the addition of tree leaves increases the calorific value. Poultry manure is not a good fuel alone though it does not deviate the actual calorific value of Saw Dust and Rice husk significantly. Mainly moisture content of manure reduces the Calorific value[26].

V. Technoeconomic Analysis

Handmade Briquettes are already available in market though it is not easily found. Moreover, to run a small-scale industry in this sector may face difficulties with the scarcity of raw materials. A details study is required to analyse the market and economic condition as the price of raw materials vary significantly by both regional and seasonal causes.

Labour Cost

The labour cost of briquette manufacturers is determined by the design of the plant. The breadth of the operation, including any considerable residue collection effort. The wage rates of the major labour categories employed, as well as the degree to which the unit is integrated with a bigger plant that can fulfil some labour demands on a part-time basis (Table 7).

Maintenance

Briquetting equipment maintenance can be rather laborious, especially for screw presses and piston presses that use abrasive materials like rice husk. The actual assignment of maintenance expenses varies depending on how maintenance is carried out and the internal accounting procedures used by plants. Maintenance expenses, which are sometimes overlooked when planning plants, can contribute significantly to the cost of producing briquettes. If proper allowances are not made in advance, it could result in a continued reliance on imported spare parts and production delays.

Raw Materials

The cost of residues is a very site-specific issue and needs to be thought of as an additional unit cost. Even if the leftover is ostensibly free, it is typical to incur transportation costs to bring the residue to the briquette facility. In the event of units located at the location where residue is produced, it can be avoided, but in other circumstances, the cost of transportation may account up a substantial portion of operating expenses. For this experiment, price of raw materials per Kg are given in Table 5.

Price of raw materials varies from region to region depending on their availability. Moreover, some additional cost is involved for transporting raw materials to the plant. The handmade briquette production machine can process raw material at a rate of 6kg per hours and it requires hard labour.

Table 5. Assumptions economic assessment for briquette Production

Compositions	Rice Husk, Saw Dust and Poultry Manure
Price of Raw Materials (BDT/Kg)	2-3 BDT
Capacity of the Machine (Kg/hr)	6
Water Supply/ Kg (WS)	0.25
Operating Hours/ Day	8
Operating Days /Year	300
Handling cost of Poultry Manure (BDT/Kg)	10
Cost of worker (BDT/Person/hr)	25
Unit of Un Skilled worker (BDT/Person/hr)	12

Data of Table 6 is prepared by using the equation provided by FAO[27] which shows the considerations for briquette production. An individual study is recommended for economic analysis for commercial production.

Table 6. Material cost involve in production

Composition	60% Primary 40% Poultry Manure	40% Primary 40% Poultry Manure 20% Tree Leaves
Operating Hours/ yr	2400	2400
Capacity of Manual Machine (Kg/hr)	6	6
Unit cost of Primary Material (BDT/Kg)	2	2
Unit cost of Secondary Material (BDT/Kg)	-	0.5
Handling cost of Poultry Manure (BDT/Kg)	1	11
Briquette Production Kg/Yr	14400	14400
Total Material Cost BDT/Yr	66316	48126

Table 5 shows that the addition of binder materials significantly reduces the total materials cost. Material cost increases dynamically when binder prices is higher. As binder, paper is used with primary materials. Addition of secondary materials can significantly reduce the cost as well as use of binder.

Table 7. Yearly Labour Cost, Fixed Cost and Revenue

Composition	60% Primary 40% Binder	40% Primary 40% Poultry Manure 20% Tree Leaves
Number of skilled workers	1	1
Number of unskilled workers	1	1
Total Labor Cost (BDT/Yr)	88800	88800
Equipment Initial Fixed cost (BDT/Yr)	5000	5000
Year of Operation	10	10
Maintenance cost (BDT/Yr)	500	500
Competitive price of briquette (BDT/ kg)	6	5
Potential Revenue (BDT/ yr)	115,200	100,800

An overview of total project cost and revenue projection is shown in Table 7. Competitive price of briquette for 60:40 ratios with Poultry Manure shows 6 BDT/Kg and 5BDT/Kg when secondary material is added. Moreover, if the machine capacity increases the price is reduced. It is observed that if tree leaves are used as secondary material the price of per kg Briquette is lowered. Poultry manure is almost free though handling cost may be included which will result an increase in production cost. Moreover, additional price will be added for transportation, Water usage, building construction etc. An improvement in hand made briquette machine can significantly reduce the cost. Increase in percentage of secondary materials in the process may pose significant reduction of production cost as tree leaves are almost available and free. It also affects the binding quality and moisture content of the briquette which may affect storage and transportation cost.

VI. Conclusion

This experimental work focuses on developing a method for manufacturing briquettes of consistent quality from poultry manure with handheld briquetting machine. To find out the best fuel, briquette samples are tested using standard laboratory instruments. The physical quality, Calorific Value, Moisture Content, Volatile Content, and ash Content were used for performance analysis. TG analysis shows highest volatile content in saw dust with 40% poultry manure and Rice Husk with 40% poultry manure and 20% tree leaves showed lowest. Moisture content is found high in rice husk where Saw dust shows the lowest percentage of moisture content. Because of Ash Content, Saw Dust shows relatively lower percentage where Rice Husk contains the higher percentage of ash content in both ratio with poultry manure and tree leaves. Saw dust shows higher calorific value than rice husk The calorific value of pure rice husk is greater (HCV) Saw dust has a value of 10.4 MJ/Kg when mixed with poultry manure in a 60:40 ratio, however pure saw dust has a value of 16.3 MJ/Kg when mixed with poultry manure. The addition of 20% tree leaves on a weight basis ratio of 40:40:20 with base materials and chicken manure results in 10.5 MJ/Kg and 11.7 MJ/Kg for rice husk and saw dust, respectively. Briquette prices are competitive for 60:40 ratios with poultry manure at 6 BDT/Kg and 5BDT/Kg when supplementary material is included.

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