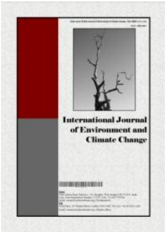

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Development and Experimental Investigation of Briquetting Machine for Use in Rural Area

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Biomass is an organic matter such as agricultural crop residues, forest plant materials and animal wastes used as animal fodder, domestic fuel energy source in India. The briquetting technology is the extrusion process of various biomass materials to produce briquettes as a biofuel substitute for fuel wood, coal and charcoal. Mahua (*Madhuca Indica*) seeds oil extraction plant have waste known as mahua deoiled cake (Doc) is major forest biomass and is locally available in southern parts of Gujarat. The development of an efficient and low-cost screw press type briquetting machine appropriate for rural peoples of developing countries was carried out. The four combinations with different proportions of raw biomass such as mahua seed deoiled cake, coal, rice husk and grass were used to produce briquette C_1 (70:10:10:10), C_2 (50:20:20:10), C_3 (100:0:0:0), and C_4 (50:0:50:0), respectively. The properties of briquettes were determined as the density of briquettes, shatter resistance, tumbling resistance, water retention test and calorific value. The highest resistance to water penetration was observed for combination C_1 briquettes as 52.20% because mahua Doc has less porosity and high density. Combination C_4 briquettes were observed for a maximum degree of densification and maximum energy density ratio as 31.37% and 1.1, respectively. Tumbler resistance and shatter resistance were observed maximum for combination C_1 as 86.70% and 99.82%, respectively which comprises 70% mahua Doc, 10%, coal, 10% rice husk and 10% grass. A high calorific value was found 3946.43 kcal/kg in combination C_3 (100:0:0:0) because briquette made of 100% mahua Doc. The addition of Mahua Doc matter in the briquette was found better results as an increase in calorific value, water retention, shatter and tumbling resistance.

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Keywords: Biomass; briquetting technology; calorific value; degree of densification.

1. INTRODUCTION

Biomass is an organic matter that mainly originated from agricultural crop residues (husks, cobs, and shells), forest plant materials (wood waste) and animal wastes (dung). Given its advantages, biomass has long been a significant source of energy in India. It has the ability to satisfy the energy needs in rural regions as a climate-friendly fuel because it is renewable, abundantly available, and carbon-neutral. Loose biomass is not easy to process of transportation, storage and handling of biomass. Generally in India, biomass is used as animal fodder, domestic fuel, industrial fuel for boilers, etc.

Madhuca Indica, commonly known as Mahua, is commonly available in the central and southern forest parts of India. The annual production of mahua seeds in the country is around 0.50 million tons. Many villages of the south Gujarat region, especially of the Narmada district, are surrounded by mahua trees with the huge availability of forest waste.

Gunvir and Dwivedi [1] studied mahua oil seed cake. They suggested that the cake was a waste that is thrown away with no further use or used as cattle feed, thus this can be used as a feedstock for the preparation of activated carbon. After the extraction of oil from mahua seeds, the remaining waste known as mahua cake is beneficial as an insecticide through smoke produced in burning it [2,3]. Mahua cakes possess insecticidal and pesticide properties and are applied to lawns and golf greens as the saponin present in them has a specific action against earthworms [4]. Rice husk is a waste product available from a rice mill in most of the land of south Gujarat.

Srivastava et al. [5] studied that “in the screw presses, material fed continuously into a screw which forced it into a cylindrical die. The die was often heated to raise the temperature to the point where lignin flow occurred”. Mathur et al. [6] used “carbonized biomass, sawdust, rice husk and straw for briquettes and cow dung slurry as binder material”.

For efficient utilization of biomass, the production of briquettes through densification of loose biomass particles for utilization as fuels. The densification process for the production of briquettes is termed briquetting technology. Briquetted biomass is easier to transport, handle and has higher fuel efficiency. Briquette is an eco-friendly, sustainable and economical usage of biomass materials as solid bio-fuels employing compaction of the agricultural residues and forest waste and could provide a renewable source of energy by converting biomass waste into high-density fuel briquettes [7]. In comparison to wood or coal, biomass briquettes have low ash content as well as low moisture level.

Currently, several briquetting technologies are available in the market for the production of biomass briquettes. The failure of the adoption of developed briquetting machines is due to some reasons for instance inappropriate technology, lack of knowledge, extreme initial and operating cost, lack of operating skill and the low local prices of wood fuel and charcoal [8]. Therefore need for the development of an appropriate briquetting machine suitable for the local area. The main objective of this paper is to present an efficient and low-cost briquetting machine appropriate for rural peoples of developing countries; in terms of its operating easiness and socio-economic requirements.

2. MATERIALS AND METHODS

In this study, an effort was made to study and utilize the locally available biomass materials and the potential of safe disposal of it. The development of the screw press type briquetting machine suitable for rural people to use nearby biomass material for household usage was carried out at the College of Agricultural Engineering and Technology, Dediapada, Narmada district, Gujarat State, India.

2.1 Operation of the Briquetting Machine

The developed briquetting machine (Fig. 1) can be powered by both; a pulley and motor mechanism or manually through a handle connected with the pulley. The briquetting machine has a screw press extruder type mechanism for the compaction of low bulk density waste to convert it into briquettes. When the briquetting machine was switched on for operation, the mixture of biomass was fed to the hopper for further densification. The prime mover, which is the electric motor or manual handle, drives a pulley mounted on a shaft and the movement of the shaft enables the rotation of the screw extruder. The poured material was to be pressed between the screw and barrel and propelled by the rotating screw in a direction parallel to the axis. The configuration of the screw and its shaft was such that material should progressively be compressed as it moves on, toward the discharge end of the cylinder. The gradually increasing pressure releases the temperature which tends to flow lignin which functions as a binder in the process, thus there was no or less need for any binding agent.

2.2 Selection of Biomass Materials

For the selection of the raw materials as biomass, some important properties were considered as its high calorific value, alternative use, low nutritional value and high biomass/ash ratio [9]. De-oiled cake (Doc) of mahua seed, rice husk, charcoal and grasses type of biomass raw materials were used for the production of briquettes. Rice husk was gotten from a local rice milling industry (Fig. 2). De-oiled cake of mahua seed was obtained from a local oil extraction mill and charcoal was procured from a local market of Dediapada. Grass-type biomass material was collected from the college campus. De-oiled cake, rice husk and grass were initially sun-dried for some period to decrease the moistness present in the biomass materials.

To obtain the briquette of the desired quality, various mixtures were formed and four samples/combinations were produced (Fig. 4) for each of the compositions as shown in Table 2. The mixture of the biomass was fed to the briquetting machine for the production of the briquette.

2.3 Performance Evaluation

For the performance evaluation, briquette samples were randomly selected from the all samples. The briquettes ejected from the dies, the mass and the dimensions of the briquettes were measured. Physical properties and calorific value as thermal properties were determined. The physical properties of briquettes as the overall length, diameter of briquettes, density, shatter resistance, tumbling resistance and water retention were determined.

Fig. 1. Developed briquetting machine

Table 1. Technical specification of the developed briquetting machine

Sr. No.	Particular	Specification	
1	Machine	Capacity	10 kg/h
		Overall Dimensions (L x B x H)	440 x 255 x 290 mm
2	Screw	Diameter (D)	75 mm
		No. of turns	4
3	Die	No. of die	3
		Diameter (D_D)	20 mm
		Length (D_L)	35 mm
4	Pulley	Diameter (D_P)	255 mm
5	Hopper	Size (L x B x H)	180 x 165 x 90 mm
6	Handle	Diameter (D_H)	30 mm
		Length (H_L)	80 mm

a) Mahua Doc

b) Rice husk

c) Charcoal

d) Grass

Fig. 2. Locally available biomass materials

Fig. 3. Briquettes coming out from the developed briquetting machine

Combination C_1

Combination C_2

Combination C_3

Combination C_4

Fig. 4. Different samples of briquettes

Table 2. Mixtures of biomass samples

Combinations	Doc	Rice husk	Grass	Coal
C_1	70%	10%	10%	10%
C_2	50%	20%	20%	10%
C_3	100%	0%	0%	0%
C_4	50%	0%	50%	0%

2.4 Bulk Density

The bulk density of the biomass was determined by measuring the volume of raw biomass through the water displacement method according to BSI 3424 standard. An empty cylindrical-shaped container of known volume and mass was filled with the biomass material up to completely fill the container and weighted it. After that, the mass of filled raw biomass was determined. The bulk density of the biomass was calculated by dividing the mass of the biomass by the volume of the container [10].

2.5 Resistance to Water Penetration

"Resistance to water penetration test is important to determine briquette response during rainy seasons or while in contact with water. Water absorption of a briquette was determined by immersing the briquette completely in water at room temperature of 27°C for 30 seconds. The gain in weight of the briquettes in percentage was calculated and recorded as the percentage of water absorbed by briquettes" [11]. The percent water gain was calculated by using equation (1).

$$\text{\% Water gained by briquette} = \frac{W_2 - W_1}{W_2} \times 100 \quad (1)$$

Where W_1 and W_2 are the weight of the briquette before and after water immersion

$$\text{\% Resistance to water penetration} = 100 - (\text{\% water gain}) \quad (2)$$

2.6 Degree of Densification

The degree of densification for briquettes was determined by calculation of the percentage increase in density of raw biomass material due to compaction of it as briquettes [12]. Degree of densification was calculated by using equation (3).

$$\text{Degree of densification} = \frac{\text{Density of briquette} - \text{Density of raw material}}{\text{Density of raw material}} \quad (3)$$

2.7 Energy Density Ratio

The energy density ratio of briquettes was determined through the calculation of the ratio of energy content per unit volume of raw biomass to energy content per unit volume of briquettes [12]. It was calculated by using equation (4).

$$\text{Energy density ratio} = \frac{\text{Energy content of raw material per unit volume}}{\text{Energy content of briquetted fuel per unit volume}} \quad (4)$$

2.8 Shatter Resistance

“Shatter resistance was used for determining the hardness of briquettes. The briquette with known weight and length was repeatedly dropped from 1 m height onto a concrete surface. The mass of the briquettes decreased due to shattering/disintegration. The loss of material percentage was calculated and recorded as the shatter resistance of briquettes” [12]. The shatter resistance of the briquettes was calculated by using following equation (6).

$$\text{Percent weight loss} = \frac{W_1 - W_2}{W_1} \times 100 \quad (5)$$

Where W_1 and W_2 are the weight of the briquette before and after shattering

$$\% \text{ Shatter resistance} = 100 - (\% \text{ weight loss}) \quad (6)$$

2.9 Tumbling Test

“A tumbling test was used for testing the durability of briquette fuel. The cuboid formed by an angle iron frame having dimensions of 30×30×45 cm and fixed over a hollow shaft diagonally was used to conduct the tumbling test. The sample of briquettes was put inside and the cuboid is rotated for 15 minutes” [12]. After 15 minutes of tumbling action, the briquette was taken out and weighed. Furthermore percent loss of weight was calculated by using equation (7).

$$\text{Percent weight loss} = \frac{W_1 - W_2}{W_1} \times 100 \quad (7)$$

Where W_1 and W_2 are the weight of briquette before and after tumbling

$$\text{Durability Index} = 100 - (\% \text{ weight loss}) \quad (8)$$

3. RESULTS AND DISCUSSION

3.1 Physical Properties of Briquettes

The physical properties of briquette fuel such as length, diameter, weight, volume and density were recorded. The result obtained was depicted in Table 3.

The length of briquettes and diameter of briquettes were observed in the range of 4.95 to 6.60 cm and 1.6 to 2.1 cm, respectively. The weight and volume of the briquette were recorded maximum for combination C_4 as 8.23 gm and 24.49 cm^3, respectively compared to other combinations. The maximum average density of briquettes was observed for combination C_3 as 0.632 g/cc which comprises 100% mahua Doc.

3.2 Bulk Density

The bulk density of raw biomass i.e. mahua seed de-oil cake (Doc), coal, rice husk and the grass was determined and the results of the average bulk density were recorded as shown in Fig. 5.

Based on the study of Rajaseenivasan et al. [13] “an increment in briquette density leads to a reduction in size; thereby improving combustion rate”. Akowuah et al. [14] reported that “high-density briquette is said to have sufficient strength that can withstand failure and shocks during handling, transportation and storage. Coal particles are smaller than rice husk particles hence the pores were reduced in the briquettes. It is suggested that for more compaction of the biomass material, smaller particle sizes could be utilized”.

Table 3. Physical properties of briquettes (Average value)

Properties	C_1	C_2	C_3	C_4
Length (cm)	5.05	4.95	5.4	6.6
Diameter (cm)	1.9	1.9	1.6	2.1
Weight (g)	7.77	6.27	7.56	8.23
Volume (cm^3)	13.22	13.95	12.03	24.49
Density (g/cc)	0.587	0.448	0.632	0.335

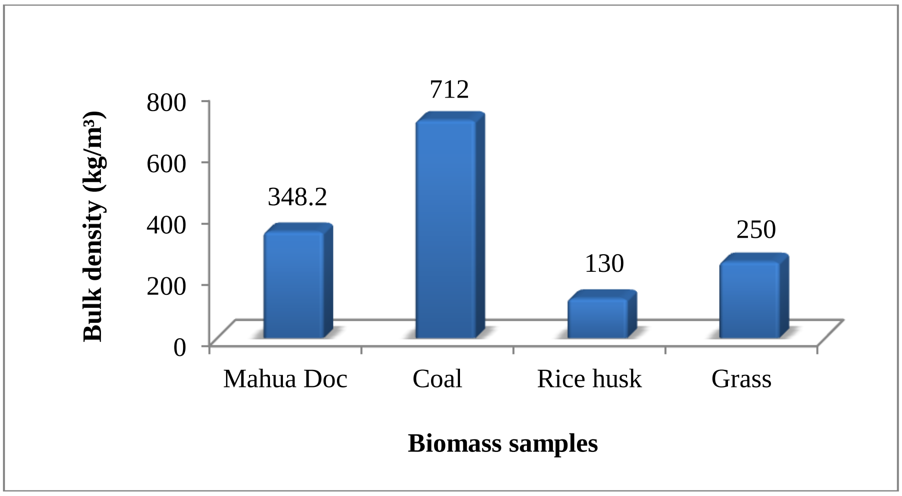

Fig. 5. Bulk density of raw biomass

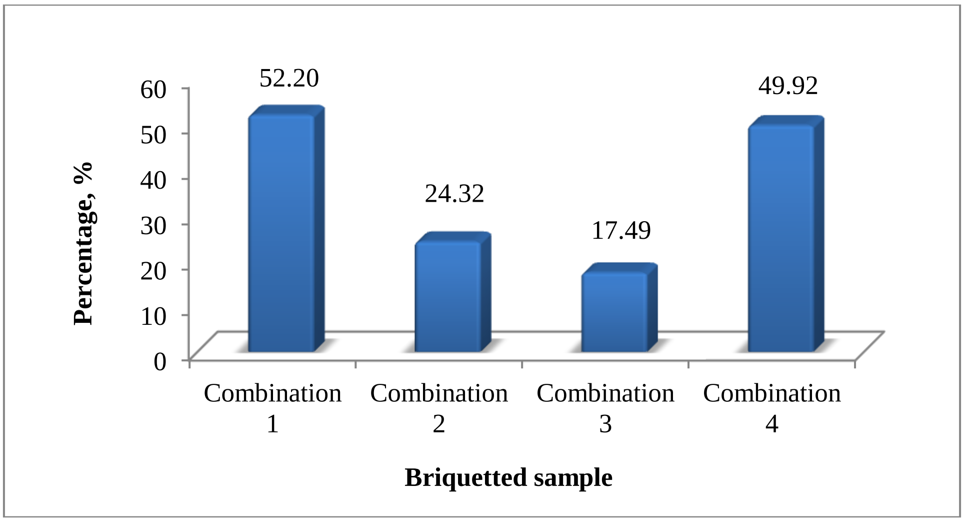

Fig. 6. Resistance to water penetration of briquettes

3.3 Resistance to Water Penetration

To understand the behavior of the briquettes in a high humidity environment during storage or transportation, water resistance analysis was carried out and the obtained results are depicted in Fig. 6.

Fig.6 showed that the highest resistance to water penetration was for combination C_1 briquettes as 52.20% followed by combination C_2 and C_4 briquettes having a resistance of 24.32% and 49.92% respectively. The least resistance to water penetration was observed for combination C_3 briquettes having a resistance of 17.49%. It indicated that the briquettes formed using a higher percentage of rice husks and grasses were porous and non-homogeneous, which allowed water penetration. As revealed in the work of Davies and Davies that the briquette with the least water absorption characteristics has the best hygroscopic property [15].

Based on the analysis, the minimum value of water gained was obtained from combination C_1 due to the higher percentage of mahua Doc. This implies that the combination C_1 has the highest resistance to water penetration because of its less porosity and high density. This makes combination C_1 the most desirable in terms of water resistance property when compared to other combinations.

3.4 Degree of Densification

The degree of densification represents a percent increase in the density of biomass material due to briquetting. The results obtained from the degree of densification are shown in Fig. 7.

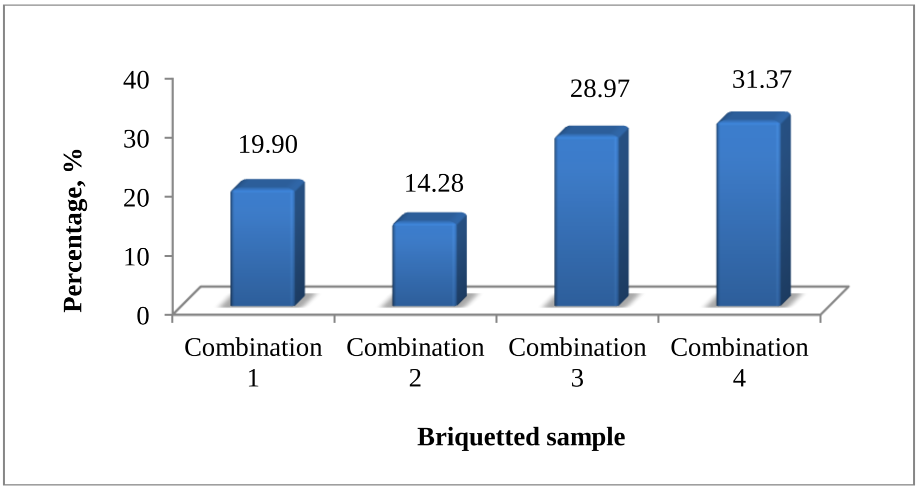

Fig. 7. Degree of densification for briquette fuel

Fig. 7 showed that the maximum degree of densification was found to be 31.37% in C_4 (50:0:50:0). The lowest degree of densification was found to be 14.28% in C_2. It indicated that during briquetting the material with a higher amount of biomass in form of powdered coal, rice husk, and grass could not be compressed as compared to biomass containing more mahua Doc.

3.5 Energy Density Ratio

The energy density ratio is the ratio of the energy density of raw material to the energy density of briquette fuel. The energy density ratio is depicted in Fig. 8.

From Fig. 8, the maximum ratio of energy density was observed for combination C_4 briquettes as 1.1 followed by combination C_3 briquettes having an energy density ratio of 1.03. Combination C_1 and C_2 briquettes were observed as having the same ratio of energy density.

3.6 Shatter Resistance of Briquette Fuel

Briquette strength can be measured and known through the shatter index. To avoid distortion of briquettes during handling, the shatter index and impact resistance test must be carried out. The results obtained from the shatter index test are depicted in Fig. 9.

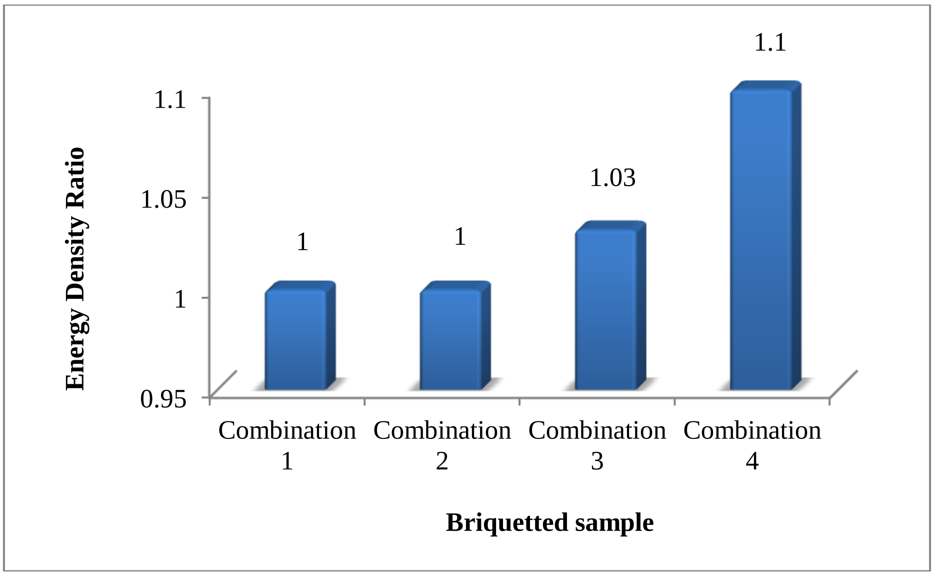

Fig. 8. Energy density ratio of briquette fuel

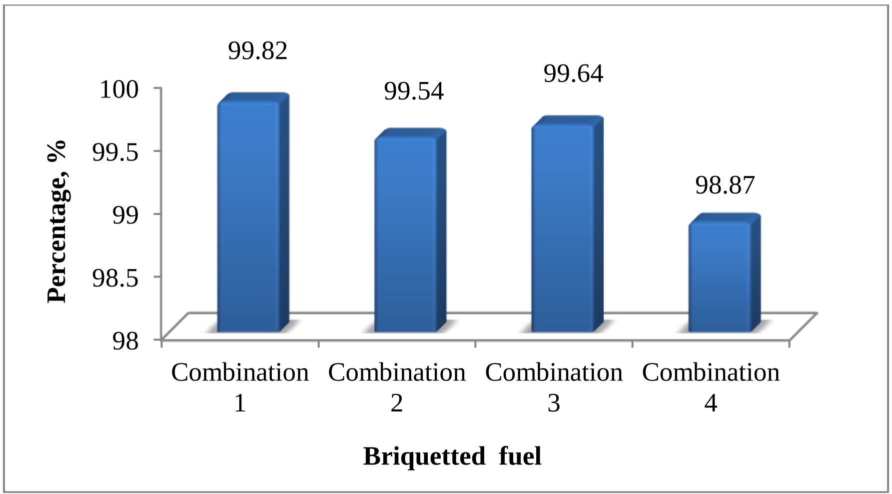

Fig. 9. Shatter resistance of briquette fuel

Fig. 9 shows the shatter index values obtained for combinations C_1, C_2, C_3 and C_4 as 99.82, 99.54, 99.64 and 98.87%, respectively. Combination C_1 has a higher shatter index because it contained more percentage of mahua Doc. The high shatter index showed the briquette had high shock and impact resistance. Hence combination C_1 was found more suitable for handling and transportation when compared to other combinations.

3.7 Tumbler Test

A tumbler test was carried out to examine the durability index of the briquettes. The results of the tumbling test are presented in Fig. 10.

Fig. 10 shows that the maximum tumbler resistance was found to be 86.70% in combination C_1 which comprises mahua 70% Doc, 10%, coal, 10% rice husk and 10% grass. The lowest tumbler resistance was found to be 69.09% in combination C_3 which comprises 100% mahua Doc. It was observed that a higher percentage of mahua Doc has less tumbling resistance.

After analyzing the various properties of briquettes from each combination, it was observed that the briquette fuel from combination C_1 and C_4 was found good in the resistance to water penetration. Shatter and a tumbling test showed that combination C_1 and C_4 had good shock and impact resistance and were good for handling and transportation. They also had a good energy density ratio.

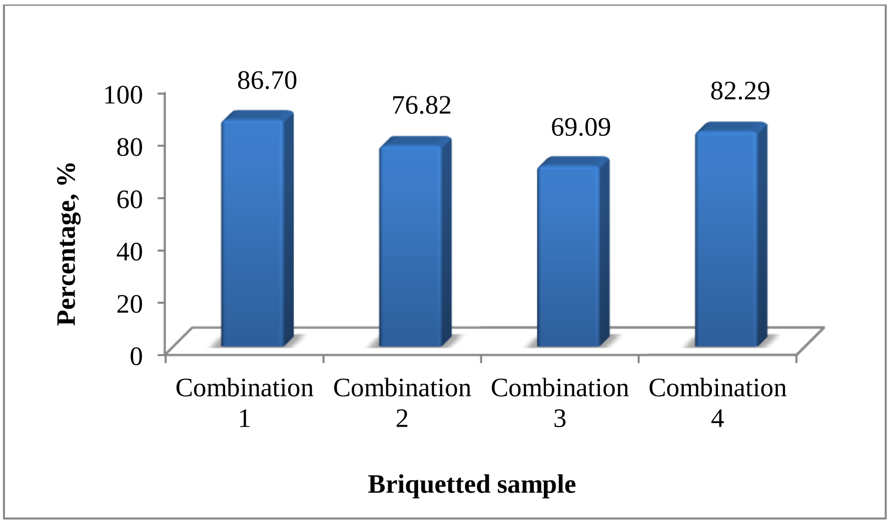

Fig. 10. Tumbler test for briquette fuel

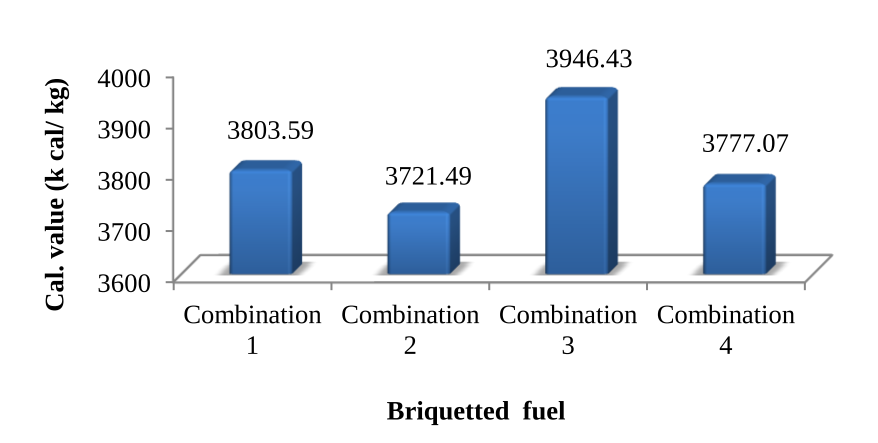

Fig. 11. Calorific value of different briquette fuel

Table 4. Comparison between various properties of briquette sample

Combinations	M.C. (%)	C.V. (kcal/kg)	Shatter Index (%)	Tumbling (%)	W.R. (%)	D.D. (%)	EDR
C_1	6.90	3803.59	99.82	86.70	52.20	19.90	1
C_2	7.05	3721.49	99.54	76.82	24.32	14.28	1
C_3	6.48	3946.43	99.64	69.09	17.49	28.97	1.03
C_4	6.42	3777.07	98.87	82.29	49.92	31.37	1.1

3.8 Calorific Value of Briquettes

The calorific values of briquette fuel for all combinations of briquettes are shown in Fig. 11. The maximum calorific value was found 3946.43 kcal/kg in C_3 (100:0:0:0) combination which comprised 100% mahua Doc. The lowest calorific value was found as 3721.49 kcal/kg in C_2 (50:20:20:10) combination which comprised mahua Doc, rice husk, grass and coal as 50%, 20%, 20% and 10%, respectively. The calorific value was considerably increased and decreased among all combinations because of mahua Doc which possessed more calorific value than the other biomass i.e. rice husk and grass. Out of four combinations, combination C_1 briquettes achieved the highest calorific value, hence selected as the best combination briquette fuel.

The study on the development of a biomass briquetting machine is of great importance to poor and developing countries. In rural areas, hand-operated or small capacity briquetting machine is the most beneficial and efficient technology. In the local area, it is the most economical and easy to operate manually for household small agro-based income generation. The four combinations with different proportions of raw biomass mahua seed de-oiled cake, coal, rice husk and grass C_1 (70:10:10:10), C_2 (50:20:20:10), C_3 (100:0:0:0), and C_4 (50:0:50:0), were used during the study.

4. CONCLUSIONS

The following conclusions were derived from the study:

1) The maximum shatter resistance, resistance to water penetration and durability index was observed in combination C_1 as 99.82%, 52.20%, and 86.70% respectively.
2) Combination C_1 has the highest resistance to water penetration because of its less porosity and high density.
3) The maximum degree of densification and calorific value was observed in combination C_3 as 28.97% and 3946.43 kcal/kg, respectively. Whereas the minimum degree of densification and calorific value was observed in C_2 as 14.28% and 3721.49 kcal/kg, respectively.
4) The combination C_1 and combination C_2 briquettes showed that they have good shock and impact resistance values; so they will be good for handling and transportation.
5) The calorific value of the briquettes was considerably increased with an increasing percentage of Mahua Doc in the briquette as 3721 to 3946 kcal/kg.
6) The maximum density was observed for coal material as 712 kg/m^3 due to smaller particle size.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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