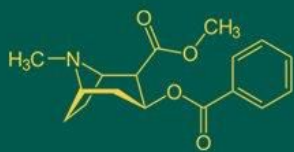


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Development and evaluation of a screw press briquetting machine for biomass fuel production

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Abstract

The rising global energy demand presents a significant challenge, particularly as the world population continues to grow. To address this, sustainable energy solutions such as renewable technologies are crucial. In India, biomass—primarily used in the form of wood and charcoal—remains a key energy source, especially in rural areas. However, this reliance on traditional fuels has led to widespread deforestation. Biomass briquettes, made from agricultural waste, offer a viable alternative. This research focuses on the design and development of a motor-operated briquetting machine, created to produce up to 1,020 briquettes per hour with a feed rate of 130 kg/h. Various biomass mixtures, including sawdust, rice husk, and cow dung, were tested to evaluate the machine's performance. The B2 mixture (20:05:40 ratio of sawdust, rice husk, and cow dung) produced the longest briquettes, while B3 exhibited the highest compressed density of 1.24 g/cm³. The cost of briquette production was lowest for the B1 mixture. This study demonstrates that motor-operated briquetting machines can contribute to more sustainable fuel options, reducing the need for traditional wood and charcoal fuels.

Keywords: Global energy demand, sustainable energy solutions, renewable technologies, biomass energy, rural energy sources, deforestation

Introduction

The global energy demand continues to rise, creating significant challenges for sustainable energy production and resource conservation. In developing nations like India, the reliance on traditional fuels such as wood and charcoal has resulted in widespread deforestation and environmental degradation. These conventional fuels, while accessible, are not sustainable and contribute to increased carbon emissions and a negative environmental impact (Alam, 2000) ^[1]. With the growing need for cleaner and more renewable energy alternatives, biomass energy has emerged as a viable solution (Obi *et al.*, 2016) ^[2].

Biomass, particularly from agricultural waste, offers a renewable and environmentally friendly alternative to conventional fuels. Briquetting technology has gained traction as a method of compressing loose biomass materials such as rice husk, sawdust, and cow dung into dense briquettes. These briquettes serve as an efficient and sustainable energy source, addressing the challenges posed by agricultural waste disposal while reducing dependence on fossil fuels (Jorapur *et al.*, 1995) ^[3].

Although the concept of biomass briquetting is not new, with applications dating back several decades, the technology has yet to reach its full potential in India. Mechanized briquetting systems were introduced in the 1980s, but they remain underutilized due to design inefficiencies and high operational costs (Prokhorov, 1982) ^[4]. Past studies have demonstrated the potential of briquettes made from various biomass materials, such as sawdust and rice husk, in achieving high calorific value and energy efficiency (Osarenmwinda & Imoebe, 2006) ^[5]. However, there remains a need for more energy-efficient, cost-effective machines that can produce durable briquettes with optimized properties.

This study seeks to address these challenges by designing and developing a motor-operated briquetting machine capable of efficiently converting biomass materials into briquettes. The machine is evaluated based on its performance in terms of briquette density, moisture content, shatter index, and production cost.

By improving the efficiency of the briquetting process, this research aims to offer a more practical and sustainable alternative to conventional fuels, contributing to rural energy solutions and promoting environmental sustainability (Madhava *et al.*, 2012; Pachpor *et al.*, 2019) [6, 7].

Material and Methods

1. Experimental Setup

The study was conducted at the Department of Farm Machinery and Power Engineering, Vaugh Institute of Agricultural Engineering and Technology, Sam Higginbottom University of Agriculture, Technology & Sciences, Prayagraj, Uttar Pradesh, India. The primary objective of the experiment was to design, develop, and evaluate the performance of a motor-operated briquetting machine.

Various machines and tools, including a lathe, drilling machine, welding machine, and grinding tools, were utilized during the fabrication process. The major components of the briquetting machine include a base frame, motor, hopper, gears, bearings, screw conveyor, and die. A 2 HP motor with a rotational speed of 2880 RPM was used as the

primary power source to drive the machine.

2. Materials Used

2.1 Biomass Materials: The biomass materials used for briquetting were:

- **Rice Husk:** A by-product of rice milling, which is known for its high ash content and medium calorific value (approximately 3000 kcal/kg). It was collected locally and used as one of the raw materials for briquette production. (fig. 1)
- **Sawdust:** Fine particles of wood produced from cutting or grinding wood. It has a calorific value of around 3600 kcal/kg and was used in different proportions in the experiment. (fig. 1)
- **Cow Dung:** This material served as a binder due to its sticky nature, providing cohesion to the briquettes. It was used in varying proportions to enhance the compressibility of the biomass mixture. (fig. 1)
- **Glycerine:** A small quantity of glycerine was added as a binder to further improve the cohesiveness of the biomass mix. Glycerine was used at a rate of 0.5 liters per trial.

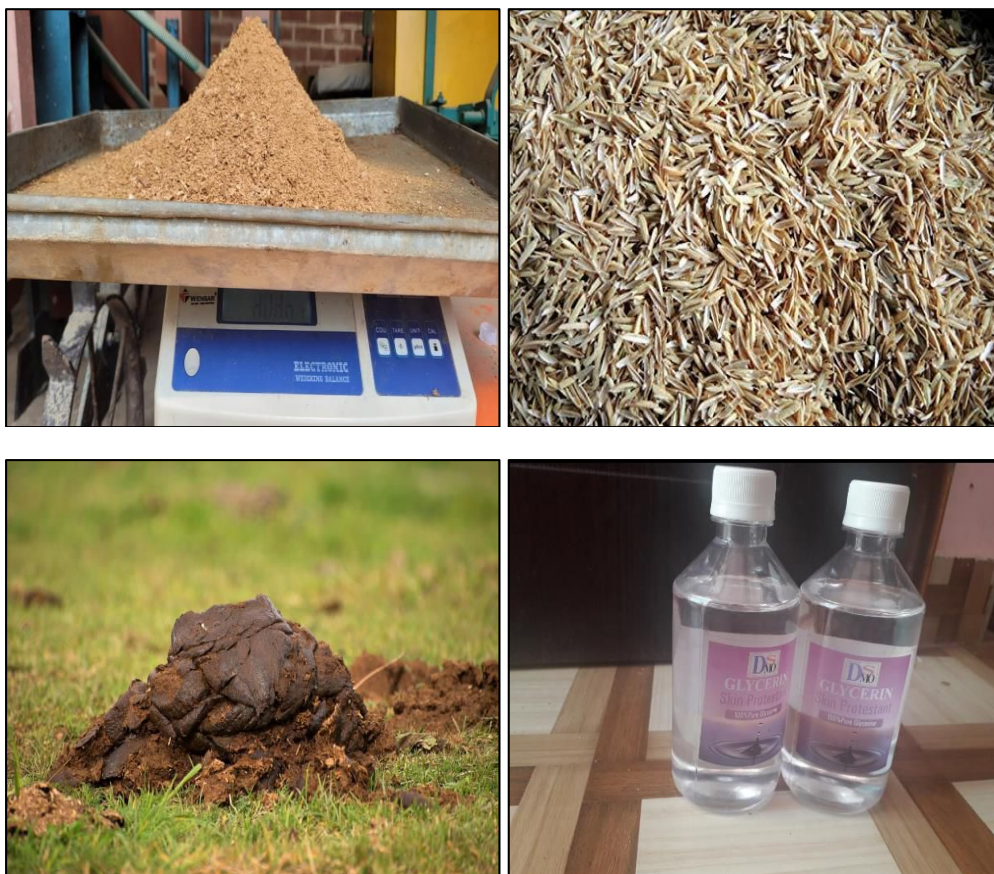


Fig 1: The biomass materials used for briquetting

Table 1: Properties of raw materials

Raw materials	Composition	B 1	B 2	B 3
Saw dust	6.5 kg	1.5 kg	2.0 kg	1.5kg
Rice husk	3.0 kg	1.0 kg	1.0 kg	1.0 kg
Binding materials				
Cow dung	10 kg	2 kg	4.0 kg	4.0 kg
Glycerine	0.75 kg	0.25 kg	0.25 kg	0.25 kg

3. Machine Design and Fabrication (fig. 2)

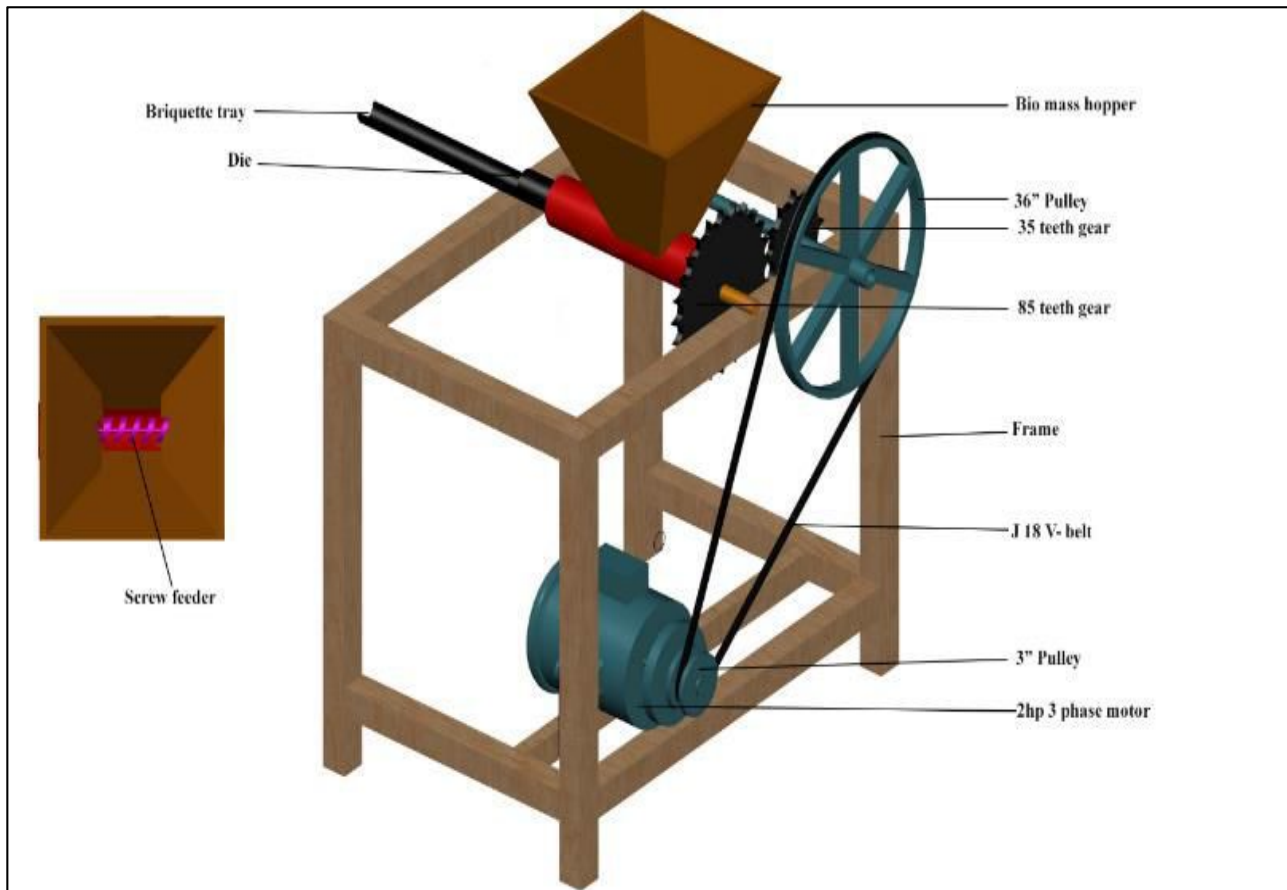


Fig 2: CAD View of motor-operated briquetting machine

3.1 Hopper Design

The hopper was designed to hold 10 kg of biomass, and its volume was calculated using the formula: (Sharma & Mukesh, 2010) ^[10]

$$V_b = 1.1 \times V_s$$

Where V_s is the volume of the biomass in the hopper, calculated as:

$$V_s = \frac{W_s}{\gamma_s}$$

where:

- W_s = Weight of biomass in the hopper (g),
- γ_s = Bulk density of the biomass (g/cm³),
- V_b = Volume of the biomass hopper (cm³).

3.2 Power Transmission

A belt drive system was employed to transmit power from the motor to the screw conveyor. The speed of the driver pulley was 2880 RPM, and the driven pulley had a lower speed to optimize the compression of the biomass. The velocity ratio was calculated to ensure efficient power transmission with minimal slip.

3.3 Screw Conveyor Design

The screw conveyor was designed to move the biomass mix through the system and compress it into briquettes. The helix angle, screw volume per pitch, and theoretical screw revolution were calculated based on the following formulas:

Helix angle

$$\theta = \tan^{-1} \left(\frac{S}{\pi D} \right)$$

where:

- S = Screw pitch,
- D = Screw diameter.

Screw Volume per Pitch

$$V_s = \frac{\pi}{4} \times (D^2 - d^2) \times s$$

where:

- d = Shaft diameter.

Screw Revolution

$$N = \frac{Q}{60 \times V_s \times \rho \times \phi}$$

where:

- Q = Feed rate (kg/h),
- ρ = Material density (kg/m³),
- ϕ = Filling efficiency (Mordi, 2007; Osarenmwinda & Imoibe, 2006) ^[8, 5].

Selection of Bearing

L_{10} = years of use (approx.) x Days in an yr. x hours/day x min x rpm of shaft.

The screw conveyor was designed to transfer with 150 kgh of biomass.

C = inclination correction factor

3.4 Capacity of a screw conveyor

The capacity of a screw conveyor with a standard screw flight can be estimated the following way: (H.G. Patil, Machine Design DATA Hand Book)

$$Q = 60 \times \left(\frac{\pi}{4} \right) \times D^2 \times S \times N \times \alpha \times \rho \times C$$

With

Q = screw capacity in kg/h

D = screw diameter in m

S = screw pitch in m

N = screw speed in rpm

α = loading ratio

ρ = material loose density in kg/m³

Table 2: Design of Briquette Machine

S. No	Particulars	Details
1	Calculation of helix angle	6.35 degrees
2	Screw volume per pitch	66 m ³
3	Screw revolution	223 rpm
4	Drive power	7.34 kW
5	Torque on the Screw	314 N-m
6	Pulley shaft power	11 Kw
7	Motor power	13.53 kW
8	Drive pulley diameter	84.45
9	Drive pulley rpm	894 rpm
10	Belt velocity (V)	3.96 m/s
11	Power Transmitted by shaft	579.125 N-mm
12	Selection of Bearing	L ₁₀
13	Estimation of Conveyor Speed	149 rpm
14	Hopper capacity	25 kg

Table 3: Specifications of Motor- Briquette Machine

S. No	Particulars	Details
1	Number of Screw feeder	1
2	Diameter of Shaft	10.8 mm
3	Length of Die	90 mm
4	Diameter of Die	50.8 mm
5	Overall width of machine	609.6 mm
6	Overall height of machine	762 mm
7	Overall length of machine	914.4 mm
8	Capacity of machine	130 kg/ hr

4. Development of Briquetting Machine (fig. 3)

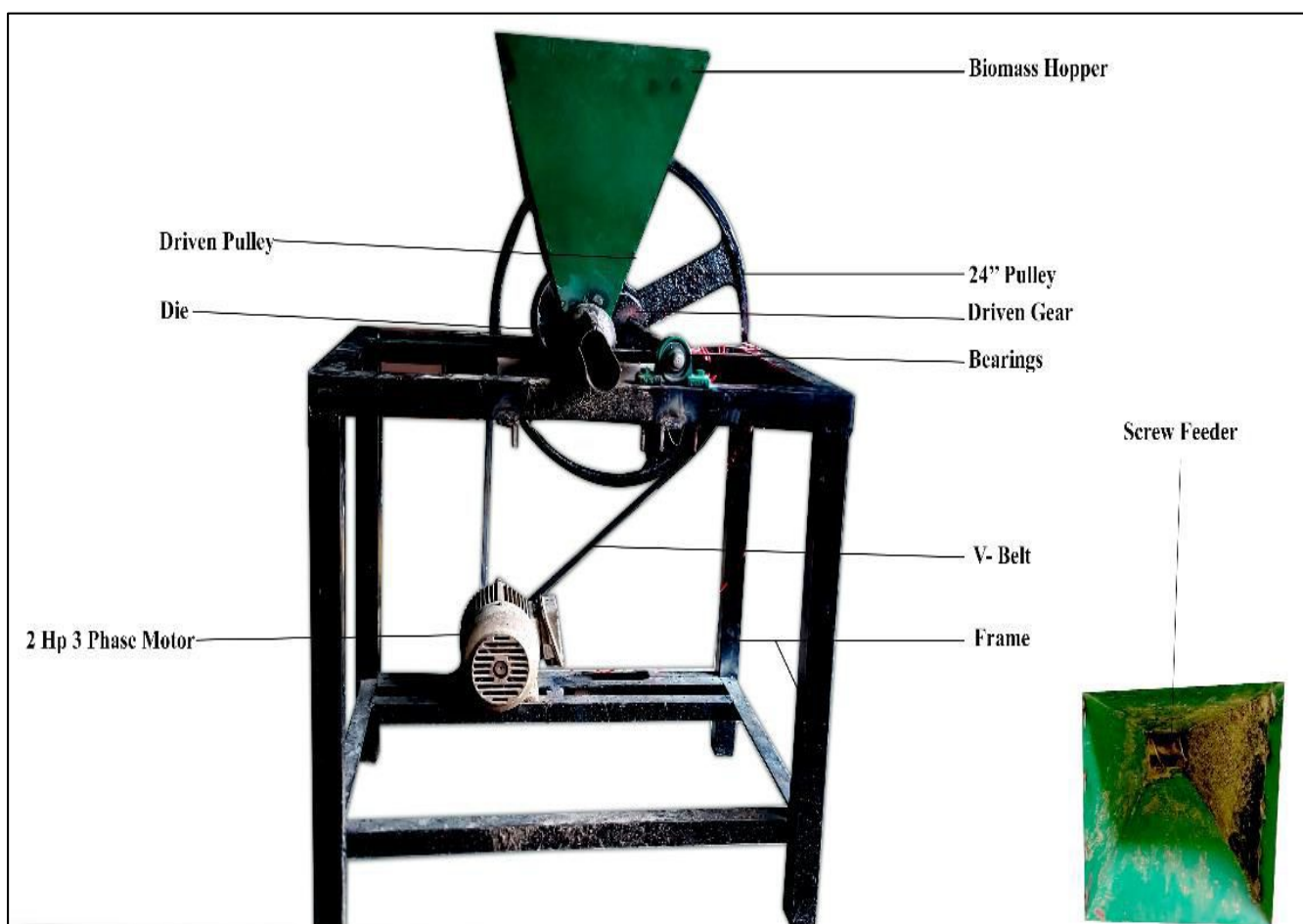


Fig 3: Developed Motor Operated Briquetting Machine

Key Components and Their Functions

Gears

Gears are integral to power transmission within the system, enabling the generation of the necessary force for briquette production through carefully arranged gear configurations.

Bearings

Bearings serve to minimize rotational friction and support radial and axial loads. This is achieved using two or more races containing balls that facilitate load transmission. Typically, one race remains stationary while the other rotates, ensuring efficient load handling.

Motor

The motor employed is a 2 HP, 2800 RPM, 380V, three-phase unit, mounted at an incline on the base. This configuration provides the power required for the operation of the system.

Hopper

The hopper functions as the feeding mechanism, channeling raw materials into the screw housing. Constructed from sheet metal, it comes in various shapes and sizes tailored to the briquetting process. As the machine operates, waste biomass (e.g., husk) is fed gradually from the hopper, facilitating continuous briquette production.

Base Frame

The base frame supports the entire system, including the screw, barrel, and screw housing. Made from angle bars and sheet metal, the frame is engineered to withstand vibrations

during operation while securely holding the motor.

Main Pulley

The main pulley, cast in a circular shape, supports the movement of cables or belts around its circumference. Fabricated through operations such as facing, turning, boring, and groove cutting (V-type), it serves as a power transmission device, transferring energy from the motor to the primary power transmission component of the briquetting machine. By using pulleys of different diameters, the motor's RPM can be reduced to an optimal rate of approximately 160 RPM, suitable for the briquette production process.

5. Performance Evaluation of a Briquetting Machine

The study evaluated the impact of various factors, including ingredient composition and moisture content, on the capacity and briquetting efficiency of a briquetting machine. These factors were determined based on experimental observations and practical operating conditions.

5.1 Briquette Production

The primary constituents for briquetting were sawdust and rice husk, with cow dung and glycerin used as binding agents. An electric motor system (1.5 kW) powered the production process, where a driven pulley (diameter 914.4 mm) was connected to a driving pulley rotating at 2880 rpm. The mixture was fed into the briquetting machine, where the material was moved forward by the screw's geometry, forming briquettes. (auger). (fig. 4)



Fig 4: Briquette production

5.2 Physical and Thermal analysis of Briquettes:

Density

Two briquettes were randomly selected from each production batch to assess physical properties. The mean compressed density was calculated immediately after extraction from the machine by taking the ratio of the measured weight to the calculated volume. A digital weighing balance (Fig. 6) measured briquette weight, while diameters and lengths were recorded using digital Vernier calipers (Fig. 5). Measurements for diameter and height were taken at 0 minutes, on the first day, and on the second day. The volume of each cylindrical briquette was then

computed, and density was determined as the weight-to-volume ratio.

Shatter Index

The durability of the briquettes was evaluated using the shatter index, a measure of briquette breakability. This involved repeatedly dropping briquette samples from a height of one meter onto a solid surface. The retained fraction of each sample served as an index of breakability, with weight loss expressed as a percentage of the initial mass. The Shatter resistance, an indicator of durability, was calculated by subtracting the percentage weight loss from 100 (Gorpade, 2006; Sengar *et al.*, 2012) ^[11, 12].

$$\text{Percentage weight loss} = \frac{\text{Initial weight before shattering} - \text{final weight after shattering}}{\text{Initial weight before shattering}}$$

Shatter index (%) = 100- Percentage weight loss

Moisture content

The moisture content of the raw materials was determined on the triplicate samples by oven air method the sample were placed for 24 h in a hot air oven maintained at 104 ± 1 °C. Initially cleaned and empty aluminium moisture determination boxes along with lids were weighed with electronic top pan balance with 0.001 g accuracy and noted as weight W_1 g. About 20 g of sample of each raw material were placed in the boxes and closed with the lids tightly and noted their weights as W_2 g. Then the lids were opened and the boxes along with the lids are placed in hot air oven being maintained at 105 ± 1 °C for 24 h. The lids were replaced tightly before taking out the boxes from the oven and the

boxes were placed in a desiccator for 5 minutes to cool down. the weights of the boxes along with the dried material weighed and noted as W_3 g. the moisture content (MC) on dry basis (d. b.) calculated by using the following equation. (fig. 6)

$$M.C\% = \frac{(W_2 - W_1) - (W_3 - W_1)}{(W_3 - W_1)}$$

Where,

W_1 = weight of the empty box,

W_2 = weight of the box + weight of the sample, g

W_3 = weight of the box + weight of the bone-dry material, g



Fig 5: Dimensions of Briquette



Fig 6: Measuring moisture content and weight of briquette

Results

Performance evaluation of briquetting machine:

Production of Briquette

Experimental results for briquettes produced using the developed, fabricated briquetting machine are presented in Table 2. The briquettes were evaluated for changes in density and diameter relative to the specified diameter. The briquettes exiting the die maintained a diameter of 50 mm, while their lengths varied due to the absence of a cutter. The density of the briquettes ranged around 1.109, with moisture content between 2.9% and 3.4%. The temperature of the briquettes post-die ranged from 40 °C to 44.2 °C. It was observed that optimal density was achieved with lower

moisture content and a higher die temperature, specifically at 2.9% moisture and 44.2 °C.

Table 4: Physical Properties of Briquettes

S. No	Properties of Briquettes	Briquette
1	Average length (mm)	66
2	Average Diameter (mm)	50
3.	Average weight (g)	128
4	Average volume (cm ³)	10.0
5	Average density g/cc	1.1

Properties of briquettes

The properties of briquette like briquette density, radial compressive strength, durability, calorific value, shatter

Index, water resistance and stability of briquette were evaluated as per the standard method and the experimental findings are given in the Table 1.

Table 5: Properties of Rice husk and Saw dust Briquettes

S. No	Parameters	Briquette
1	Briquette density g/cc	6.0
2	Durability	86
3.	Shatter Index (%)	70.31
4	Water resistance (%)	68.97
5	Bulk Density Kg/m ³	150
6	Calorific Value Kcal/kg	4000
7	Degree of densification	0.89
8.	Moisture content %	3.8

Density of briquette

The density of the briquettes was measured to assess their relative compactness, ease of transportation, and

enhancement of burning quality, which collectively improve the briquettes' combustion properties. The densities of all briquettes are presented in Table1

Table 6: Density of briquettes

Briquettes	Average weight of briquette, (g)	Average volume of briquette, (cm ³)	Average density of briquette, g/cm ³
B ₁	120	117.81	1.01
B ₂	200	157	1.24
B ₃	133	98.125	0.91

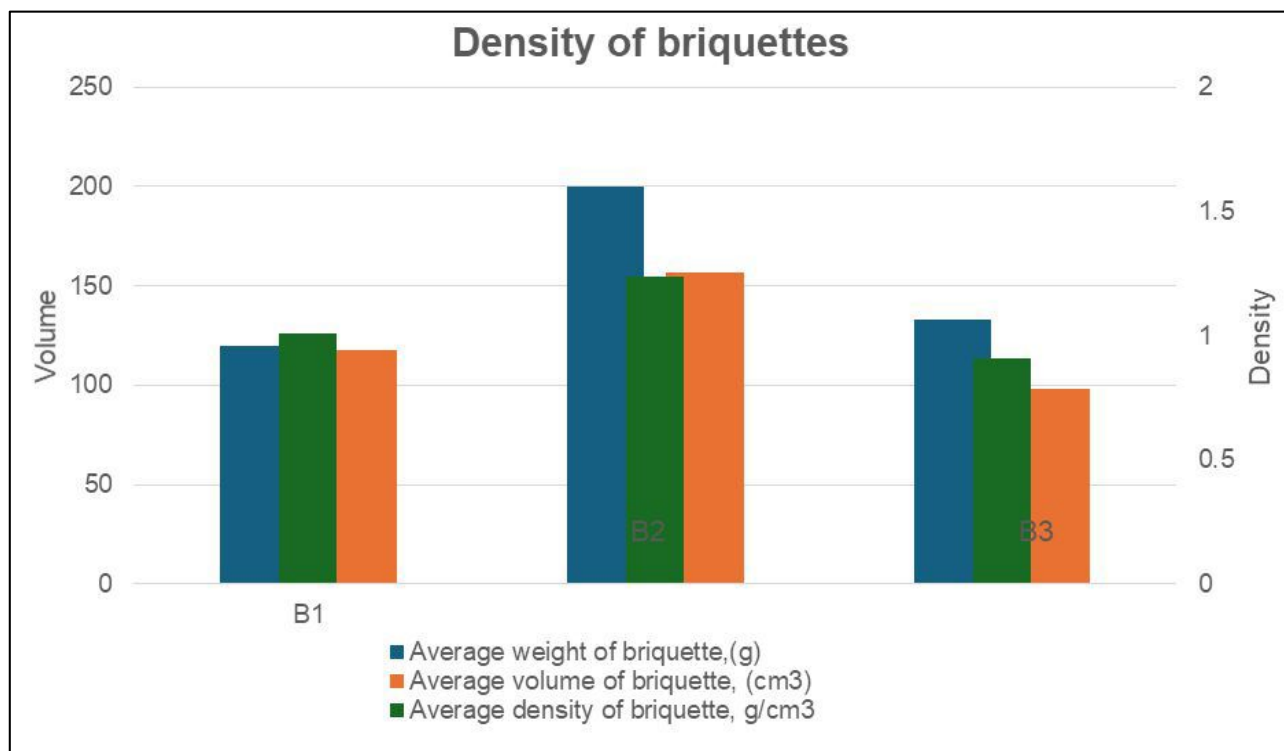


Fig 7: Graphical representation of Density, Volume and weight of briquettes

From the table 6 Saw dust briquette has more density in B₂. The average weight of the briquettes varied based on the type of biomass used, with B₃ briquettes having the highest average weight and B₂ the lowest. Similarly, average volume differed across briquette types, largely due to shrinkage in diameter, which is influenced by the moisture content of the biomass. Consequently, B₃ briquettes had the highest density at 1.24 g/cm³, indicating greater durability,

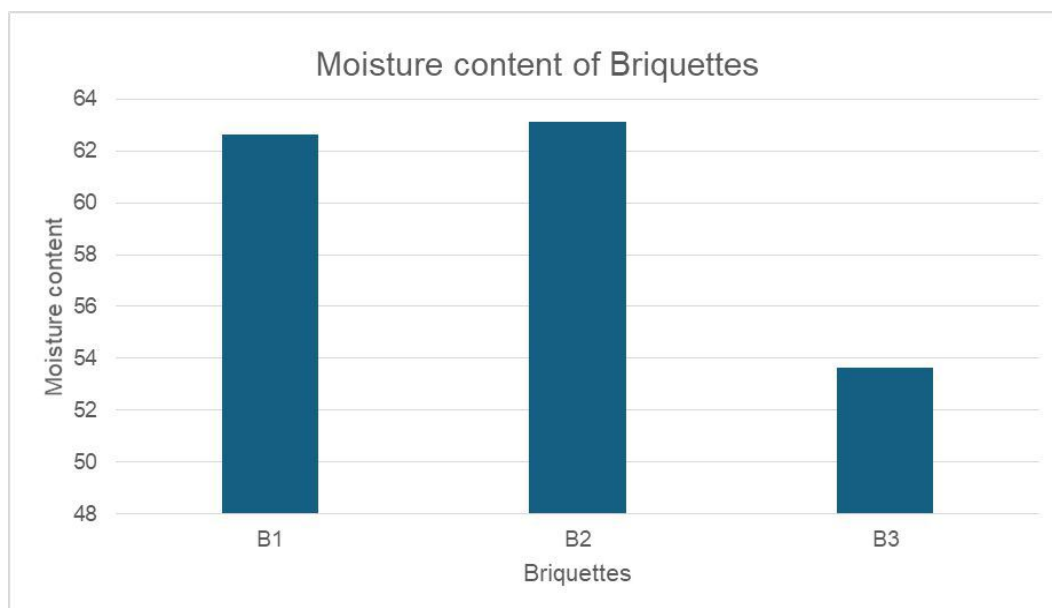
strength for transportation, and extended burning time compared to other biomass briquettes.

Moisture Content

The moisture content test was conducted to evaluate the drying efficiency of the briquettes and to determine its impact on reducing chemically bonded water in the structure.

Table 7: Moisture content

Biomass	Initial weight before drying,	Initial weight after drying	Percentage moisture content $C = (A-B)/A \times 100$
B ₁	120	75.18	62.65
B ₂	200	126.22	63.11
B ₃	133	71.34	53.64

**Fig 8:** Graphical representation of Moisture Content

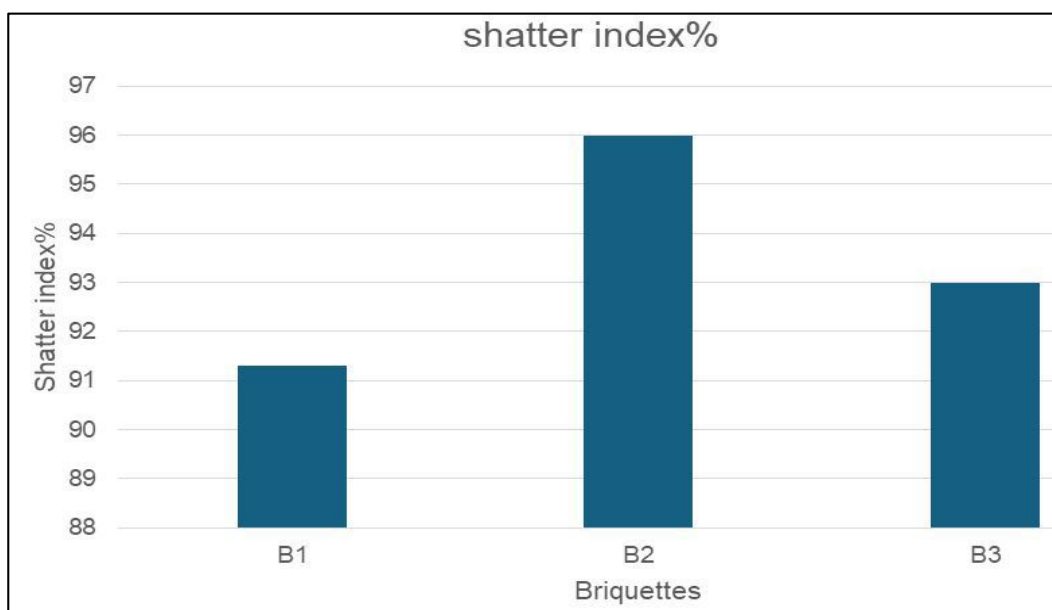
The data revealed that B3 briquettes, composed of sawdust, rice husk, and cow dung in a 20:05:40 ratio, had the lowest moisture content at 53.64%. This lower moisture level enhances combustion efficiency and ensures safer storage and transportation compared to other biomass briquettes.

Shattering index

This test was conducted to assess the durability of the briquettes and to evaluate their resistance to breakage during transportation.

Table 8: Shattering index

Briquettes	Initial weight before drying, (g) A	Initial weight before drying B	Percentage wt loss $C = (A-B)/A \times 100$	Shatter index $100-C$
B ₁	110	100.43	8.81	91.3
B ₂	100	96	4	96
B ₃	120	111.6	7	93

**Fig 9:** Shattering index

The data in Table 8 indicate that the B2 briquette exhibited the lowest weight loss (4%) during the shattering test, demonstrating the highest shattering resistance at 96%. These results suggest that B3 briquettes are the most durable and safer for handling and transportation. In contrast, B1 briquettes showed the lowest shattering resistance at 91 and the highest weight loss of 4%.

Table 9: Performance of briquetting machine

S. No	Briquettes	Feeding rate (kg/hr)	Machine output (dry.wt.kg/h)	Machine efficiency (%)
1	B ₁	135	127	94.00
2	B ₂	130	125	95.00
3	B ₃	140	126	90.00

Table 6 shows that the feeding rate of raw materials varied with different biomass ratios. B3 and B2 had higher feeding rates compared to B1. The highest machine output was recorded for B3 (47 kg/h), followed by B2 (46 kg/h), while the lowest output was observed in B1 (41 kg/h). As indicated in Table 9, machine efficiency was also highest for B3 production at 85.45%, likely due to the fine and

Machine Performance

The overall performance of the power-operated briquetting machine was found to be satisfactory for briquette production, though it varied depending on the type of raw material used. The feeding rate and machine output were recorded and are presented in Table 9.

homogeneous texture of commercially available sawdust, which facilitates easier briquette formation.

Cost Analysis

Data on cost of production of briquettes with different biomass is presented in Table 10.

From the Table 10, cost of production varies with the different types of biomasses used for briquette production.

Table 10: Cost analysis of briquettes production

S. No	briquettes	Cost of production (Rs/h)	Gross income (Rs/h)	Net income (Rs/h)	Cost of production (Rs/h)
1	B ₁	123.63	164	40.37	0.98
2	B ₂	128.63	184	55.37	1.2
3	B ₃	138.63	188	49.37	1.05

The cost of operating power operated machine was remaining constant Rs.23.63 per hour for all types of biomass briquette production, while cost of production of briquettes was determined different for each biomass due to its purchasing rate. Cost of production by power operated machine was found maximum to produce B3 briquettes as Rs. 138.63 per hour and minimum for the B1 briquette as Rs. 123.63 per hour. The gross income (Rs/h) from the selling of briquettes @ 4 Rs/kg was found maximum for the B3 briquettes as Rs. 188 per hour and minimum for the B1 and briquettes as Rs. 164.00. The net income generated was found maximum for the B2 briquettes as Rs. 55.37 per hour and minimum for the B3 Rs. 49.37 per hour. Hence, the briquette production from the B2 using power operated machine was found more profitable compared to other biomass briquettes

Conclusion

This study investigated the properties of rice husk and sawdust to understand their suitability for briquetting. A screw press briquetting machine, designed with a 130 kg/h capacity, was developed to process these materials into fuel briquettes. During briquetting, rice husk and sawdust were heated to 200 °C, with cow dung acting as a binder. The machine produced briquettes with a 50 mm diameter, a concentric hole of the same diameter, and a variable length of 120 mm. These briquettes demonstrated high durability due to their bulk density and low moisture content, along with moderate water resistance and a favorable shatter index, ensuring stability and suitability for fuel use.

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