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Production, Analysis and Optimization of Low Cost Briquettes from Biomass Residues

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Authors' contributions

This work was carried out in collaboration between all authors. Author Ajit Kaur designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Author Arvind Kumar produced and optimized briquetting process. Author PS guided for the machine manufacturing. Author KK managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Biomass is the alternative source for generation of energy for the masses. Biomass residues from our common surroundings and other fields mainly agriculture are produced in abundance in continuation. Such a large quantity needs to be managed in order to refrain from solid waste pollution, as if left unused such residues are usually burnt inefficiently. In this context, biomass briquetting present an energy efficient solution by managing such solid waste. Biomass briquettes can be the excellent source of energy for households as well as for commercial sites and is ideal for replacing continuously depleting fossil fuels. This study is based on production of such briquettes using dry leaves, rice husk and straw, analysis of physical and chemical parameters of such briquettes. This study concluded that briquettes produced from groundnut shells bonded by paper pulp has highest calorific value of 5407 Kcal/kg, which is quite higher than commercially available cow dung briquettes (3452.34 kCal/kg). Physical parameters like Total Solids (%), Volatile Solids (%), Ash (%), and sulfur (%) were determined by standard methods of AOAC and were similar in

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briquettes made by groundnut shells and paper pulp. To lower the cost of production, a simple screw press machine was designed and developed to produce briquettes at low cost. A simpler chullah was also designed for burning of the groundnut shell briquettes produced using paper pulp as a binder, where lowest ignition time of 12 second was obtained for the groundnut shell briquette made by paper pulp. Burning time for this briquette was 4 minutes and 50 seconds. This technology can be used to popularize the use of biomass briquettes to replace the commercially available cow dung briquettes.

Keywords: Agricultural waste; biomass; briquetting; fuel characteristics; screw press machine.

1. INTRODUCTION

Over exploitation of fossil fuels has led to shortage of energy sources. There is a long history of finding new methods to produce energy and program intercessions. Every country of the world is now focusing on production of energy through non-conventional sources. India has assessed of around 79,500.MW of sustainable power source control potential, basically from the sources like wind, biomass and small-scale hydro projects. Various limited time strategies and financial impetuses are being provided to tap the evaluated sustainable power source potential of approx. 3930 MW, or 3.6% of the total presented limit in the nation in which biomass control contributes approx.537 MW. Usually the agro-buildups including rice husks and sugarcane tops, leaves and junk groundnut. Shells and plants; cotton stalk; coconut deposits; mustard stalk; and squanders from twelve other rural item are utilized for animal feed, local cooking, or different purposes and deserting 140 to 170 million tons of usable, agro-deposits every year, which could be made accessible for power produced. But some of this residual biomass is burnt in open causing earth pollution. The biomass which is having large volume is hard to deal with, store, transport, used and cause far-reaching air contamination. Thus, to dispense with these issues, this biomass is changed over into the coupling structure which is known as briquettes.

Briquetting or Biomass densification is a high-pressure process done at raised temperature or at a surrounding temperature depending upon the innovation one applies. It transforms the biomass buildups into a helpful fuel. In some briquette methods, the materials are packed with or without usage of binder.

Various types of materials have been attempted and used for briquette production till now e.g. wheat straw, rice straw, groundnut shells, tree leaves, grass, rice and maize husks, banana take offs, paper, sawdust and charcoal fines etc. The selection of raw material depends upon its effortlessly accession in the encompassing regions. The choice of the crude material also depends upon its capacity to bond together when compacted. Contingent upon the sorts of gear utilized, Briquetting is of five categories: Piston press densification, where biomass is punched into a die on by a responding ram with a high weight consequently packing the mass to acquire a compacted item. Screw press densification, where the biomass is ejected continuously by screws through a decline press the container which is warmed remotely to decrease the grinding. Roller press densification, in which the feedstock falls in the center of two rollers, pivoting in inverse bearings and is compacted into cushion molded briquettes. Pelletizing, that has firmly identified with briquette aside from that it utilizes littler kicks the bucket (around 30 mm) so that the littler items are called pellets. Manual press are used for the purpose or adapted from existing implements used for other purposes making manual clay. Advantages of using Briquettes compared to other Solid Fuels

- It is Easy in handling, compact in size, and transportation of briquettes can be made any of type and size.
- Ash content limits of briquettes are below than 10% as compared to coal which has 25 to 40% resulting in low boiler ash disposal problems.
- It has low amountofsulfur dioxide, which is low as compared to coal.
- Briquetting has low ignition point when compared to coal. It burn easily.
- There is no corrosion effect on boiler equipment and has low maintains.
- This is a clean and cheap fuel for use for produced energy.
- No gas and effluents like coal. So there should be no bad effect on human health.
- It has high Volume reduction during briquetting process.

- It has no fly ash during burning briquettes.
- Briquettes have quality high burning efficiency.

Maninder et al. [1] reported that apart from the transportation, storage, and handling problems biomass briquette have several advantages over coal, oil etc. so we have to use it for our domestic purposes like heating and cooking. Agricultural residues are available in abundance in our country. India delivers 98 million tons of paddy with around 130 million tons of straw of which just about half is utilized for feed. Similarily, around 350,000 tons of stick junk is also available that can be an amazing biomass fuel. With high silica content, it has no market utilize and is in this manner totally consumed. Other aggro squanders are maize, cotton, millets, heartbeat, sunflower and different talks, bull surges (Sirkanda), groundnut shells, coconut junk, and so on all of them are good bio-fuels. Biomass as fuel can reduce CO_2 emissions depending on the technology adopted; and solid biomass combustion produces emissions savings generally above 60% both for power and heat produced, and reaching over 70% in some cases. In this context, briquetting is an easy, economical, easy to use and safe option for the environment to produce the energy and remove the solid waste. E.g. It was found that Bio-coal upon oxidation breaks down to form a combustible gas that can be cleaned and filtered to remove problematic chemical compounds [2]. Moreover, biomass burning in the coal-fired boiler is close to the gas combustion because the fuel is about around 80% volatile, which has a huge difference from the coal [3].

The present study was on Production, analysis and optimization of Briquettes from Biomass residues. It was conducted to evolve briquettes with different combinations of biomass and binders in order to enhance their efficiency and reduce pollution compared to selected commercial briquettes. To develop an alternative fuel from biomass following objectives were formulated.

- Production and process optimization of briquettes from different Agricultural wastes with suitable binder.
- Proximate analysis of produced briquettes and Quality testing of produced briquettes for efficient burning.
- Design and development of low-cost efficient briquette machine and improved challah/tandoor to suit with developed briquettes.

2. MATERIALS AND METHODS

2.1 Briquette Preparation

2.1.1 Procurement and preparation of raw material

For this study, three biomass residues were chosen viz. dry leaves, peanut shell, and paddy straw due to their large availability in Ludhiana area. These residues were collected from the premises of Guru Nanak Dev Engineering College and CSIR-CMERI, Centre of Excellence in Farm Machinery in Ludhiana. The procured materials were then sun dried for 2 days so that the moisture content is vaporized. After drying the material was pulverized to 1 mm size using Food pulverizer available in host institute i.e. CSIR-CMERI, Ludhiana, so that its volume can be reduced and can be easily compressed and used, reducing the volume (Fig. 2). The whole process of briquetting is shown in Fig. 1.

2.1.2 Selection of binders

A good Binder is a kind of paste (ideally burnable) which is compacted with the briquettes keeping in mind the end goal to keep it from going into joining together. This can be used for formulating and combinations standardized when treated. For this study, two type of binders i.e. the paper pulp and cow dung was used. For paper pulp, waste paper was collected from hostels of GNE College Ludhiana. Total of 500 gm of waste paper was cut and soaked into one litre water and kept for 2 days, grinded to use it as a binder. Both binders are easily available and low in cost.

2.1.3 Moulds and loading of charge

Molds and plungers were manufactured to form the briquettes: cylindrical moulds (of different dimensions) to form a large briquette, that could be cut into smaller slabs. In order to control the mass of charge used for each briquette, the pulp was weighed, before being loaded by hand.

2.1.4 Residue compression for preparation of Briquette

The briquettes were formed by compression of the mixture of biomass and binders in the mold with C-Clamp. A range of pressures between 0.1 and 2 Mpa was used to form briquettes. For a briquette with a diameter of 60 mm, the lowest of these pressures could is achieved by hand pressure alone and the C clamp, compressing the pulp, until the desired pressure was reached. It was observed that if the C-Clamp was held stationary at this point, the resultant force on the: A cylindrical mould used to form briquettes riddled around the mold to allow the expulsion of water from the pulp during compression C-Clamp would reduce as water flowed out of the pulp. In order to keep a constant pressure during this water expulsion and relaxation phase, the speed of the compression screw was continually reduced, according to the rate of relaxation, keeping the resultant force on the piston constant. The pressure was held for 5 minutes.

With this method, it was found briquettes could be formed with a density reproducible. The associated uncertainty is due to a

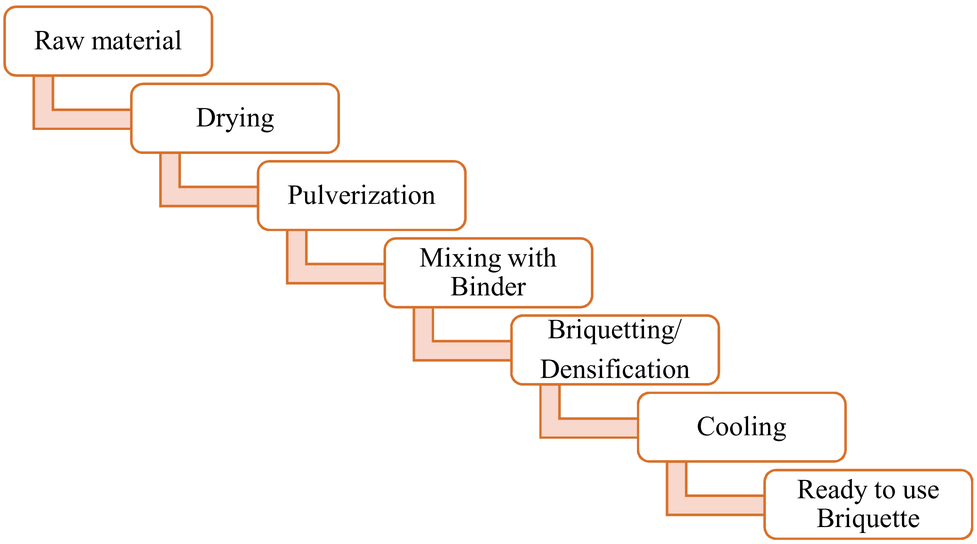

Fig. 1. Process of briquetting

Dry Leaves

Peanut Shell

Wheat Straw

Dried and Powdered leaves

Dried and Powdered groundnut shells

Dried and Powdered straw

Fig. 2. Different types of raw and prepared biomass

combination of factors, such as variations in the amount of charge in the mold, the control of the compression velocity by the operator, and includes the uncertainty associated with the measurement method used for the determination of the dry density of the final briquette. Combinations were prepared by using the above process. Total 21 briquettes were made as per the composition given in Table 1. The prepared briquettes were then sun dried for three to four days to remove the moisture content.

2.2 Design and Development of Low-cost Efficient Briquette Machine

A low cost screw type briquette machine was developed to minimize the cost of the briquette as shown conceptually in Fig. 3. Screw type briquette machines give maximum output and are easy to maintain. For the design purpose, the mild steel was used for the construction of machine. All the materials were purchased from the local market of Ludhiana. The machine was fabricated at the GNDEC College Ludhiana workshop. The electric arc welding was used for the fabrication of machine. The compaction of biomass material was done using a screw auger that press the material against a high pressure with a holding time. The conceptual design of the fabricated machine is shown in the Fig. 3.

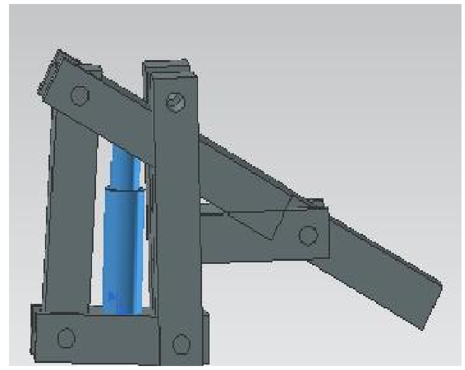

Fig. 3. Conceptual design of screw press briquetting machine

2.2.1 Description of the machine

A manually operated biomass briquetting machine was planned and constructed which consist of 3 molds with diameter of 35 mm each. Holes were provided to remove excess water. At the bottom, a 20 mm thick plate was provided with holes in it, to hold the briquette and remove the water. Each hole has 3 mm diameter. At the top of the machine, a screw is provided attached to a plate. As the screw is pressed, the plates move downward and press the feed. The constructed machine is shown in Fig. 4 with upper and side view.

Table 1. Composition of Briquettes to be prepared

Sample	Dry leaves (gm)	Groundnut shells (gm)	Paddy straw (gm)	Weight of dry briquettes (gm)	Binder used
A1	15	0	0	18.81	Cow Dung
A2	0	15	0	12.08	Cow Dung
A3	0	0	15	11.07	Cow Dung
A4	7.5	0	7.5	23.11	Cow Dung
A5	7.5	7.5	0	19.26	Cow Dung
A6	0	7.5	7.5	20.24	Cow Dung
A7	5	5	5	18.57	Cow Dung
B1	15	0	0	18.21	Paper Pulp
B2	0	15	0	24.60	Paper Pulp
B3	0	0	15	19.11	Paper Pulp
B4	7.5	0	7.5	22.36	Paper Pulp
B5	7.5	7.5	0	19.12	Paper Pulp
B6	0	7.5	7.5	18.72	Paper Pulp
B7	5	5	5	18.37	Paper Pulp
AB1	15	0	0	14.93	CD+PP
AB2	0	15	0	19.18	CD+PP
AB3	0	0	15	17.48	CD+PP
AB4	7.5	0	7.5	16.51	CD+PP
AB5	7.5	7.5	0	17.04	CD+PP
AB6	0	7.5	7.5	17.64	CD+PP
AB7	5	5	5	14.12	CD+PP

2.2.2 Design of machine element and material selection

a) Properties of mild steal

> Ultimate strength = 400MPa
> Yield strength (σy) a. tensional = 250MPa

b) Shear = 145MPa

>Modulus of elasticity (E) = 200GPa
>Modulus of rigidity = 77.2GPa
Density (ρ) = 7860 kg/m3
Coefficient of thermal expansion = 11.7GPa
(Source: Mechanics of Materials, sixth edition by Ferdinand P. Beer, et al., 2012.)

c) Mould (cylinder)

Briquette cross-sectional area (Ab1)
Area = πr^2, where r = 3.4925 cm Area-π×12.35=38.465 m^2
Total area= 38.46532×10-3 m2×3 = 1.15 m

d) Mould cover

It is round in shape and its thickness is 5 mm.

e) Piston rods

2.3 Characteristics of Biomass Residue and Their Experimental Procedures

Calorific Value, Total Solids (TS %), Volatile Solids (VS %), Density, Moisture Content were determined using standard methods. Ignition Time was determined by burning 200 gm of briquettes in charcoal stoves as recommended by Rotich [4]. Burning Time was measured as the time taken from the moment briquettes ignite until the complete burn out of complete briquettes of the composites briquettes were burned in charcoal stoves and the burning time measured [4]. Polluting Parameters like total Sulphur content was measured as per ASTM D-3173. Characteristics of different briquettes as shown in Fig. 5 were different as per their feedstock.

2.4 Improved Chula/Tandoor to Suit with Developed Briquettes

Low-cost Chula is made from the soil and bar of iron. it is low cost and no machine is used for making for this it is totally handmade. Holes are provided for more air inlet so that more oxygen can be supplied. Fig. 6 shows the in-house developed challah for using briquettes.

Fig. 4. Construction of low cost Briquetting machine

Briquettes using cow dung | **Briquettes using paper pulp** | **Biomass+Cow dung+Paper Pulp** | **Briquettes made in-house machine**

Fig. 5. Biomass Briquettes using different binders

Fig. 6. Improved chulla/tandoor to suit with developed briquettes

Component used –

1) Soil-Special type of soil is used for making the Chula that is collected from near Gill village Ludhiana.
2) Iron bar -Small rod iron are used for this length of 24 mm with area of $3mm^2$.

3. RESULTS AND DISCUSSION

The briquettes prepared manually by c-clamp as well as by low-cost briquetting machine were analyzed for their calorific value, moisture content, density hardness, volatile matter, the amount of solid carbon, ash etc. using standard methods of quality testing. The results are given in Tables 1-4. Studies have shown that the binder has an observable impact on biomass briquette forming, mechanical properties, and combustion properties. In giant reed briquettes, the best addition of the binder is 30%. It is clear from Table 2 and Fig. 5 that Briquettes made from cow dung and the mixture of cow dung and paper pulp as binder are fine in physical appearance, shape, texture etc. Biomass content is another important factor. When loss and lime serve as the binder, the best addition of the biomass is 45%. Outcomes of experiments by Jain et al. [5] showed that briquettes produced using charcoal tidy and different biomass materials with starch mixes were best in physical qualities with most elevated scores while briquettes produced using charcoal tidy with bovine manure blends were observed to be most noteworthy in calorific value. When dairy animals waste is utilized as a fastener with charcoal clean and different biomass materials, it was giving higher calorific value. The utilization of starch as a binder with charcoal tidy and different biomass materials was making briquettes smooth in surface, minimal, dry, uniform, even without breaks and shiny. The results of proximate and chemical analysis in this study reveals that groundnut shells as substrate and paper pulp as binder are good residues for quality briquettes (Tables 3,4).

The results from Table 3 concluded that by using cow dung as a binder maximum total solid were found in briquette A1 (dry leaves) 93.16%, and in paper pulp made briquettes, it was 95.82 for B1 (dry leaves) and for paper pulp it was 93.52 in AB4 (dry leaves and ground nut shell). While, Ash content was maximum for cow dung was at A5 33.92 and in paper pulp was 33.96 in B4 and for cow dung+ paper pulp was 18.68 in AB3. For cow dung, Volatile matter was 74.5 in A1 (paper pulp) were 94.31 at B3 and paper pulp, cow dung was 94.03 it can observe that the paper pulp has the maximum volatile matter. Chaney et al. [6] reported that the amount of volatile matter is higher (70-86% of dry weight) in biomass briquettes than in bituminous coal (35%). Consequently, the fractional heat impact of the volatiles is more for biomass, making it more responsive fuel than coal, giving a much faster burning rate during the devolatisation phase.

Table 2. Physical characteristics of biomass Briquettes

Physical characteristics of Briquette	Binder used		
	Cow dung	Paper pulp	Paper pulp+cow dung
Surface	Rough	Rough	High
Hardness	Good	Good	Good
Color	Brown	Light brown	Brown

Table 3. Proximate analysis of biomass Briquettes

Briquettes	TS%	Ash content %	VS%	Moisture content (%)	Density (gm/cm^3)
A1	93.16	25.50	74.50	10.30	0.79
A2	91.31	25.80	74.20	10.90	1.20
A3	88.91	28.10	71.90	9.80	0.45
A4	92.71	33.00	37.00	7.50	0.46
A5	85.88	33.92	66.08	9.50	1.06
A6	90.70	19.80	80.20	7.50	0.57
A7	85.20	14.00	80.56	5.70	0.35
B1	95.82	25.78	80.56	4.18	0.24
B2	80.72	23.99	91.31	7.28	0.34
B3	89.72	24.76	94.31	10.52	0.33
B4	89.48	20.78	66.04	10.22	0.24
B5	89.78	29.98	79.16	9.96	0.38
B6	90.04	32.89	74.94	10.56	0.34
B7	90.04	25.78	81.23	5.60	0.35
AB1	93.52	20.00	70.53	6.80	0.28
AB2	82.20	8.69	83.15	17.80	0.34
AB3	81.32	5.78	63.58	18.68	0.27
AB4	94.00	33.96	77.04	6.00	0.34
AB5	92.20	20.84	56.62	8.00	0.54
AB6	84.15	25.06	90.33	15.85	0.43
AB7	80.20	18.68	94.03	9.80	0.19

In the similar context, Oladeji et al. [7] studied that the biomass size of 2-8 mm gives best briquettes. However, the presence of different size particles improves the packing dynamics and also contributes to high static strength. Moisture content is between 10-15% briquettes has strong and low no crack formed the operation is easily works. At the elevated temperature, the machine can be operated with less power and the life of the die is prolonged. By pre-heating the feedstocks, a more stable and quality briquettes could be produced. Moisture content was between 10.3 to 18.68 maximum moisture content was for binder cow dung it was 10.3% in A1 and in paper, pulp was 10.52% and for AB3 18.68% it is in the range of briquette parameter less moisture content has maximum calorific value. Calorific Value is an important term of any briquetting as we can see paper pulp has high calorific value as compared to other binder groundnut shell has highest calorific value compared to other. Roy et al. [8] demonstrated that briquettes delivered by utilizing the sustain stocks and cow dung waste as a cover had a calorific estimation of 5920.40 kCal/kg, which was higher than different briquettes utilized paper mash (5874.12 kCal/kg) as a binder and furthermore higher than the monetarily accessible cow dung briquettes (3452.34 kCal/kg). Different properties of ash content, sulfur content and chloride substance were less and further more, there was an expanded rate of the volatile matter when contrasted with customary dairy animals manure briquettes. It concludes that biomass can be replaced for cow dung commercially used.

Calorific value of briquettes created from a test of *Afzelia Africana* and *Terminalia superb* mix reinforced with starch had the most astounding calorific estimation of 33116 kCal/kg while briquette created from a test of *Afzelia Africana* and *Terminalia superb* reinforced with fiery debris had the minimum calorific estimation of 23991 kCal/kg. Since the point of briquette is to deliver briquette that will fill in the as great source of fuel and boost burning, the best briquette was delivered when sawdust was blended with starch. Density plays important role in briquette it can observe that more the density has more the calorific value. Panwar et al. [9] showed the average volatile matter contents of the biomass materials in the range of 71.3–86.51% with wheat straw having the minimum value and sawdust having the maximum value.

The ash content of the biomass materials was given to be 13.36% for mango leaves, 8.9%for wheat straw, 7.29% for eucalyptus leaves, and 2.84% for mango sawdust 0.28–1.069%, which are very low concentrations. They reported higher heating values of the biomass materials in the range of 17.51 MJ/kg (wheat straw) and 19.42 MJ/kg (eucalyptus leaves). Sawdust was reported as the best material for compaction which has better density and better performance than wheat straw, mangoleaves and eucalyptus leaves at 70 Mpa. Among leaves, eucalyptus was reported as a better option because of high heating values, where a 10 second holding time can add further to the quality of logs by improving density at the same pressure and improving the long-term handling performance of the logs. The cow dung has maximum burning time as compared to cow dung and cow dung+paper pulp and least burning time is with paper pulp. Ignition Time is the minimum for paper pulp and maximum for the cow dung as shownin the table. It can conclude that paper pulp has easy to burn compared to another binder. Pandey et al. [10] worked on the analysis and test of biomass briquettes and stoves, and confirmed that medium size feedstock with low moisture content is more efficient compared to others. They recommend the use of bio-briquettes as an alternative fuel as it has lower amount of smoke

Table 4. Fuel/Burning characteristics of biomass Briquettes

Briquettes	Calorific value (kCal/kg)	Ignition time (Seconds)	Burning time (Minutes)
A1	2447	45	8.40
A2	3729	34	6.30
A3	2647	49	9.30
A4	3752	23	5.60
A5	3986	54	8.10
A6	2027	45	7.54
A7	2889	14	5.35
B1	4009	23	6.30
B2	**5407**	12	4.50
B3	3407	18	5.45
B4	3729	14	6.10
B5	2729	31	7.43
B6	3729	16	8.56
B7	3245	32	5.60
AB1	3449	34	7.40
AB2	3174	21	5.40
AB3	2097	36	6.30
AB4	4051	30	7.45
AB5	3108	33	6.57
AB6	4102	35	5.44
AB7	2449	26	5.60

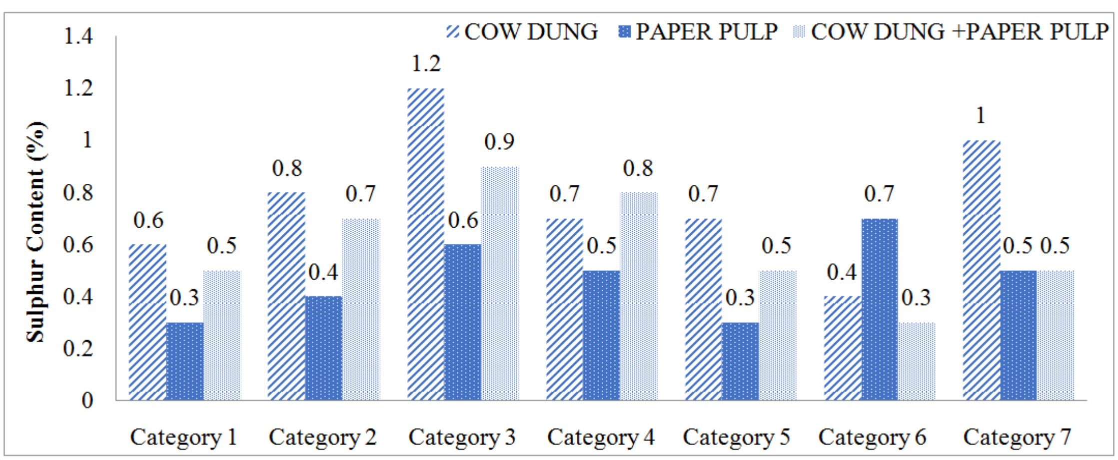

Fig. 7. Sulfur content of Briquettes

emission, higher calorific values. The effects of sulfur on the environment are very bad when the ash is disposed to soil and water it causes the environmental problems. So the briquettes should have low ash content and Sulphur content. The Fig. 7 shows that all the briquettes produced in this study are emitting low sulphur, which is in range to be a biofuel.

4. CONCLUSION

In the present study, Briquettes of different raw material with suitable binder were produced and their efficiency with low-cost Chula and briquette machine was analyzed. Following conclusions were drawn from the present study:

(i) Biomass residues viz. dry leaves, peanut shells, and paddy straw can be used for making briquettes.
(ii) Paper pulp is a better binder for briquette as it is low sulfur content as compared to cow dung.
(iii) Low-cost briquette can be made with help of screw type machine, which gives good strength and better compaction to briquettes.
(iv) Low-cost Chula was designed to improve the efficiency of burning the briquettes. It is 12% more efficient to traditional Chula.
(v) From the data, it was found that briquettes made from ground nut shells bound by using paper pulp give highest calorific value i.e. 5407 kCal/Kg, thus is a very efficient fuel for burning.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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