Topic : **Feasibility of biomass briquettes as a coal substitute**

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Abstract:

The use of coal in India is widespread in several industries, most prominently mining, electricity generation, and metallurgy. India consumes nearly 1 billion tons of coal annually, accounting for some 55% of the country's energy requirements and 12% of the world's coal consumption, second only to China. As a result, the effects of coal combustion—which include the emissions of SO_2 and NOx, generation of smoke, and increased prevalence of respiratory illness—are widespread in India, especially among factory workers who work closely with coal. The environmental problems caused by coal consumption are further exacerbated by the stubble burning techniques employed by farmers in order to clear their fields in the winter season. Biomass briquettes solve both problems. Biomass briquettes are a renewable substitute for coal and can be used at a similar level of thermal efficiency in the relevant industries that rely on coal while generating a lesser amount of emissions due to its low ash content. The briquettes are comprised of agricultural residue, which can be collected as an alternative to this waste being burned, thus negating further emissions.

Introduction:

Coal is used in a great number of industries, constituting a large percentage of all non-renewable energy on both a global and nationwide level. The combustion of coal generates heat, which is also key to processes in various industries. In thermal powerplants, coal is used to generate heat in order to convert water to steam which, in turn, is used to turn a turbine and generate energy. It is also used as a fuel source for kilns in brickmaking, boilers in the textile industry, and in chemical power plants. Due to its high ash content—ranging between 20 and 40 percent—the mass usage and combustion of coal results in great releases of greenhouse gases, such as Carbon Dioxide (CO_2), as well as sulphur, smoke, and fumes. These greenhouse gases, in turn, cause severe environmental damage, resulting in numerous issues such as air pollution, holes in the ozone layer, and global warming. Crop burning contributes to this issue. When fields are harvested, there is a portion of the crop that is not usable and is left in the field. In large fields, this crop residue accumulates, resulting in large amounts of agricultural waste for farmers to dispose of. As a result, the easiest and most common way of disposing of this waste is to employ stubble burning techniques, which further increases environmental pollution, as similar greenhouse gases, such as Carbon Monoxide (CO), Methane (CH_4), Carbon Dioxide, and other hydrocarbons and harmful organic compounds are released into the atmosphere, causing the aforementioned problems to escalate. On a large scale, when coal combustion and usage and stubble burning combine, hundreds of thousands of tonnes of greenhouse gases are released into the atmosphere annually.

Biomass briquettes provide an alternative solution to both issues. While not a perfect substitute for coal, biomass briquette serves the same purposes that it does in the various industries mentioned and can be used as a replacement. For context, the calorific value—or thermal efficiency—of coal is 5000-5500 kcal/kg. Biomass briquettes are slightly lower at 3800-4500 kcal/kg. As a result, they are still viable for usage as fuel sources. They contain a lower ash content as a result of the compaction and pyrolysis process through which they are made, ranging from 0.5 to 6%, much lower than even the highest grades of coal. They also have a lower moisture content, with biomass briquettes containing a maximum of 8% and coal ranging from 10 to 20%. Moisture absorbs heat, so the efficiency of coal is relatively reduced due to its higher moisture content. Biomass briquettes cost less per kilogramme than coal; current market prices for coal and biomass briquettes are Rs.8/kg and Rs.5/kg respectively. As a result, they are more affordable to buy in bulk for usage in industrial processes.

Objective:

The objective of this study is to create biomass briquettes with high densities and calorific values and low moisture and ash contents. The higher density the briquette, the easier the briquette will be to store, and the higher the calorific value, the more energy the briquette will produce when combusted. On the other hand, lower moisture contents are needed, as moisture hinders the combustion process and lowers thermal efficiency (calorific value). A lower ash content will result in less pollutants generated by the briquette upon combustion, resulting in a more environmentally-friendly alternative to coal. Lastly, the briquette should be cost-effective.

Background:

Biomass

Biomass energy is primarily derived from forest, urban, and agricultural waste. Biomass can be divided into three categories:

- Forest biomass, which comes from branches and cutting residues, bark, sawdust, crowns, needles, and other forest waste
- Agri-food biomass, the bulk of which comes from crop and livestock production and field waste
- Urban biomass, which is made up of municipal, commercial, and industrial waste

Since biomass contains carbon and hydrogen, it can be considered a fuel. It is used in a number of industries to meet a variety of energy needs, including electricity and heat. It can also be used in the production of alcohol or biodiesel fuels for automobiles.

Biomass is an environment-friendly energy source. Biomass plays a key role in protecting the environment because it makes it possible to reuse waste, reduce landfill costs, and prevent soil and groundwater contamination.

The potential agricultural residues which do not pose collection and drying problems are rice husk, groundnut shells, coffee husk and coir waste (obtained through the drying process).

At present, loose rice husk, groundnut shells and other agro-residues are mostly used in small scale boilers in process industries. Apart from being inefficient, these boilers do not have the ability to capture fly ash and unburnt carbon, resulting in extensive air pollution. In Ludhiana, one of the industrialized cities of Punjab (India), about 2,000 tonnes of rice husk is burnt every day (Grover and Mishra, 1996).

This pollution problem has become so severe that the State Government of Punjab has banned the burning of loose husk in such boilers, with many other Indian states likely to follow. The users have been advised to use husk either as briquetted fuel or in fluidized bed boilers with proper pollution control measures.

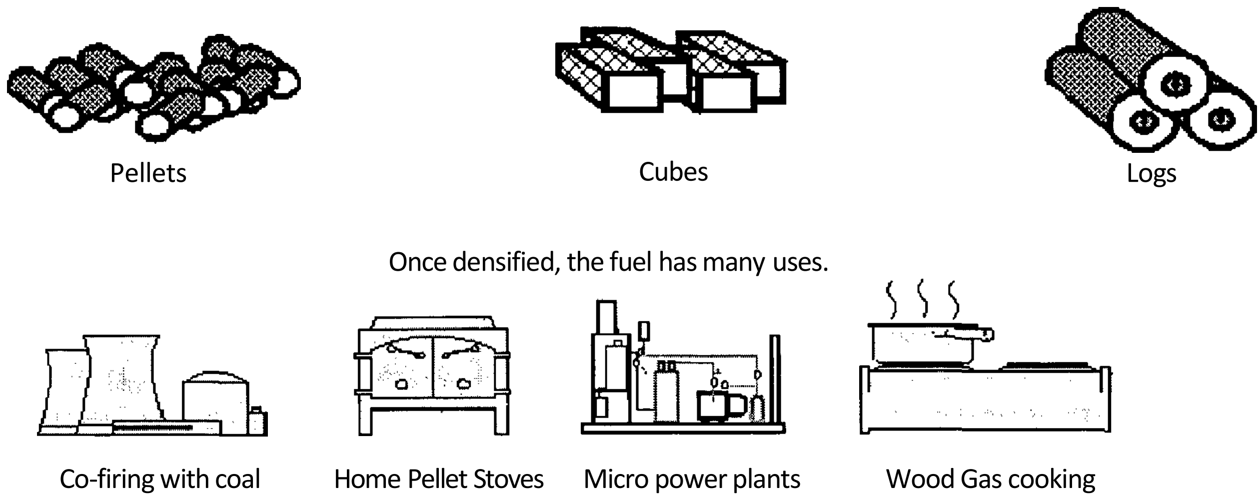

Figure 1: Densified Biomass Types—Pellets, Cubes, Logs—and their uses

Characteristics

There are many factors to consider before biomass qualifies for use as feedstock for briquetting. Apart from its availability in large quantities, it should have the following characteristics:

Low moisture content

Moisture content should be as low as possible, generally in the range of 10-15 percent. High moisture content will pose problems in grinding and excessive energy is required for drying.

Low ash content and composition

Biomass residues (with the exception of tobacco dust, jute dust, rice husk, and deolfied bran with 20%) typically have much lower ash contents than coal, but their ashes have a higher percentage of alkaline minerals, especially potash. These constituents have a tendency to devolatilise during combustion and condense on tubes, especially those of super heaters. These constituents also lower the sintering temperature of ash, leading to ash deposition on the boiler's exposed surfaces. The following table illustrates the ash contents of biomass briquettes created from different types of agricultural residue:

Table 1: Ash contents of several agricultural residues

Biomass	Ash content (%)	Biomass	Ash content (%)
Corn cob	1.2	Coffee husk	4.3
Jute stick	1.2	Cotton shells	4.6
Saw dust mixed	1.3	Tannin waste	4.8
Pine needle	1.5	Almond shell	4.8
Soya bean stalk	1.S	Area nut shell	5.1
Bagasse	1.8	Castor stick	5.4
Coffee spent	1.8	Groundnut shell	6.0
Coconut shell	1.9	Coir pith	8.0
Sunflower stalk	1.9	Bagasse pith	8.0
Jowar straw	3.1	Bean straw	10.2
Olive pits	3.2	Barley straw	10.3
Arhar stalk	3.4	Paddy straw	15.5
Lantana camara	3.5	Tobacco dust	19.1
Subabul leaves	3.6	Jute dust	19.9
Tea waste	3.8	Rice husk	22.4
Tamarind husk	4.2	Deolifed bran	28.2

Methods:

Biomass briquettes are created from agricultural residue sourced from farms. This agricultural residues is the remains of the plants after the crops have been harvested from the fields. Usually, these remains are burned through stubble-burning techniques—releasing greenhouse gases and organic compounds into the atmosphere due to the crops' high ash content—but the repurposing of this residue in the briquetting process negates these emissions. The material that the briquettes are made out of is flexible; it varies from region to region based on the dominant crops in the region, and therefore the most common crops in the region likely generate the most agricultural waste. Common crops used are corn stalks, rice husks, wheat stalks, and wood.

The steps involved in the creation of biomass briquettes are detailed below, represented in the flowchart:

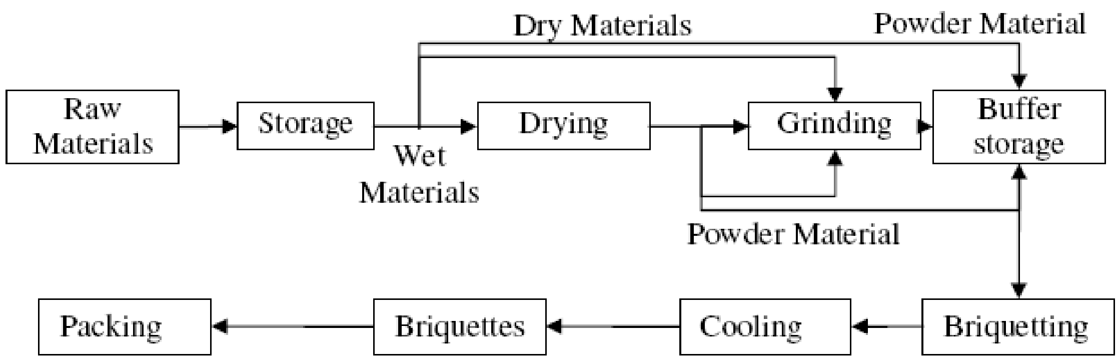

Figure 2: Biomass Briquetting Flowchart

The first step of the process involves a size reduction, wherein the agricultural waste is compacted in such a way that a much larger amount of it can be stored in a small space. When it is loosely stored, it attains a density of around 20 kg/m^3. When it is compacted and stored in briquette form, it can have a density as high as 600 kg/m^3, meaning that much larger amounts can be transported.

After the size reduction, the second step in the process is the removal of moisture in the crops. Typically, crops contain between 4 and 6 percent moisture, which must be removed, as moisture will hinder the combustion of the briquettes, thus lowering their thermal efficiency. This is done through solar drying, or furnaces / laboratory ovens at temperatures of around 100ºC. After the drying process, the acceptable moisture content in the briquettes is 1-2%.

The third step in the process is dependent on the needs of the producers. As coal has a large variety of uses and a large variety of grades based on calorific value and ash content, different types of biomass briquettes are more useful in different industries than others. As a result, two distinct processes are used based on these needs: The compaction process is used when the briquettes need to be prepared mechanically while the pyrolysis process is used when the briquettes need to be completely ash free:

- The compaction process is done at high pressures, typically between 140-150 kg/cm^2, or between 13700-14700 kPa, in a hydraulic press.
- The pyrolysis process is done to remove the ash through combustion without combusting the briquette entirely. As such, the briquettes are heated to temperatures of 200-300ºC, which burns away the ash while leaving behind the rest of the briquette. This emits sin gas.

After these processes are executed, producers often conduct tests on the briquettes to determine their effectiveness. These tests are known as Proximate Analysis and Ultimate Analysis:

- Proximate analysis is a procedure used to determine the moisture content, ash content, volatile matter, and fixed carbon in coal and other substances used for heating. This allows producers to determine the thermal efficiency of the fuel, as high levels of moisture, ash, and volatile matter, and lower levels of fixed carbon can lower thermal efficiency and increase emissions.
- Ultimate analysis is a procedure used to determine the levels of carbon, hydrogen, nitrogen, oxygen, and sulphur present in the fuels.

After production, the producer must ensure that the briquettes are packaged securely, in order to isolate them from moisture, which naturally occurs in the air, contamination, and pyrophoric materials, in case of a fire hazard.

Economic Model of Biomass Briquetting:

Biomass briquettes are becoming increasingly popular in India—for use both households and commercial cooking—primarily because of their low prices. Fixed and low-income people are using biomass briquettes as an alternative fuel due to escalating prices of liquefied petroleum gas (LPG).

In India between INR 40,000 to 50,000 is initially required to set up a briquette manufacturing company in the preliminary stage.

Research was conducted by professors at the Universities of Vigo and La Rioja in Spain to determine the energy and cost requirements of produce briquettes using different screws (new screws, locally made screws, and screws repaired by welding) and die heating systems (electric heating coil made from pipes, kerosene burners, and electric heating coil made by putting). The production rates of briquettes were determined at every hour by operating different combinations of screws and heating systems. The energy consumption and cost were also calculated during the process. The production rate was the highest (110 kg/hr) and the cost was the lowest (1.69 Rs./kg) for repaired screw and pipe coil die heating system. It was also observed that the life of individual screws was the highest (8-10 hours), in the case of the repaired screw. It was also observed that the energy consumption was the lowest (13.55 kW-hr) in the case of repaired screw and pipe coil die heating system. It was in the highest position (17.42 kW-hr) when the heating system was kerosene burner. Therefore, based on the lowest energy consumption and cost to produce rice husk briquettes, the best suitable combination is using repaired screws and electric pipe coil die heating system. This is depicted in the following table:

Table 2: Analysis of highest briquette production system

Screw Type	**Repaired Screw**
Die Heating System	**Pipe Coil Heating system**
Life of Screw	**8-10 hours**
Energy Consumption	**13.55 kW-hr**
Production Rate	**110 kg/hr**
Cost	**1.69 Rs/kg**

Biomass briquetting operations can also create between 54,000 and 57,000 direct job opportunities as plant technicians, operators, and workers, and an additional 100,000 indirect job opportunity as sellers.

Procedure:

A straight-sided container about 6.5 cm in diameter is used as a mold to shape the briquette. A piece of iron metal that fits into the mold is used as a piston to press water out of the briquette mix. A knife, a plastic bag, and some wires are also needed.

Figure 3: Cylinder piston for sample preparation

First, the briquette mix is prepared. Waste paper is soaked in water for one to two days to soften the paper and release the fibres, which will bind the briquette materials together.

Figure 4: Waste paper soaked

Figure 5: Soft paper

The biomass is then mixed with enough water so that the mix will hold together when squeezed.

Figure 6: Mixing material with water

Figure 7: Pressing the mold

A bag of briquette mix is put into a plastic bag and inserted into the cylinder. More mix is added to the bag, while water is pressed out. After the water has been removed, the bag is pulled out of the mold and the briquettes are removed. The briquettes are then dried in the sun for 3-7 days, as briquettes that are not dry will smoke when they are burned.

Figure 8: Process of briquette creation

Figure 9: Prepared briquette samples

Properties of Briquette Samples

Composition

The composition of the briquette samples are shown in the following tables below. In every set of three samples, some components were varied, as shown:

Table 3: Samples 1-3 composition (sawdust % is varied)

Sample	Sawdust percentage (%)	Paper percentage (%)
Sample 1	80	20
Sample 2	85	15
Sample 3	90	10

Table 4: Samples 4-6 composition (sawdust % is varied)

Sample	Sawdust percentage (%)	Paper percentage (%)	Coal percentage (%)
Sample 4	55	10	35
Sample 5	60	10	30
Sample 6	65	10	25

Table 5: Samples 7-9 composition (rice husk % is varied)

Sample	Sawdust percentage (%)	Paper percentage (%)	Coal percentage (%)	Rice husk percentage (%)
Sample 7	30	10	30	30
Sample 8	30	10	25	35
Sample 9	30	10	20	40

Table 6: Samples 10-12 composition (sawdust % is varied)

Sample	Sawdust percentage (%)	Paper percentage (%)	Rice husk percentage (%)
Sample 10	45	10	45
Sample 11	50	10	40
Sample 12	55	10	35

Results and Discussion:

Results

Density

The densities of the briquettes were calculated by taking the mass over the volume. The mass was measured through an electronic balance, and the volume was calculated using the volume of a cylinder. This assumes that the briquettes are perfectly cylindrical, which is untrue, but the actual size of the briquettes is small enough that the difference in volume is marginal. The height of the produced briquettes varied between 2.75–3.50 cm, while the diameter stayed constant at 6.5 cm. The results are displayed below:

Table 7: Densities of briquette samples

Sample	Density (kg/m^3)
Sample 1	103.92
Sample 2	102.15
Sample 3	100.45
Sample 4	103.92
Sample 5	102.15
Sample 6	100.45
Sample 7	102.15
Sample 8	100.45
Sample 9	86.10
Sample 10	111.61
Sample 11	109.58
Sample 12	107.62

Calorific Value

The calorific value of the different samples is determined through bomb calorimetry. A bomb calorimeter measures the heat of a combustion reaction, returning a calorific value. The results of the bomb calorimeter measurements are given below:

Table 8: Calorific values of briquette samples

Sample	Calorific Value (MJ/kg)
Sample 1	21.7800
Sample 2	21.5236
Sample 3	21.3300
Sample 4	23.1843
Sample 5	21.8706
Sample 6	21.2347
Sample 7	22.1303
Sample 8	24.1185
Sample 9	20.2983
Sample 10	24.1364
Sample 11	23.6770
Sample 12	22.3295

Proximate Analysis

Proximate analysis was performed on the briquette samples, yielding the results displayed below:

Table 9: Proximate analysis of briquette samples

Sample	Moisture content (%)	Ash content (%)	Volatile Matter (%)	Fixed Carbon (%)
Sample 1	6.34	16.55	71.48	5.63
Sample 2	6.88	16.95	74.95	1.23
Sample 3	6.53	17.93	75.03	0.52
Sample 4	8.66	14.50	71.28	5.55
Sample 5	8.24	15.29	73.07	3.40
Sample 6	8.82	15.42	73.40	2.35
Sample 7	8.99	11.15	76.62	3.24
Sample 8	8.37	11.88	76.69	3.06
Sample 9	6.21	15.68	73.57	4.54
Sample 10	7.22	9.24	74.62	8.92
Sample 11	7.07	9.55	74.75	8.64
Sample 12	7.71	9.79	75.31	7.19

Discussion

Density

The main components of first three briquette samples were sawdust and paper. It was observed that the density of the briquette decreases when the percentage of sawdust is increased. The first sample holds the lowest percentage of sawdust, 80%, yielding the highest density of 103.92 kg/m^3, while the third sample holds the highest percentage of sawdust, 90%, and has a density of 100.45 kg/m^3

Samples 4 to 6 contain sawdust, coal, and paper. The percentage of paper is fixed; only the quantity of sawdust used is changed between these samples, thus changing the percentages of coal As seen in the previous set of samples, it was also observed that the density decreases when the percentage of sawdust increases, as Sample 4 has the lowest percentage of sawdust (55%) and the highest density (103.92 kg/m^3), while Sample 6 has the highest percentage of sawdust (65%) and the lowest density (100.45 kg/m^3). The density values for the samples including coal were virtually the same as the density values for the samples containing only sawdust and paper.

Samples 7 to 9 contain sawdust, coal, rice husk and paper. The percentage of sawdust and paper is fixed and the percentage of rice husk and coal is changed in these samples. It is also observed that the density decreases when the percentage of rice husk is increased and coal is decreased, as Sample 7 has a lower percentage of rice husk (30%) and higher percentage of coal (30%), yielding a density of 102.15 kg/m^3, while Sample 8 has a higher percentage of rice husk (35%) and lower percentage of coal (25%), yielding a density of 100.45 kg/m^3. It should also be noted that Sample 9 is an outlier, generating an unusually low value for its density, at 86.10 kg/m^3. Thus, it can be inferred that experimental errors occurred in the procedure during the creation of Sample 8.

Samples 10 to 12 contain sawdust, rice husk and paper. The percentage of paper is fixed and the percentage of rice husk and sawdust is changed in these samples. Once again, as the percentage of sawdust in the samples increases, the density decreases, as Sample 10 contains the lowest sawdust percentage (45%) and highest density (111.61 kg/m^3), while Sample 12 has the highest sawdust percentage (55%) and lowest density (107.62 kg/m^3).

Thus, from all the sets of samples, it can be concluded that increasing the percentage of sawdust used in the creation of the briquettes decreases their density, while increasing the percentage of rice husk used in the creation of the briquettes increases their density. The highest-density briquette was Sample 10, with a density of 111.61 kg/m^3, while the lowest density was that of Sample 9, with a density of 86.10 kg/m^3.

Calorific Value

From samples 1 to 3, the calorific value of the briquette decreases as the percentage of sawdust increases, with Sample 1 having a calorific value of 21.78 MJ/kg and a sawdust percentage of 80%, and Sample 3 having a calorific value of 21.33 MJ/kg and a sawdust percentage of 90%.

From samples 4 to 6, the same pattern can be observed, with the calorific value of Sample 4 and 6 being 23.1843 MJ/kg and 21.2347 MJ/kg respectively, and the sawdust contents of the two samples being 55% and 65% for samples 4 and 6 respectively.

From samples 7 to 9, the calorific value was observed to increase as the percentage of rice husk in the briquette increased, as Sample 7 had a calorific value of 22.1303 MJ/kg and rice husk percentage of 30%, while Sample 8 had a calorific value of 24.1185 MJ/kg and a rice husk percentage of 35%. Sample 9 continues to be an outlier, as its calorific value is significantly lower than the other two samples—and all previous samples—at 20.2983 MJ/kg.

From samples 10 to 12, the calorific value was once again observed to decrease as the percentage of sawdust increased, with Sample 10 having a calorific value of 24.1364 MJ/kg and a sawdust percentage of 45%, and Sample 12 having a calorific value of 22.3295 MJ/kg and sawdust percentage of 55%.

Thus, from all the sets of samples, it can be concluded that the calorific value of the briquette decreases as the percentage of sawdust in the briquette increases, and also that the calorific value of the briquette increases as the percentage of rice husk in the briquette increases. The highest calorific value was observed in Sample 10, which had a calorific value of 24.1364 MJ/kg. The lowest calorific value observed was in Sample 9, which had a calorific value of 20.2983 MJ/kg.

Proximate Analysis

From samples 1 to 3, the moisture content is relatively the same, ranging from 6.34% to 6.88%. Sample 1 had the lowest percentages of ash content and volatile matter (16.55% and 71.48%) and the highest percentage of fixed carbon (5.63%), while sample 3 had the highest percentages of ash content and volatile matter (17.93% and 75.03%) and the lowest percentage of fixed carbon (0.52%). Thus, it can be observed that increasing the percentage of sawdust increases the ash content and volatile matter while decreasing the amount of fixed carbon in the briquettes.

From samples 4 to 6, the moisture content ranged from 8.24% to 8.82%, higher than the previous set of samples. Sample 4 had the lowest percentages of ash content and volatile matter (14.5% and 71.28%) and the highest percentage of fixed carbon (5.55%), while sample 6 had the highest percentages of ash content and volatile matter (15.42% and 73.4%) and the lowest percentage of fixed carbon (2.35%). Thus, the conclusion drawn from the previous samples holds true, and increasing the percentage of sawdust increases the ash content and volatile matter while decreasing the percentage of fixed carbon.

From samples 7 to 9, the moisture content ranged from 6.21% to 8.99%, a much larger range than the previous sets of samples due to the outlier in Sample 9. Sample 7 had the lowest percentages of ash content (11.15%), while Sample 8 had the lowest percentage of fixed carbon (3.06%). The highest percentages of ash content and fixed carbon were observed in the outlier Sample 9, with 15.68% and 4.54% respectively. Sample 9 also had the lowest moisture content and volatile matter percentages, with 6.21% and 73.57%. Thus, the conclusion that can be drawn from this set of samples is less valid than the last two sets, as the data is flawed. However, it seems that as the percentage of rice husk increases, the ash content and volatile matter increase, while the fixed carbon decreases.

From samples 10 to 12, the moisture content ranged from 7.07% to 7.71%. Sample 10 had the lowest percentages of ash content and volatile matter (9.24% and 74.62%) and the highest percentage of fixed carbon (8.92%), while sample 12 had the highest percentages of ash content and volatile matter (9.79% and 75.31%) and the lowest percentage of fixed carbon (7.19%). Thus, the conclusion drawn from the previous samples holds true, and increasing the percentage of sawdust increases the ash content and volatile matter while decreasing the percentage of fixed carbon.

Summary

In summary, when the percentage of sawdust in the briquettes increased, the density, calorific value, and fixed carbon percentage of the briquettes decreased while the ash content and volatile matter percentage of the briquettes increased. When the percentage of rice husk in the briquettes increased, the density and fixed carbon percentage of the briquettes decreased while the calorific value, ash content and volatile matter percentage of the briquettes increased. The briquettes produced with coal as a component generally had higher moisture contents, with values staying above 8%, while the lowest moisture contents were observed in the briquettes containing only sawdust and paper, yielding values firmly under 7%. The highest ash contents were observed in the briquettes made with sawdust and paper only, while the lowest were observed in the briquettes created with sawdust, paper, and rice husk.

Conclusion and Evaluation:

According to the results of this study, biomass briquettes are a superior substitute to coal across multiple grades. The Indian Ministry of Coal grades coal based on (i) ash content percentage for coking coal (ii) the sum of ash content and moisture percentages for semi-coking coal, and (iii) the gross calorific values of the coal for non-coking coal. The ash content percentages of briquettes observed in the study ranged from 9.24% to 17.93%. The briquettes can be used as a direct substitute for Steel Grade-I and Steel Grade-II coking coal, and as a superior substitute to lower grades of coking coal. The sum of the moisture and ash content of the briquettes ranges from 16.46% to 24.46%. The briquettes can be used in the place of Semi Coking Grade-I and Grade-II coal. Finally, the gross calorific values of the briquettes ranges from 20.2983 MJ/kg to 24.1364 MJ/kg, which, when converted to kcal/kg, approximately ranges from 4851.41 kcal/kg to 5768.74 kcal/kg. The briquettes can be used as substitutes for G-9, G-8, G-7, and G-6 graded non-coking coal, and as superior alternatives for non-coking coal graded between G-10 and G-17. Hence, biomass briquettes are a viable substitute for multiple different types of coal due to their low ash content and high calorific value, and can be used for various purposes.

The low ash content of the briquettes ensures that, upon combustion, the briquettes produce less pollutants per kg than coal, providing a more environmentally sustainable alternative to coal. Emissions cannot be phased out entirely, as by the nature of the use of the briquettes, they need to be combusted, and thus greenhouse gases and organic chemicals will be released. However, the emissions generated by the biomass briquettes will be less than that of a similar amount of coal. Additionally, the emissions resulting from stubble burning will be negated almost entirely through the repurposing of agricultural residue in the briquetting process. As such, the use of these briquettes as a coal substitute on a large scale will result in considerable reductions in emissions and negation of stubble burning, thereby significantly lowering the incidence of the issues caused by coal combustion and stubble burning.

In the study, the briquettes were created with combinations of sawdust, paper, small amounts of coal, and rice husks. Rice husks have a relatively high ash content, thus the briquettes can be improved further with the use of different agricultural residue with lower ash contents—such as corn, soya beans, coconut shells, and groundnut shells—thereby reducing the emissions from the briquettes' combustion even further.

The compression method used in the study can be improved with sophisticated compaction using hydraulic presses and other industrial machines, resulting in much higher briquette densities.

These higher densities allow for larger quantities of briquettes to be stored in small spaces, allowing for ease of transportation and storage. As a result, widespread adoption, investment, and innovation in briquetting methods can result in highly-effective environmentally friendly coal substitutes, which can be purchased and transported very conveniently, providing incentives for companies in coal-consuming industries to switch to briquettes.

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