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**ORIGINAL ARTICLE**

# An investigation on the performance of sawdust briquette blending with neem powder

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**Abstract** This paper discusses the performance of the sawdust and neem powder briquette and its blends. In the first set of experiments, the sawdust and neem powder briquettes are produced by manually operated hydraulic pelletizer in the pressure range of 7–33 MPa. The strength of briquettes is investigated by the shatter index, impact resistance, durability index and water resistance test. The calorific value and water boiling tests have been also conducted to study the performance of the briquettes. The result shows that the neem powder briquette has significantly higher strength, but lower calorific value compared with the sawdust briquette. Also the performance of the briquettes increases with increase in pressure. Thus the maximum pressure of 33 MPa is used for the second set of experiments. In the second set of experiments, the neem powder is blended with the sawdust in the ratio of 100:0, 75:25, 50:50, 25:75, 0:100 (Sawdust:Neem powder). The study shows that the sawdust with neem powder as binding agent has considerably increased the strength of the briquette with a little reduction in burning rate.

## 1. Introduction

The renewable energy sources should be effectively utilized in order to meet the rapidly increasing energy demand. Biomass energy has greater prospective than the other form of energy, since it is renewable, in contrast to the nature of the fossil fuels. One of the major limitations of using biomass as a feedstock is its low bulk density, which typically ranges from 80 to 100 kg/$m^3$ for agricultural straws and grasses and 150 to 200 kg/$m^3$ for woody resources such as wood chips and sawdust [1].

Saidur et al. [2] have discussed the several aspects of burning the biomass in boilers and found that utilizing biomass in boilers may offer the economical, social and environmental benefits such as conservation of fossil fuel resources, financial net saving, $CO_2$ and $NO_x$ emissions reduction and job opportunities creation. Combustion characteristics and different biomass conversion technologies have been studied by Demirbas [3] and concluded that the co-firing of biomass with coal helps to reduce the total emission compared to the single coal firing. Gonzalez et al. [4] have studied the optimization of combustion process for domestic heating system for four different pellets (tomato, olive stone, cardoon and forest). The optimum residue mixture of 75:25 (tomato:forest) resulted in a boiler efficiency of 92.4%.

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Dong et al. [5] have reviewed the development of small and micro scale combined heat and power (CHP) system technologies based on the biomass energy and listed the advantages and disadvantages of the CHP systems. They have further recommended that significant research efforts are needed in order to commercialize the next generation stand-alone small-scale and micro-scale biomass fueled CHP systems. Míguez et al. [6] have reviewed the different technologies available in the European market for the small scale biomass combustion system and reported that solid fuel boiler usage has been continuously increasing across Europe. The different factors that affect the strength and durability of the densified biomass products have been reviewed by Kaliyan and Morey [7]. The compressive resistance, impact resistance, water resistance, and durability are the important parameters used to determine the strength of the densified products [7].

Chin and Siddiqui [8] have experimentally investigated the characteristics of different biomass briquettes (sawdust, rice husks, peanut shells, coconut fibers and palm fruit fibers) under different die pressures. The result shows that the sawdust briquette has better overall handling characteristics than others. Li and Liu [9] have investigated the performance of binderless compaction of the wood processing residue waste at high pressure in the range of 34–138 MPa. The result shows that the strongest logs are made with the oak sawdust, cottonwood sawdust next and the least log with pine sawdust. Yaman et al. [10] have produced fuel briquettes from olive refuse and paper mill waste at different die pressures (150–250 MPa) and suggested that it can be used as an alternative energy source. Coates [11] has made briquette from cotton plant residue and the result demonstrates that it can replace the waste paper used by the factory as an ingredient when producing pecan shell briquettes, with minimal decrease in briquette quality.

Zhang et al. [12] have reported that the briquette strength is improved by adding the bentonite, coal tar and/or polypropylene amide into rice straw-based binder. Ndiema et al. [13] have investigated and concluded that die pressure has a considerable effect on the size of biomass. Srivastava et al. [14] have found that increasing the pressure from 5 to 44 MPa increased the wafer durability rating of grass hay from 5 to 91%. Mani et al. [15] have investigated the specific energy required to produce the compact corn stover briquette and reported that the density increases with increase in pressure.

The addition of binders with biomass materials might have a positive outcome on the strength of the wood pellets, in a similar way to the adhesive resin used in the production of particle and fiber-boards. Starch, protein, fiber, fat/oil, lignosulfonate, bentonite and modified cellulose have been investigated as binders to positively influence the durability of densified products [16–21]. Ahn et al. [22] have investigated the effect of different binder contents (rapeseed flour, coffee meal, bark, pine cones, and lignin powder) on durability of wood pellets. In the production of wood pellets, binders can be used to make strong interparticle bonds in the presence of heat and moisture. Numerous organic and inorganic binders could be employed for the densification process of wood pellets [22].

The literature shows the importance of the biomass energy in today's scenario. In previous works, researchers made investigations to improve the performance of the briquettes by varying the applied pressure and different binder materials such as adhesive resin, starch, protein, fiber, fat/oil, lignosulfonate, bentonite, modified cellulose, rapeseed flour, coffee meal, bark, pine cones, and lignin powder. The literature shows that, the strength is a very important parameter in handling, transportation and steady combustion of biomass briquettes. This present work investigates the way to improve the strength of the sawdust briquette with neem powder as a new binding agent. Two sets of experiments are carried out in this work. In the first set of experiments, the performance of the sawdust and neem briquette is investigated individually. In second set of experiments, the sawdust is blended with neem powder in the ratio of 100:0, 75:25, 50:50, 25:75 and 0:100. The performances of the briquettes have been studied in terms of its shatter index test, impact resistance test, durability index test, water resistance test, calorific value and water boiling test.

## 2. Materials and methods

A manually operated hydraulic pelletizer has been used to produce the briquette as shown in Fig. 1. The die has an internal diameter of 44 mm with a height of 70 mm. The pelletizer can operate in the range of 0–52 MPa. However, for flexible and safety operation the maximum pressure is limited to 33 MPa. Each briquette is produced with 30 grams of sawdust or neem powder and five different pressures in pelletizer (7, 13, 20, 26 and 33 MPa). The thickness of the briquette will vary with the pressure, which affects the performance of the briquette. In the first set of experiments, strength of the sawdust and neem powder is investigated individually by shatter index, impact resistance, durability index and water resistance test.

The second sets of experiments are carried out based on the result of the first set of experiments. The strength of sawdust is improved by blending the sawdust with neem powder in

**Figure 1** Photographic view of manually operated hydraulic pelletizer.

**Table 1** Accuracy and experimental uncertainty for various measuring instruments.

| Sl. No. | Instrument | Accuracy | Range | Standard uncertainty |
|---|---|---|---|---|
| 1 | Thermometer | ±1 °C | 0–100 °C | 0.6 °C |
| 2 | Measuring tape | ±1 mm | 0–10 m | 0.6 mm |
| 3 | Digital stopwatch | ±0.1 s | 0–1 h | 0.06 s |
| 4 | Digital weighing scale | ±0.1 g | 0–5 kg | 0.06 g |

different ratios (100:0, 75:25, 50:50, 25:75, 0:100). A constant pressure of 33 MPa is used in these experiments and the performance is studied by the shatter index, impact resistance, durability index, water resistance and water boiling tests. Each experiment is repeated for thrice to ensure the reliability of the test results. Table 1 shows the accuracy and experimental uncertainty for various measuring instruments used in the present work. The uncertainty analysis for the measuring instruments such as thermometer, measuring tape, stopwatch, weighing scale and measuring jar is calculated from Rahbar and Esfahani [23].

Thermogravimetric analysis is carried out to investigate the mass loss percentage in pure neem and sawdust powder using the Exstar 6000 TGA analyzer. The experiment is carried out in the temperature range of 23–600 °C.

### 2.1. Shatter index test

Shatter index is used for determining the hardness of briquettes. The briquette is dropped on concrete floor from a height of one meter. The weight of the disintegrated briquette and its size is noted down. The percentage loss of material is calculated by Eq. (1) [24]:

$$\text{Percentage of weight loss} = \frac{W_1 - W_2}{W_1} \times 100 \tag{1}$$

where $W_1$, $W_2$ = weight of briquette before and after shattering, gram.

### 2.2. Tumbling test

Tumbling test is used for measuring the durability index of briquettes and it demonstrates how the briquette responds at the stage of transportation. A cuboid formed by an angle iron frame having dimensions of 30 cm × 30 cm × 45 cm and fixed over a hollow shaft diagonally is used to conduct the tumbling test. The sample of briquettes was placed inside the cuboid and rotated for 15 min. After 15 min of tumbling action the briquette is taken out and weighed to calculate the percentage of loss by using the same formula of shatter resistance test [24].

### 2.3. Impact resistance test

This test is used to investigate the strength and hardness of briquette. Each briquette sample is repeatedly dropped from a stationary starting point at 2 m height into a concrete floor until it gets fractured. The number of drops of each briquette takes to broke into pieces is recorded. The impact resistance is value of number of drops. [25].

### 2.4. Water resistance test

The briquette is immersed in water maintained at the atmospheric temperature for 30 s to determine the percentage of water resistance to penetration [26]. It shows that, how the briquettes will respond during rainy seasons or while in contact with water.

The value of shatter index, impact resistance, and durability index and water resistance should be higher in order to ensure the strength of the briquettes.

### 2.5. Water boiling test

This test is carried out as per the guidelines given in the Water Boiling Test (WBT) [27]. There are two types of tests carried out namely cold start and hot start. In cold start test, initially 5 L of water is taken in a cylindrical pot and placed in the stove. The briquettes start to burn and the fuel for combustion is supplied at regular intervals of time to maintain the burning rate. This is carried on until the water reaches the boiling stage. The firing is stopped in the combustion chamber when it reaches the boiling stage and the ash and remaining briquette is removed from the combustion chamber. Now the same procedure is repeated for hot start test. At this stage, the hot water available in the pot is replaced with freshwater at ambient temperature, but the stove and pot will remain hot. The ash produced in the combustion process is regularly removed from the combustion chamber and disposed. In each test amount of fuel used and time taken to reach the boiling point are noted. The temperature is recorded by the mercury in glass thermometer for every 10 min. A digital stopwatch is used to measure the time required to reach the boiling point of water in the pot.

## 3. Result and discussions

### 3.1. Thermogravimetric analysis (TGA)

Fig. 2 and Table 2 show the TGA of the neem and sawdust powder. In stage I, 8.12% of mass loss is observed in the neem whereas it is about 11.26% in the Sawdust. In the first stage, the maximum amount of moisture is removed and it becomes dry. In stage II, thermal degradation of hemicellulose, cellulose and lignin present in the material is lost and it shows the maximum of loss occurring in both the materials. The remaining ash content is lost in stage III. The mass loss in this stage is much lower compared to other stages.

### 3.2. Performance study on briquette without blends

The effects of density variation on the performance of sawdust and neem powder briquettes are discussed in this section. Fig. 3 shows the variation of density in neem and sawdust for different applied pressures. The density of both the materials increases with increase in applied pressure. Neem powder has higher density than sawdust at all applied pressure

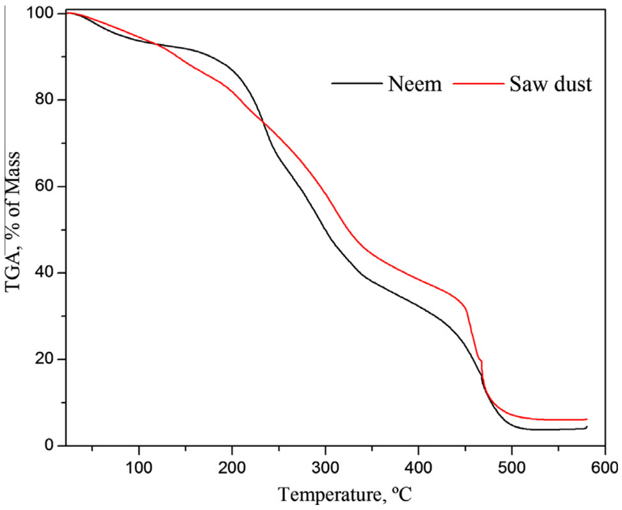

**Figure 2** TGA of neem powder and sawdust.

**Table 2** Stages of thermal degradation of the materials.

| Stage | Temperature (°C) | Mass loss, % | |
|---|---|---|---|
| | | Neem | Sawdust |
| I | 23–150 | 8.12 | 11.26 |
| II | 150–580 | 87.31 | 82.43 |
| III | > 580 | 4.57 | 6.31 |

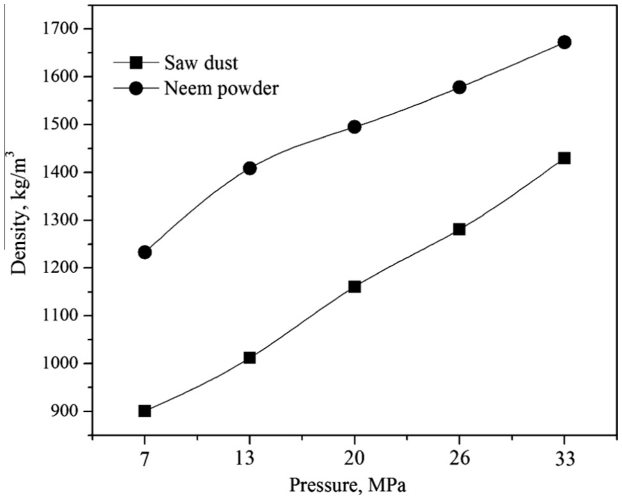

**Figure 3** Effect of applied pressure on density.

conditions. Increase in density leads to reduction in briquette size and improved combustion rate. However, sawdust has higher combustion rate than neem powder due to higher calorific value of sawdust.

Shatter index test is a measure of the briquette strength. A high shatter index and a impact resistance are necessary to avoid damages from handling. The shatter index and impact resistance for different applied pressures are shown in Fig. 4.

Neem briquette shatter index is considerably higher than that of the sawdust due to its higher binding capacity. Due to this higher binding capacity neem briquettes are hard to disintegrate in this test and resulted in higher shatter index value. While the applied pressure is varied from 7 MPa to 33 MPa, neem briquette shatter index is increased by 10% whereas sawdust briquette shatter index is increased by 15%. It shows that the applied pressure has more effect on the sawdust than on neem briquettes. At an applied pressure of 33 MPa, sawdust briquettes get fractured at 10th drop whereas neem powder briquette is fractured at 28th drop. It demonstrates that the strength of the neem briquette is higher than that of the sawdust.

Fig. 5 shows the durability index and water resistance capacity of neem and sawdust briquettes. The exposure of briquette to the rain or high humidity conditions during transportation and storage could adversely affect the quality of the briquettes. The neem powder has higher water resistance at all applied pressure condition. The durability index test is mainly used to study the strength of the briquette in transportation of briquette in vehicle, where vibrations may occur. The durability of the neem powder briquette is high which shows higher strength to resist vibrations comparable to sawdust briquettes.

Fig. 6 illustrates the effect of calorific value for different blend ratio of sawdust and neem. It illustrates that increasing the neem content reduces the calorific value of blend. It can be seen that using neem powder briquettes has higher transportation, handling and water resistance properties than sawdust. But neem powder cannot be used directly as biomass materials due to its lower calorific value.

Thus, the studies are extended to blending of neem powder with sawdust at different ratios. Also the above result shows performance of the briquette is enhanced with hike in pressure. Thus, maximum pressure of 33 MPa is used for second set of experiments.

### *3.3. Performance study of briquette with blend*

Fig. 7 shows that the parameters (durability index, shatter index, resistance to water penetration and impact resistance test) gradually decrease with reduction in neem content. This

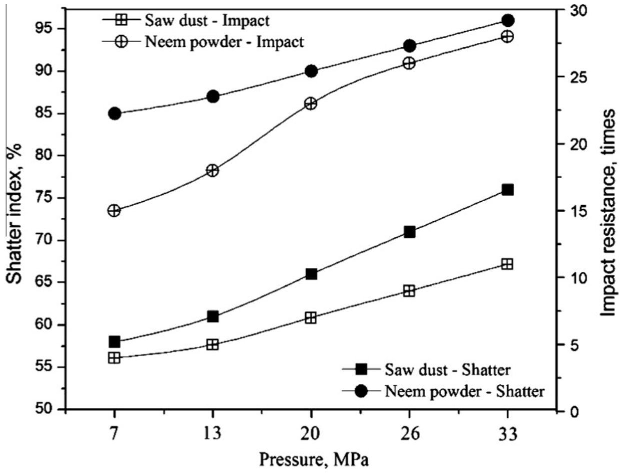

**Figure 4** Shatter index and impact resistance of briquettes.

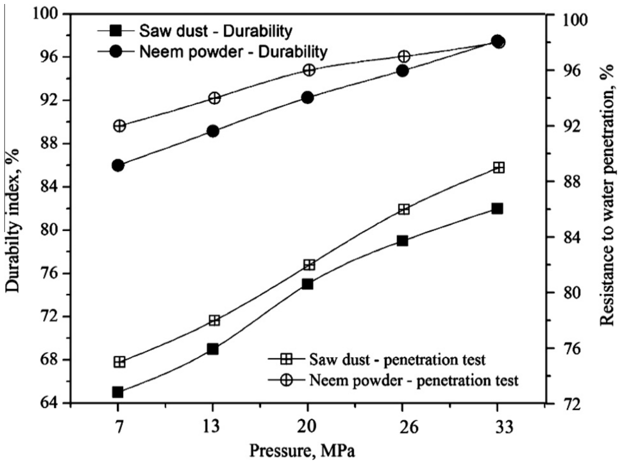

**Figure 5** Variation of durability index and water resistance.

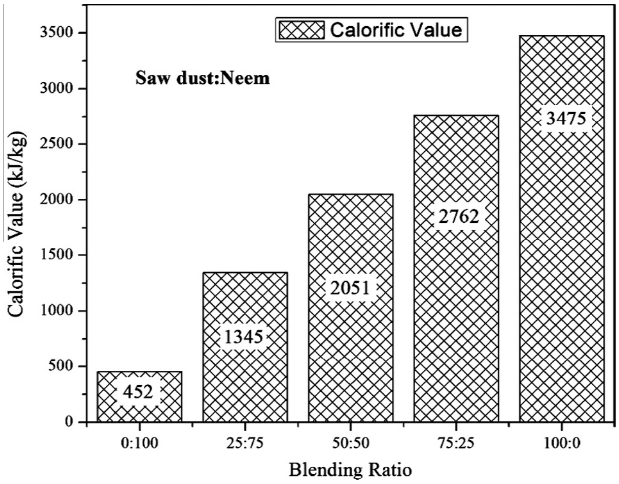

**Figure 6** Calorific value of materials at different blend ratio.

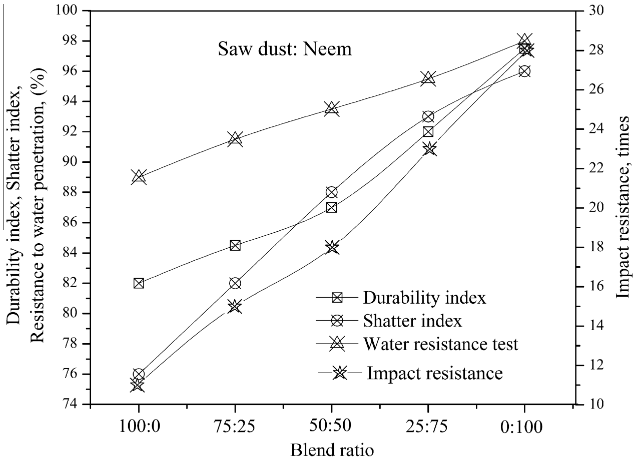

**Figure 7** Properties of blended briquettes with different ratio.

is due to the binding capacity of the neem with sawdust. Impact resistance test shows that increasing the neem content significantly enhances the strength of the briquettes.

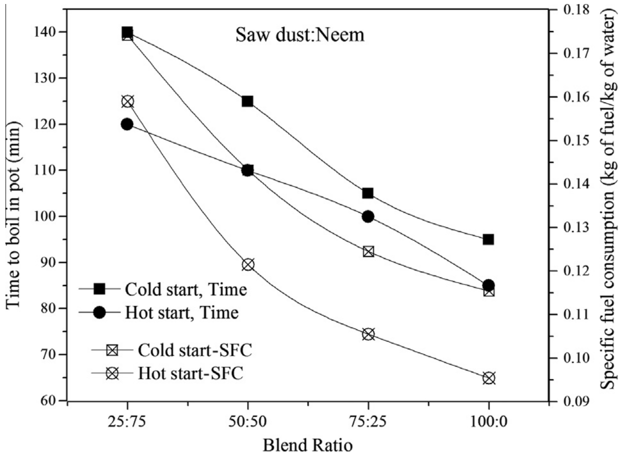

**Figure 8** Variation of specific fuel consumption and time to boil for various blend ratio.

Fig. 8 shows the result of water boiling test in terms of time to boil and specific fuel consumption (SFC) under atmospheric condition. Time used to boil (min) refers to the time taken by the water in the pot to reach the boiling point temperature. The amount of fuel required to reach the boiling stage of one kg of water is known as specific fuel consumption. The time required to reach the boiling temperature with sawdust briquette as fuel is lesser compared to blends with neem powder. This is due to the higher calorific value of sawdust briquette compared with blend. The time required for boiling and specific fuel consumption increases with the increase in neem blended in briquette. It also shows that the sawdust is burnt completely and also has a higher burning compared to the blended one.

## 4. Conclusions

This work investigates the performance of sawdust, neem power and its blend briquettes. The result illustrates that the neem powder has higher strength, handling and water resistance properties and lower calorific value than the sawdust briquettes. Thus the neem powder is added as a blending material with sawdust to increase the handling and water resistance properties of the briquettes. The tests with various blend ratio show that increasing the neem content in briquette enhances the strength of the briquettes. The water boiling test results show that the increase in neem content reduces the burning rate and increases the time required for boiling. Also the presence of the neem content increases the specific fuel consumption. As a result it can be concluded as that neem powder can be used as binder material with biomass briquettes, which increases the strength by considerably and reduces the performance by slightly.

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