Original Research Article

Effect of moisture content and particle size on characteristics of fuel pellets using flat die type pelleting machine

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Abstract

Fuel pellets are a popular form of biomass energy due to their high energy density, ease of handling, and reduced emissions. The quality of fuel pellets is influenced by various factors, including the moisture content and particle size of the raw materials used during the pelletization process. In this study, the effect of moisture content and particle size on the characteristics of fuel pellets produced using a flat die type pelleting machine was investigated. Different moisture content levels (ranging from 20% to 30%) and particle sizes (ranging from 4 mm to 8 mm) were used to pelletize a biomass feedstock. The pellet characteristics, including pellet durability, bulk density and water resistance and energy consumption were evaluated. The results showed that both moisture content and particle size significantly influenced the characteristics of the fuel pellets. Based on the findings, an optimal moisture content of 25% and particle size of 6 mm were determined for producing fuel pellets with desirable characteristics using the flat die type pelleting machine. These results can provide valuable insights for biomass pellet producers and researchers in optimizing the pelletization process to achieve high-quality fuel pellets with improved properties.

Keywords: Fuel pellets, moisture content, particle size, pellet durability, energy consumption, flat die machine

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1. Introduction

Recent years have seen a rise in the exploration of alternative and environmentally friendly energy sources in an effort to ensure energy security due to the depletion of fossil fuel reserves, a volatile oil market, an unstable geopolitical environment and most important the environmental risk associated with the widespread use of fossil fuels (Mahlia et al., 2020). As a proven possible replacement for fossil fuel in recent years, biomass is an important renewable energy source. As a local fuel, biomass plays a crucial role in reducing local energy crises on macro and micro levels. There is a huge amount of waste produced each year in developing countries, such as India, which produces about 62 million tonnes of waste each year. As of 2030, there are estimated to be 2.3 billion people who depend on traditional fuelwood for cooking (Niinimaki et al., 2020). Currently, emerging countries are dealing with the difficult socioeconomic issue of growing fuelwood scarcity. It has been demonstrated that the production of pellets from various agricultural waste products is a sustainable solution to the current fuelwood shortage.

There is an abundance of biomass in rural India, and it is almost free to use. Nearly 70% of India's population lives in rural areas that depend heavily on biomass for their energy supply. In India, the number of households with access to electricity and LPG has steadily increased over the past decade, but in parallel approximately 220 MT of firewood is consumed annually for cooking in rural areas (Purohit and Chaturvedi, 2018). Large-scale firewood consumption can contribute to soil erosion and forest deterioration. India produces 500 million tonnes (Mt) or more of crop residue annually, of which 12.2% is burned as a solid fuel for electricity production, according to the Indian Ministry of New and Renewable Energy (MNRE). However, the majority (88%) of biomass is still untapped (Sarkar et al., 2020). This utilized of biomass from agricultural waste provide considerable potential for biotransformation into a range of biofuels, including pellets. Agro-residues are mostly burned in the open field and stored improperly which poses risks to the environment and human health. The main problems by using agro residue in their natural forms contain high moisture content, low bulk density, low energy density, uneven physical shapes, difficulty in handling and storage, and low energy density. A total of 141 and 157 MT of crop residues (excluding those from plantations and spices) will be available for biomass pellet production in India during 2030-2031 (Purohit and Chaturvedi, 2018). Biomass pelletization is a convenient way to eliminate problems associated with biomass use. Pellets have superior physico-chemical properties in comparison to raw materials. The Indian Ministry of Power has announced a policy for co-firing 5-10% of biomass pellets in all of the country's thermal coal power plants. According to estimates, co-firing in a thermal plant with a 1000 MW capacity would require about 0.3 million tonnes of biomass pellets (Choudhury et al., 2021). To secure a wide and consistent supply of raw materials for the production of pellets, it is necessary to investigate the effect of process parameters such as moisture content and particle size on the characteristics of pellets. The present work studied the physico-chemical characteristics of pellets made from soybean straw and cotton stalk to investigate the agro residues' unexplored energy potential.

Soybean straw and cotton stalk were selected in the present work, which is abundantly available in India and can generate electricity. The annual production of soybean straw and cotton stalk is found to be around 315 million tons and 23 million tons in India, respectively (Juikar and Nadanathangam, 2020; Jagtap and Kalbande, 2022). One of the most important factors is particle size (20 % impact) affecting pellet durability. The amount of proteins, fibres, carbs, and fat influence 40 % and moisture content affects (20 % impact). Many studies on the pelletization of biomass have been published in the literature, using different agro residues and pellet mills. Mani et al., (2006) analyzed the effects of compressive strength, particle-size distribution and moisture content of raw material on the physical properties of the pellets found to significantly affect pellet density from wheat straw. The pellet density was found maximum of 1136 kg/m³ at 12% moisture content and 3.2 mm particle size. Yilmaz, 2018 produced pellets from corn stalks with a bulk density of 715 kg/m³ at 14.75% moisture content. According to Kaliyan and Morey's review, reducing the particle size increases the durability of biomass pellets.

However, there is a lack of studies to understand the effect of moisture content and particle size using soybean straw and cotton stalk. The aim of this study is to investigate effect of moisture content (20, 25, 30 % w. b.) and particle size (4, 6, 8 mm) on pellet density, durability, resistance to water penetration and energy consumption.

2. Materials and methods

2.1 Collection of agro residues

The agro residues (soybean straw and cotton stalk) were obtained from the field of Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. India. The agro residues were ground by a hammer mill with a particle size of 4, 6 and 8 mm. The ground agro residues were conditioned at 20, 25 and 30% moisture content by spraying water with a material mixer. Three different moisture content (20, 25 and 30%) and three different particle sizes (4, 6 and 8 mm) were used in the experiments.

2.2 Production of pellets

The flat die type of pellet machine was used for the production of agro residue pelletsas shown in Fig. 1. The pelleting machine can produce about 45 to 50 kg/h pellets. The pelleting press is a die and roller mechanism and the throughput capacity of the machine depends on the types of agro residue and its characteristics. The unit has a stainless-steel hopper and chute. Detailed specification includes a) power: 420 V/10 hp/ 3 phase b) hopper:

top dia. 250 mm and bottom dia. 50 mm c) diameter of die hole: 15 mm d) type of press: flat die and roller. The grounded agro residue was fed into the hopper and this flows down into pelleting chamber by gravity flow. A shaft that was connected to the gearbox of the electric motor drives the die plate. The roller picks up the feed materials and compress them into the die holes to form pellets. The pellets were cut by a cutting knife and discharged from the pelleting chamber. The pellets were collected into the tray and dried for 1 day before storage.

Fig. 1 Flat die type pelleting machine

2.3 Determination of moisture content

The known weight of the pellets was placed in the air oven and kept at the temperature of 105°C. The known weight of the sample was left in the oven for 24 h. The final weight of the sample was recorded. The moisture content was calculated by using the following equation:

$$\text{Moisture content (\%)} = \frac{(B-C)}{(B-A)} \times 100 \qquad \text{…. Eq. 1}$$

Where,

A = Weight of the sample box, g.

B = Weight of the sample box + sample, g.

C = Weight of the sample box + sample after drying at 105°C at 24 hr.

2.4 Determination of pellet density

The pellet density is defined as the ratio of the mass (kg) occupying a given bulk volume to the volume of the container (m³). It was calculated by using the following formula (Akbar et al., 2021)

$$\rho_p = \frac{m_p}{v_p} \quad \text{…. Eq. 2}$$

Where

ρ_p= Pellet density, kg/m³

m_p= Pelleting mass, kg

v_p= Pellets sample volume, m³

2.5 Determination of durability

Pellet durability can be described as the ability of pellets to withstand destructive loads and frictional forces during handling and transport. According to ASABE (ASAE S269.4 DEC1991, R2007) the pellet durability was determined as follows; 500 g of pellets were placed in the tumbling box device for tumbling for up to 10 minutes at 50 rpm after which the broken and cracked pellets were separated and the weight determined. The durability was calculated using the following relation (Okwewole and Lgbeka 2016)

$$PD = \frac{W_a}{W_b} \times 100 \quad \text{…. Eq. (3)}$$

Where,

PD= Pellet durability, %

W_a= Mass of the pellet after shaker treatment, g

W_b= Mass of the pellet before shaker treatment, g

2.6 Determination of water resistance

It was measured by the percentage of water absorbed by a pellet when immersed in water. Each pellet was immersed in 25 mm of water at 27°C for 30 seconds. The percent water gain was calculated and recorded by using the following formula (Sengar et al., 2012).

$$\text{Water gained by pellets}=\frac{W_2-W_1}{W_1}\times 100 \qquad \text{.... Eq. (4)}$$

$$\text{Resistance to water penetration}= 100 - \text{water gains} \qquad \text{.... Eq. (5)}$$

Where,

w_1 = Initial weight of pellets, g

w_2 = Final weight of pellets, g

2.7 Determination of energy consumption

The energy consumption was recorded directly by using an energy meter connected between pelleting machine and the plug-in.

3. Results and discussion

3.1 Moisture content

Fig. 3 shows the soybean straw and cotton stalk pellets produced at 25% moisture using a 6 mm particle size. The moisture content of pellets after one day of storage was observed from 5 to 6 % (w. b.)

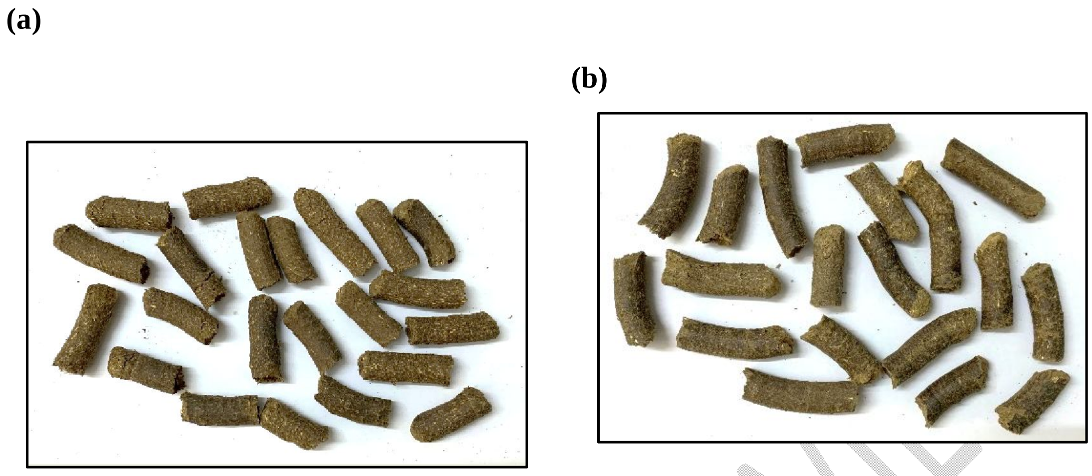

Fig. 2 (a) Soybean straw pellets (b) Cotton stalk pellets produced using flat die type pelleting machine

3.2 Pellet density

The effect of moisture content and particle size were found significant at a 5% level of significance. The pellet density of soybean straw and cotton stalk is represented in Fig. 3. The three different moisture content 20, 25 and 30 % three different particle sizes 4, 6 and 8 mm were used for the experimentation. The data indicated that at moisture content 20 to 25% and particle size 4 to 6 mm resulted in increasing pellet density from 602.85 kg/m³ to 620.45 kg/m³ whereas at moisture content 25 to 30% and particle size 6 to 8 mm observed pellet density 620.45 kg/m³ and 586.42 kg/m³ for soybean straw. With increasing 20 to 30% moisture content and 4 to 8 mm particle size, pellet density increased from 598.21 to 625.67 kg/m³ then decreased from 625.67 kg/m³ to 576.84 kg/m³ for the cotton stalk. The fine particle size and lower moisture content were not sufficient to produce durable pellets. The fine particle size required higher conditioning and particle do not stick together with lower moisture content. The higher moisture content was undesirable because it unconsolidated particle layer during the pelleting process and occurs cracks which reduce density. The 25%

moisture content and 6 mm particle size were desirable for higher density. Naindeng et al., (2015) observed that particle size affected the density due to increased porosity, and small particle resulted a denser packing. Tumuluru (2015) found that high moisture content in the biomass lowers pellet density.

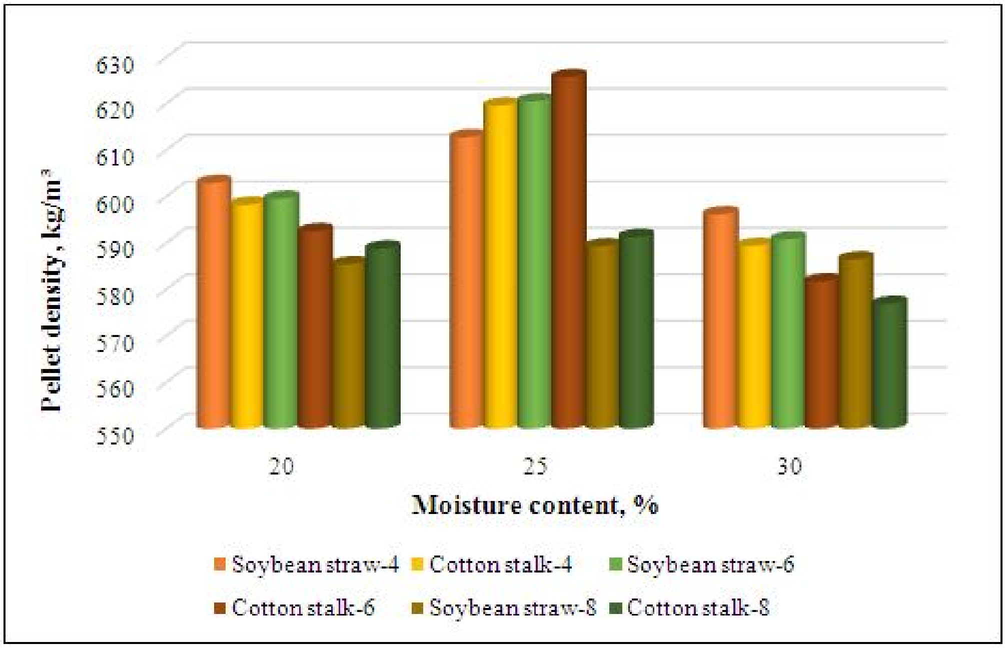

Fig. 3 Pellet density of fuel pellets at different process parameters

3.3 Durability index

The durability index of pellets at different moisture content and particle size is shown in Fig. 4. The maximum durability index was observed at 90.24 % for soybean straw and 91.28% for cotton stalk at 25% moisture content and 6 mm particle size whereas minimum durability index was observed 78.23 % for soybean straw and 80.74% for cotton stalk at 30 % moisture content and 8 mm particle size. During pelletizing process, the binding is formed due to the formation of solid bridges due to elastic and plastic deformation and particle rearrangement resulting in particle interlocking bonds. The pressure increases interfacial forces and cohesion among the particles layer resulting in solid and liquid bridges which are formed due to optimum moisture content. The medium particle size has a higher contact surface area observed bringing particles together whereas the fine particle size required higher moisture content and jamming the die plate. The large particle size was observed lower durability due to small contact area among particles. A significant effect of moisture content and particle size on durability was found by Kocer and Kurklu (2022).

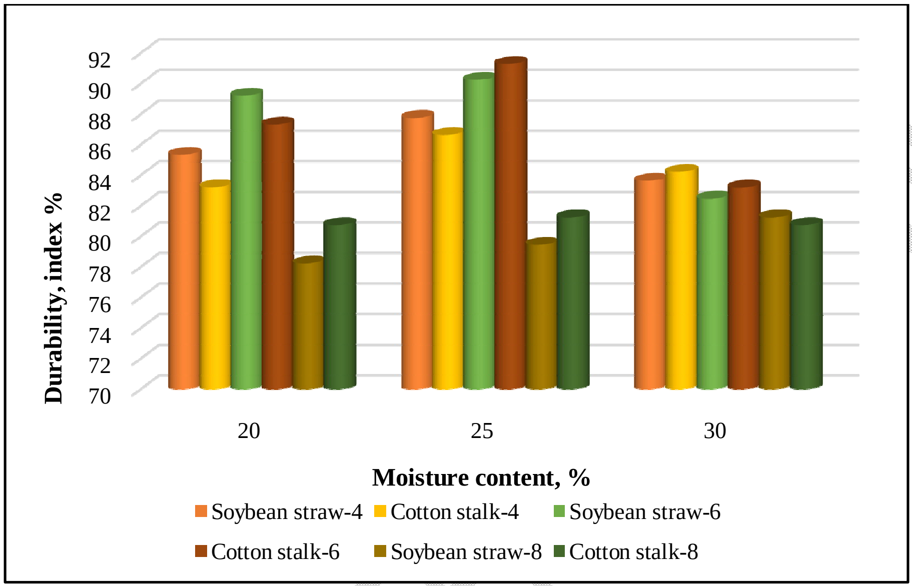

Fig. 4 Durability of fuel pellets at different process parameters

3.4 Water resistance

The water resistance test was used to determine the percentage of water observed by pellets when pellets are placed in water. The effect of moisture content and particle size were significant on the water resistance. The maximum water resistance was observed at 92.72 % at a moisture content of 25% and particle size of 6 mm whereas the minimum was observed at 80.89% at a moisture content of 30% and particle size of 8 mm for soybean straw. In the cotton stalk, water resistance was found maximum at 89.37% and minimum at 79.14% as shown in Fig. 5. When materials have higher moisture content, they tend to absorb more water, which can result in reduced water resistance. This is because the additional moisture can increase the porosity of the material, allowing water to penetrate more easily. It can also weaken the intermolecular forces and increase the mobility of the material, making it more susceptible to water penetration (Yoshida et al., 2021). Particle size can also influence its water resistance. Finer particle size can result in increased surface area and higher water absorption due to capillary action, which can lead to reduced water resistance. In contrast, larger particle size can result in lower surface area and reduced water absorption, leading to improved water resistance. Particle size can also affect the packing arrangement of particles, porosity, and permeability of a material, which can further impact its water resistance (Sarkar et al., 2023).

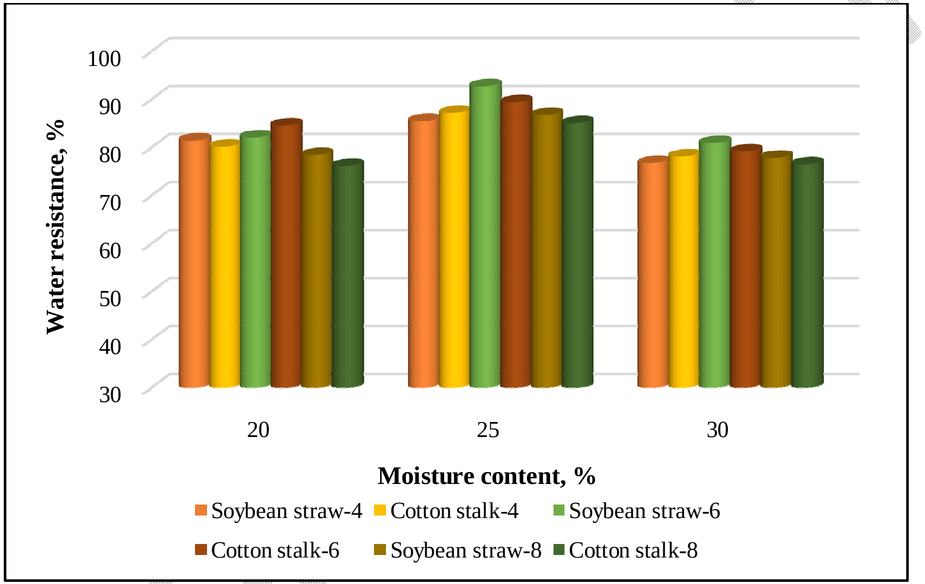

Fig. 5 Water resistance of fuel pellets at different process parameters

3.5 Energy consumption

During the pelletization process, the feedstock materials are typically densified into pellets, which require energy to compress and form the pellets. The particle size of the feedstock material can affect the densification energy consumption. The maximum energy consumption was observed as 14.14 kWh at a moisture content of 20% and particle size of 4 mm whereas the minimum was observed at 9.91 kWh at a moisture content of 25% and particle size of 8 mm for soybean straw. In the cotton stalk, water cotton stalk was found to a maximum at 13.27 kWh and minimum at 10.14 kWh as shown in Fig. 6. Generally, coarser particle size requires more densification energy compared to finer particle size, as larger particles may have less surface area for interparticle bonding, and thus may require more energy to achieve sufficient densification. The energy consumption during pelletization can vary depending on the type of feedstock material, pelletization equipment, process conditions (Styks et al., 2020).

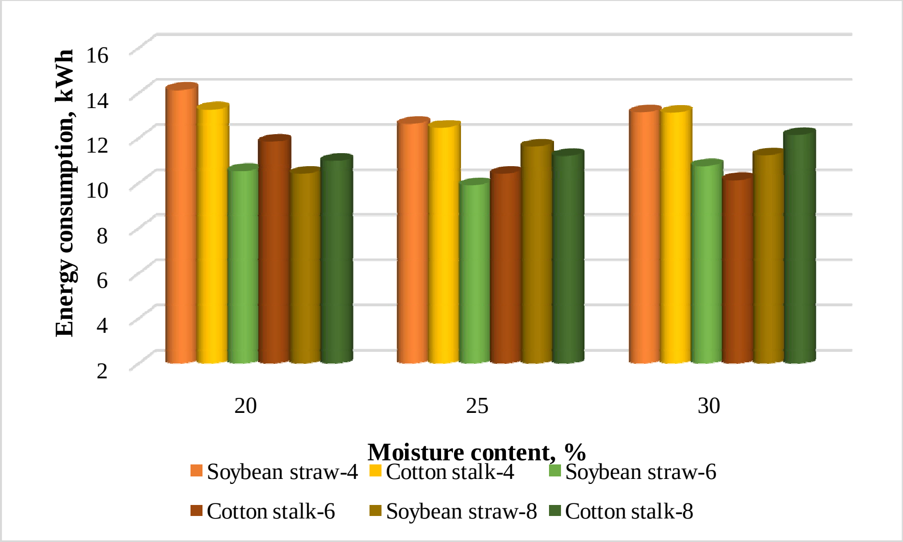

Fig. 6 Energy consumption of fuel pellets at different process parameters

4. Conclusion

The moisture content and particle size of materials used for fuel pellet production using flat die type pelleting machines are crucial factors that can significantly impact the characteristics of the resulting pellets. Optimal moisture content and particle size are critical for achieving high-quality fuel pellets with desirable properties, such as good pellet durability ranging from 576.84 kg/m^3 to 625.67 kg/m, pellet durability from 78.28 to 91.23%, water resistance from 79.17 to 92.72% and energy consumption 9.91 to 14.14 kWh. High moisture content can result in reduced pellet durability, increased energy consumption during pelleting, and decreased storage stability of pellets. On the other hand, low moisture content can lead to increased brittleness, reduced binding properties, and increased energy consumption during pelleting due to increased friction and decreased flowability. Particle size also plays a vital role, as smaller particle sizes can result in increased energy consumption, reduced flowability, and lower pellet durability, while larger particle sizes can result in improved flowability and lower energy consumption during pelleting.

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