Relationship between Raw Material Composition and Pellets Physical Properties

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Abstract. The mutual interaction between pellets quality, which is represented by the pellets physical properties, and the input composition of raw material is very interesting and complicated itself. Therefore, the main aim of this research paper is to determine the relationship between the raw material composition, which influences the pellets quality and the pellets quality indicators - physical properties of pellets. During the biomass densification, also the raw material properties significantly influence the final solid biofuels quality. Therefore the raw material composition represented by different mixtures from spruce sawdust, wheat straw and spruce bark, in various ratios (90/10, 80/20, 50/50, 80/10/10 and 50/30/20) and in various raw material composition (sawdust/straw, straw/bark, straw/sawdust/bark) were investigated. During this research study in total 14 different material composition was used. Effect of mentioned raw material mixtures on pellets bulk density, mechanical durability, abrasion, particle density and hardness were determined. Research findings presented in this paper are based on a realized experimental research that was done on Faculty of Mechanical Engineering STU in Bratislava. This experimental research was a logical result of and based on authors practical experience and wide theoretical analyses of selected variables influence. Described experimental research was realized by real pelleting machine that is a part of semi-production pelleting plant on Faculty of Mechanical Engineering STU in Bratislava. The experimental findings presented here are showing the importance of mentioned variables and parameters during the pelleting process.

1. Introduction

Mechanical treatment of biomass is necessary conditions before its final recovery. Densification process as a solid biofuels (pellets) production is included to the mechanical treatment and is a suitable option of biomass treatment to gain effective energy balance at energy recovery of biomass.

During the biomass pelleting, various technological variables and raw material parameters significantly affect the final solid biofuels (pellets) quality [1]. The quality of pellets is determined by the end user’s requirements on the heating system and the handling properties [2, 3]. In general, the pellets quality depends on the properties of the raw material (feedstock) – in terms of biomass type, moisture content and particle size; and quality management of the manufacturing process – in terms of operating conditions, technological variables, pelletizer type and binding agent [4, 5]. Many parameters effect the pelleting process and thus the quality of the final solid biofuels – pellets [5, 6]. The properties of the raw material, raw material treatment and composition as well as technological demands are very important during the solid biofuels production process [7, 8].
Among renewable resources, residual biomass is envisaged to play an important role in the new energy conception since agricultural and forest residues are a local energy resource with an important production throughout the world. With the development of solid biofuels market and biomass recovery technologies and with the gradual decrease of the quantities of usable wood biomass, increases the requirements for the processing of other types of biomass, e.g. agricultural - herbaceous biomass [5, 7]. Each different type of raw material requires a separate approach [6, 8]. As each type of raw material has its own specific properties and chemical composition, any small change in the properties of the raw material can influence the final quality of the pellets [6-8]. Different raw material properties produce different conditions during the densification process, and this causes the final quality of the pellets produced to be very different [2, 7]. This is the reason why it is so important to undertake experimental research to determine the relationship between raw material composition and pellets physical properties.

In general, solid biofuels production is very complicated process, because during solid biofuels manufacturing the technological and raw material variables influence the densification process and thus also the final solid biofuels quality (pellets). Quality of pellets is defined and given by EU standards [9], and is evaluated by physical-mechanical and thermo-chemical indicators [10]. In this study the pellets quality, as a final output of the pelletizing process, by its particle density, bulk density, mechanical durability, abrasion resistance and durability were evaluated. These physical-mechanical indicators of quality are evaluated from the storage, transport and dust emissions reasons [9, 10]. Low-quality pellets can cause operational problems during storage, in transport systems and in combustion systems, including undesired effects in the equipment, and may originate substantial amounts of and particulate matter (PM) emissions [2, 4, 8].

The main goal of presented experimental research is to determine the effect of raw material composition on pellets final quality. During this study, the spruce sawdust, wheat straw and spruce bark, as typical Slovakian biomass residues were used. The raw material composition represented by different mixtures from spruce sawdust, wheat straw and spruce bark, in various ratios (90/10, 80/20, 50/50, 80/10/10 and 50/30/20) and in various raw material composition (sawdust/straw, straw/bark, straw/sawdust/bark) were investigated. The experimental findings presented here are significant from pellets production point of view to make a solutions with regarding the economic aspects [5, 11].

2. Materials and Methods

2.1. Raw material properties
Spruce sawdust, wheat straw and spruce bark originating from Southwestern Slovakia were chosen for this experiment. Suitable spruce sawdust and spruce bark were obtained from wood processing company. Wheat straw was obtained from local agricultural company. Initially, Retsch Vibrating Sieve Equipment AS 200, according to the EN ISO 17827-1, for analyzing of the particle size distribution was used [12]. The raw material particle size distribution was determined, proportions by weight see in the Table 1.

| Particle size (mm) | Spruce sawdust | Wheat straw | Spruce bark |
|-------------------|----------------|-------------|-------------|
| 0 – 0.5           | 26.72          | 15.53       | 25.71       |
| 0.5 – 1.0         | 27.45          | 6.81        | 14.05       |
| 1.0 – 2.0         | 36.88          | 77.08       | 52.34       |
| 2.0 – 4.0         | 6.71           | 0.48        | 7.50        |
| 4.0 <             | 1.91           | 0.11        | 0.09        |
Moisture content of spruce sawdust, spruce bark and wheat straw before pelletizing was measured with the aid of a Kern MRS 120-3 balance. This measurement consisted in heating the raw sawdust (gravimetric method of moisture content measuring) [13] at 105 ± 2°C until a constant weight was achieved. Bulk density of spruce sawdust, spruce bark and wheat straw before pelletizing was determined according to the EN ISO 17828 [14]. This European Standard describes the determination of the bulk density of solid biofuels using a standardized measuring vessel. This method is applicable to all solid biofuels with an upper nominal size of 100 mm. Properties of raw materials before mixing and pelleting can be seen in the following Table 2.

**Table 2** Properties of raw materials before mixing and pelleting.

| Properties of raw material | Spruce sawdust | Wheat straw | Spruce bark |
|----------------------------|----------------|-------------|-------------|
| Bulk density (kg.dm⁻³)     | 118.7          | 74.76       | 261.7       |
| Moisture content (%)       | 9.8            | 7.49        | 12.5        |

2.2. **Mixtures material composition**
Main goal of this research was to determine the relationship between the raw material composition, which influences the pellets quality and the physical properties of pellets. The raw materials composition represented by 12 basic raw material mixtures were investigated and with 100% raw material of spruce sawdust and wheat straw were compared. Selected mixtures of raw material composition with its description can be seen in the Table 3.

**Table 3** Mixtures material composition.

| Sample number | Sample label | Description – material composition                             |
|---------------|--------------|----------------------------------------------------------------|
| 1             | 100W         | 100 % of spruce sawdust                                         |
| 2             | 95W/5S       | 95 % of spruce sawdust + 5 % of wheat straw                      |
| 3             | 90W/10S      | 90 % of spruce sawdust + 10 % of wheat straw                    |
| 4             | 80W/20S      | 80 % of spruce sawdust + 20 % of wheat straw                    |
| 5             | 20W/80S      | 20 % of spruce sawdust + 80 % of wheat straw                    |
| 6             | 50W/50S      | 50 % of spruce sawdust + 50 % of wheat straw                    |
| 7             | 100S         | 100 % of wheat straw                                            |
| 8             | 95W/5B       | 95 % of spruce sawdust + 5 % of spruce bark                      |
| 9             | 90W/10B      | 90 % of spruce sawdust + 10 % of spruce bark                    |
| 10            | 80W/20B      | 80 % of spruce sawdust + 20 % of spruce bark                    |
| 11            | 80S/20B      | 80 % of wheat straw + 20 % of spruce bark                       |
| 12            | 50S/50B      | 50 % of wheat straw + 50 % of spruce bark                       |
| 13            | 80S/10B/10W  | 80 % of wheat straw + 10 % of spruce bark + 10 % of spruce sawdust|
| 14            | 50S/30B/20W  | 50 % of wheat straw + 30 % of spruce bark + 20 % of spruce sawdust|
2.3. Pellets production
For the pellets production a vertical pelleting machine KAHL 33-390 with flat round matrix was used. During the pelleting process, a matrix with ø 6 mm holes was used. The constant operating parameters for the pelleting press were the pressing pressure (12 MPa), the pressing temperature (100 °C) and the circumferential speed of rolls (2.2 m.s⁻¹). Semi-operational tests for pelleting of mixtures were carried out without technical and technological complications. The pelleting process was continuous. On following figures, you can see the produced samples of pellets from selected raw material composition.

![Pellets samples](image)

**Figure 1.** Samples of pellets from different material composition.

2.4. Pellets evaluation
Subsequently, pellets were subjected to laboratory testing and the determination of physical properties according to the EN technical standards [15]. Effect of mentioned raw material mixtures on pellets bulk density, mechanical durability, abrasion, particle density and hardness was determined. Pellets bulk
density according to EN ISO 17828 [10], pellets mechanical durability according to EN ISO 17831-1 [16], particle density according to EN ISO 18847 [17], pellets abrasion according to DIN Standard [18] were determined. However, pellets hardness determination procedure is not supported by any Standard, the pellets hardness typically relates to the final pellets quality [19] and in this contribution was determined by specialized KAHL apparatus.

All results in this paper, showing the dependencies between lonely pellets physical quality indicators and input material mixtures, were depicted graphically, as seen in the figures below. Each of these displayed values is the average value from at least six measurements. It means at least six times each value was determined and measured. This value of repeatability was chosen according to requirements of standard mathematical and statistical methods for experiment evaluation.

3. Results and Discussion
The comparison of pellets particle densities can be seen in Figure 2. Wood/straw (samples 1-6) pellets particle density increases with increasing of straw amount in mixture. This was caused by straw better compressibility [20, 21] and material particles interconnection [22, 23]. Wood/bark pellets (samples 8-10) particle density decreases with increasing of bark amount in mixture, despite in straw/bark pellets (samples 11-12) the particle density increases with increasing of bark amount in mixture. Due to the properties and chemical composition of the bark [24, 25]. A similar trend was noted also at the comparison of pellets bulk densities, see Figure 3.

![Figure 2. Comparison of particle density of pellets.](image2)

![Figure 3. Comparison of bulk density of pellets.](image3)
The comparison of pellets mechanical durability can be seen in Figure 4. Wood/straw (samples 1-6) pellets mechanical durability decreases with increasing of straw amount in mixture, respectively with increasing of bark amount in mixture (samples 8-10). Vice-versa, straw/bark (samples 11-12) pellets mechanical durability increases with increasing of bark amount in mixture. Logically, wood/straw (samples 1-6) pellets abrasion resistance decreases with increasing of straw amount in mixture, respectively with increasing of bark amount in mixture (samples 8-10). Due to the structure and properties of the straw [24, 26]. A similar trend was noted also at straw/bark (samples 11-12) pellets where the pellets abrasion resistance decreases with increasing of bark amount in mixture. Comparison of pellets abrasion resistance is displayed on Figure 5.

![Figure 4. Comparison of mechanical durability of pellets.](image)

![Figure 5. Comparison of abrasion of pellets.](image)

Pellets hardness means pellets resistance to split by external force [11] and the strength of pellets in the direction perpendicular to the pellet axis is determined through the acting force value. Then the value of force that caused the pellets splitting is comparative criterion [21, 26].

The comparison of pellets hardness can be seen in Figure 6. Wood/straw (samples 1-6) pellets hardness very gently decreases with increasing of straw amount in mixture, respectively with increasing of bark amount in mixture (samples 8-10). Hardness determination showed that pellets with bark additions were more resistible against the splitting than pellets with straw additions. This was caused in
order to better empty space filling by bark between raw material particles [21, 23] and thus better particles interconnection [5, 26].

![Pellets hardness comparison](image)

**Figure 6.** Comparison of hardness of pellets.

**Conclusion**

The main conclusions that can be withdrawn from this study are as follows:
- all pellets studied fulfilled the physical and mechanical requirements for non-industrial pellets [15],
- raw material composition affected the pellets physical properties,
- increasing of straw amount in wood pellets positively influences the pellets particle density and pellets bulk density,
- increasing of straw amount in wood pellets negatively influences the pellets mechanical durability, pellets abrasion and pellets hardness,
- increasing of bark amount in wood pellets negatively influences the physical properties of pellets,
- increasing of bark amount in straw pellets positively influences the physical properties of pellets,
- both, the wheat straw and spruce bark can be effectively used for mixture pellets production in order to reduce the amount of clear spruce sawdust.

**Acknowledgments**

The paper is a part of the research done with in the project VEGA 1/0420/16 – “Determination and research of parameters influence on final briquettes quality at waste biomass densification” and the project KEGA 061STU-4/2017 – “Increasing the level of the educational process in the field of production and environmental technologies by implementing of innovative tools”. The authors would like to thank to the Ministry of Education of Slovak Republic and to the Slovak Academy of Sciences.

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