Investigation of Wood Sawdust Effect on Production and Final Quality of Composite Pellets Based on Sunflower Husks

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Abstract. The pressure to diversify the raw material base of solid biofuels is steadily rising worldwide. The waste from agricultural production and its post-processing represents a huge but still little used energy potential. The use of such plant waste brings many technical problems. The paper is focused on research of increasing physical, mechanical and thermal quality indicators of composite pellets based on a mixture of sunflower husks and spruce sawdust. Tested mixtures varied by increasing the weight proportion of wood sawdust from 0% up to 40% in sunflower husks. The quality of this fuel pellets was evaluated using standardized parameters - particular density, bulk density, pellet moisture, mechanical durability, pellet hardness, calorific value, ash content etc.. Realized experiments have shown that it is not only possible to successfully transform this homogenized mixture into fuel pellets (pure sunflower husks represent a considerable problem with densification regard to their composition), but the qualitative parameters of the fuel also increase by increasing the weight proportion of wood in sunflower husks. The research results showed that the optimum ratio of wood component in the composite fuel is 30% based on the resulting mechanical quality parameters and economy of its production.

1. Introduction

Each type of densified material has its own specific properties. Processed materials differ in their structure and composition, what influences all the thermal and mechanical parameters of their densification process. The source of raw materials for the production of solid biofuels is mostly used soft and hard wood, bark, energy crops (e.g. fast-growing tree species) and phytomass. [1]

The field of phytomass densification for energy purposes is still not very well developed. Phytomass is used more often as raw material for gasification. The reason is the different chemical composition of the phytomass, which creates certain restrictions in combustion compared to wood. At present, the production of solid biofuels from phytomass used agricultural waste as a raw material, but also whole crops of cereals (straw together with grain). Phytomass has a much higher ash content compared to wood [2, 3]. Also, the concentration of nitrogen, sulphur and chlorine must be carefully monitored because they cause serious problems for combustion plants [1, 4]. Another critical aspect of the use of phytomass as a raw material for the production of solid biofuels is its low ash melting point [2, 5, 6] and increased fly ash and aerosol emissions [5, 7]. For these reasons, it is not appropriate to use such biofuels for small combustion systems. Mixing phytomass with woody raw material to produce solid biofuels with appropriate qualitative properties appears to be a solution. Suitable mixtures of these materials may reduce or even eliminate the above mentioned problems [8]. Another solution may be the addition of additives such as aluminium hydroxide, kaolin, calcium oxide or limestone. The result is an
increase in the ash melting point and reduction of slag formation. At the same time, these additives also lead to an increase in mechanical quality indicators. Nevertheless, mixed biofuel from phytomass and dendromass are more widely used for large combustion plants. [2, 9, 10, 11, 12, 13, 14]

However, the phytomass has its advantages from the point of view of producing solid biofuels. High availability and low cost is its economic advantage. The results of scientific studies show that the densification process of phytomass needed significantly lower compacting pressures than dendromass to achieve the same pressings density. At the same time, it is possible to reduce the energy costs of drying the raw material, provided that the conditions of its collection and storage are kept in a dry state.

2. Materials and methods

2.1 Materials
The experiment is focused on the research of properties of composite pellets made from different ratios of the mixture of phytomass - sunflower husks (just a straw wrapper, not seed expeller) and dendromass – spruce sawdust (Figure 1). The problem of using pure sunflower husks as a biofuel in the form of pellets intended for automated combustion systems is a low content of binders (lignin etc.) what causes very low mechanical properties of the pellets with a high proportion of dust particles. The aim of the research is to define the effect of added spruce sawdust on the physical and mechanical quality parameters of the resulting composite pellets. The quality parameters of solid high-grade biofuels, which dependent on the ratio of raw materials has been investigated, are the particle density, bulk density, moisture content, mechanical durability and hardness.

![Figure 1. Raw materials – sunflower husks and spruce sawdust.](image)

The experiment comprises five proportions by weight of the mixtures listed in Table 1. It was produced 50 kg of pellets from each mixture for experimental purposes.

| Mixture | Proportion by weight (%) | Moisture content of pelleting mixture (%) |
|---------|-------------------------|-----------------------------------------|
|         | Sunflower husks | Spruce sawdust |                           |
| 1       | 100               | 0             | 8.96                      |
| 2       | 90                | 10            | 8.90                      |
| 3       | 80                | 20            | 8.80                      |
| 4       | 70                | 30            | 8.78                      |
| 5       | 60                | 40            | 8.73                      |
Table 2  Particle size distribution of sunflower husks and spruce sawdust

| Particle size (mm) | Proportion by weight (%) | Sunflower husks | Spruce sawdust |
|-------------------|--------------------------|-----------------|----------------|
| ≥ 4.00            | 21.04                    | 2.56            |
| 2.00 - < 4.00     | 14.92                    | 12.69           |
| 1.00 - < 2.00     | 37.53                    | 35.92           |
| 0.50 - < 1.00     | 18.89                    | 26.06           |
| < 0.50            | 7.62                     | 22.77           |

The preparation of the material consists in accurately weighing the ratios of the individual components of the mixtures and their significant homogenization. Since the fractional composition of both raw materials (Table 2) as well as their relative humidity (Table 1) are suitable for the used pelleting technology, the material was not required to be modified.

2.2 Densification process
Pellets were produced by an industrial scale process, by the Amandus KHAL 33-390 pelleting press. Pellets (diameter 6 mm) of each mixture sample were produced under the same conditions (pressing temperature, pressure, moisture, etc.). It must be mentioned that value of pressing temperature (measured on pelleting die) for each sample did not differ significantly, the value fluctuated 95±2 °C. It was caused by the same friction in pressing chambers which was controlled by pressure and moisture for each sample. Once the pelleting process had reached a stable state, a sample of 50 kg of each pellet mixture was used for testing (Figure 2).

2.3 Particle density
Generally, the particle density of pellets influences their combustion behaviour. Fuels with a higher particle density have a longer burnout time. [2]

The length, diameter and weight of pellets were measured using a digital calliper and an electronic balance. The particle density of the pellets was calculated by means of the ratio between pellet weight and its volume including pore volume. The volume of pellets was calculated as the volume of a cylinder with dimensions (length and diameter) measured as previously described, according to ISO 17829. The average particle density was calculated for each sample of 50 pellets at two stages – immediately after pelleting and 2 days after pelleting.

Figure 2. Samples of pellets from 5 mixtures of sunflower husks and spruce sawdust.
2.4 Bulk density
The bulk density is dependent on the particle density and the pore volume [2]. The higher the bulk density the higher is their energy density, and the lesser are the transport and storage costs. The bulk density of each sample of pellets was determined according to ISO 17828. The average value of bulk density for each sample was calculated from 10 measurements.

2.5 The pellet hardness
The hardness of pellets is not a biofuel qualitative parameter defined by ISO 17 225. Its importance is very similar to mechanical durability, but this test was carried out to compare the effect of papermaking sludge on mechanical properties of pellets and its positive ability to bind. [2]

The determination of pellet hardness is based on the comparative method, in which the tested pellet sample is placed between two spikes of the Hardness Tester Amandus KAHL and the maximum value of the resistance (hardness) of the pellet to the pressure is measured. The values of the pellet hardness are expressed in Newtons. The average value for each sample was calculated from 20 measurements.

2.6 Mechanical durability
When the mechanical durability of fuel pellets is low, a large amount of fines can cause bridging in the storage facility, blocking of the feeding screw, it can stop the fuel supply, increase particular matter emissions from combustion, as well as dust emissions during manipulation. Consequently, it can cause an explosion due to the dust. Therefore, the mechanical durability of pellets is one of the most important mechanical parameters of the fuel. [2]

Mechanical durability of each sample of pellets was determined according to ISO 17831. Measurements were performed by the Tumbler tester 1000 device, where the samples of tested pellets were subjected to controlled impacts of the mutual bombarding of the pellets and the pellets hitting the walls in the defined test chamber during a defined time period of 10 minutes. The mechanical durability of the pellets was calculated from the weight of the sample before insertion into the test chamber and the weight of the same sample after the impacts (the fines were separated).

2.7 Moisture content
The final moisture content of pellets is relevant to the net calorific value, the efficiency of the furnace and the combustion temperature [2]. The moisture content of the pellets was measured in 2 days after pelletizing. The determination of the moisture content was based on heating the pellets to 105±2°C until a constant weight was achieved according to the standard procedure described in ISO 18134-3.

3. Results and discussion
The physical and mechanical properties of the pellets significantly affect the quality of the fuel itself. These properties impact on the stability, dustiness and the space requirement during transport, handling and storage, and on the energy density of the fuel. The procedures for quantification of the individual parameters defined by standards were used to evaluate the quality of composite fuel.

3.1. Effect of wood content on particle density of composite pellets
Based on the research results, the particle density of pellets has an increasing tendency depending on the weight proportion of the spruce sawdust in pellets produced under the same technical and technological conditions. This fact is based on the higher density of the wood sawdust in comparison with sunflower husks. The results are shown in the Figure 3. The most significant increase can be found at mixture 2 in comparison with mixture 1. It is caused by absent of binder in pure sunflower husks, and after adding the wood containing lignin, the pellets become more compact.

Assubsequent experiments proved, the increase in pellet density has a direct effect on their mechanical durability and hardness. The higher density also favorably influences the shape and volume stability of the pellets.
Densification of the biomass causes the expansion of the pressings, therefore a certain period of stabilization after compacting has to be considered. It is possible to encounter two types of dilation for various materials and pressing conditions, namely dilation with decreasing or increasing in the pressing density. In the experiments, the dilation was observed as a decrease in the pellets density at each mixtures. The results can be seen in the Figure 3. The maximum percentage change in pellet density after stabilization is only 0.5%, which means that the pellets are stable and the dilation has only a slight effect on the change in density. Densification of the biomass causes the expansion of the pressings, therefore a certain period of stabilization after compacting has to be considered. It is possible to encounter two types of dilation for various materials and pressing conditions, namely dilation with decreasing or increasing in the pressing density. In the experiments, the dilation was observed as a decrease in the pellets density at each mixtures. The results can be seen in the Figure 3. The maximum percentage change in pellet density after stabilization is only 0.5%, which means that the pellets are stable and the dilation has only a slight effect on the change in density.

Figure 3. Variation of particle density and change in density of pellets with weight proportion of wood content in pellets.

Figure 4. Variation of bulk density with weight proportion of wood content in pellets.

3.2. Effects of wood content on bulk density of pellets

Measurement results of bulk density are shown in the Figure 4. Experiments have shown that the bulk density of the pellets is increased by the addition of wood sawdust to sunflower husks. It can be seen from the results that the increase in the proportion of the wood component in the composite fuel over 30% by weight ratio is not significant. This is caused by increasing the length of the pellets in increasing the wood content. Therefore the pore volume in bulk fuel increases and the bulk density decreases, even despite the higher particle density. At this value of the wood content in the mixture 4, the bulk density of the pellets increased by 13% compared to the mixture 1. In view of the raw material costs it is economically advantageous to minimize the proportion of wood fuel component.

3.3. Effects of wood content on mechanical durability and hardness of pellets

Based on the experiment, it has been unequivocally demonstrated that increasing the proportion of wood sawdust in composite pellets significantly increases the value of mechanical durability. This is due to the effect of lignin as a bonding agent containing in sawdust. This significant increase can be observed till mixture 4 with wood content of 30% (Figure 5). The values of mechanical durability do not change significantly with a higher wood proportion (40%). The mechanical durability of pellets produced purely from sunflower husks has a value of 66.88%, so after the test there is a lot of dust. This leads to potential technical and security problems. However, the proportion of dust particles was significantly reduced by the addition of the wood component, thereby achieving the applicability and use of the energy potential of sunflower husks as raw material. The experiment results show the optimal proportion of wood 30% (mixture 4), when the mechanical durability of the pellets reaches 81.5%.
As Figure 5 shows, increasing the wood proportion in pellets causes a significant increase in their hardness. Information on the hardness of pellets is not subject to any standards, which is indicated by the size of the radial force that the pellet can resist. The force at which the pellet breaks down is the value of the highest hardness of the pellets. As expected, the highest hardness is achieved by the pellets of mixture 5 (wood content 40%) with an increase of 25% compared to the mixture 1.

Figure 5. Variation of hardness and mechanical durability with weight proportion of wood in pellets.

3.4. Effects of the change in moisture content

The initial moisture content of the prepared samples of the mixture was measured right before the entrance into the chamber of the pelleting press. The moisture content of pellets was measured 48 hours after the densification. The final pellets were stored at a room temperature 20°C, and with a stable relative humidity of 55% in the laboratory.

Figure 6 shows the values of the optimum moisture content of each mixture of raw material entering the press chamber of the pelleting press and the moisture content of the pellets after stabilization (48 hours). The graph shows that the increase in the proportion of wood causes a slight reduction of the optimum moisture content of the pellet feedstock and thus the finished pellets. The distribution of optimal moisture values of pelleted mixtures was very small, moisture values varied from 8.96% to 8.73%. The moisture values of the pellets of each mixture after stabilization are also very similar (from 7.64% to 7.91%). The average decrease in moisture content during the pelleting process was only about 1.1%.

Moisture content is one of the quality properties limited by biofuel standards. According to ISO 17225, biofuel pellets have to contain a moisture content lower than 10%. All samples of tested pellets had a moisture content lower than 10% what means that composite fuels meet the standard limits. One more interesting conclusion can be drawn from the results of the minimum differences in moisture content of composite pellets. After performing the measurements it was found that the gross calorific value (GCV) of the sunflower husks and spruce sawdust has a very similar values (GCV of sunflower husks was 20.34 MJ.kg\(^{-1}\); GCV of spruce sawdust was 20.21 MJ.kg\(^{-1}\)). On the basis of these findings, it was not worth exploring in more detail experimentally the effect of increasing the content of the wood component in pellets to the resulting net calorific value (NCV) of this composite fuel. Differences in the net calorific value are minimal, in the order of only 0.01 MJ.kg\(^{-1}\).

4. Conclusion

The results of the experiments clearly demonstrated that by increasing the weight of spruce sawdust added to the matrix of sunflower husks, the individual qualitative parameters of this biofuel also increase significantly. From the measured values, it can be stated that the optimal weight ratio of sunflower husks and wood sawdust is 70:30 (mixture 4). Further increase in the proportion of wood component does not significantly increase bulk density and mechanical durability. The values of moisture content and particle density are comparable for all composite mixtures. Only pure sunflower husks achieved
different (lower) values of particular density. The hardness of the pellets was significantly increased by adding 30% by weight of the wood component. The results show that an increasing proportion of wood will continue to increase qualitative parameters of the biofuel, however, account must be taken to minimize the proportion of wood because the woody raw material is considerably more expensive than the raw material from the phytomass which otherwise would not be used its energy potential.

To improve the quality of this solid composite biofuel, it would also be desirable to change the compression conditions of the pressing channels in pelleting die to increase the pressing force. The application of these measures presupposes a positive increase of the individual indicators of the quality of solid composite fuel, which may be the subject of follow-up research.

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