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Influence of raw material properties on the quality of solid biofuel and energy consumption in briquetting process

A. Muntean[1], T. Ivanova[1,*], P. Hutla[2] and B. Havrland[1]

[1]Czech University of Life Sciences, Faculty of Tropical AgriSciences, Department of Sustainable Technologies, Kamýcká 129, CZ 16500 Prague, Czech Republic
[2]Research Institute of Agricultural Engineering, Drnovská 507, CZ 16101 Prague, Czech Republic
[*]Correspondence: ivanova@ftz.czu.cz

Abstract. The present paper is related to a pressing process research of raw materials with different density in order to investigate impact of biomass density on a formation of monolithic structure and the briquette's strength. Another focus of the study is an influence of raw materials particles' size on agglomeration process and quality of final product. Different biomass materials like two varieties of miscanthus, industrial hemp and apple wood were selected for experimental purposes of this research. Mechanical durability which represents one the main indicator of briquettes' mechanical quality (strength) was determined. The research was conducted using hydraulic piston briquetting press. For assessment of briquetting efficiency during the whole process energy consumption was measured. One of the most important factors that can affect briquetting process is the temperature of pressing chamber which was registered as well. The main goal of the research was practical study of possibilities for increasing production efficiency and quality of briquettes on hydraulic piston briquetting press with respect to optimization of particles' size of raw materials and use of raw materials the most appropriate density.

Key words: briquettes, bulk density, densification process, initial fraction, mechanical durability, piston press.

INTRODUCTION

In comparison with liquid and gaseous biofuels, today, densified solid biofuel in the form of briquettes gained wider application. This has happened primarily due to the fact that above mentioned type of biofuel is easier to produce and also thanks to an attractive price (Havrland et al., 2011). Solid biofuels market is developing rapidly year by year. The growing trend of solid biofuels' consumption will continue to increase, and not only in EU countries but also around the world. Nowadays, because of large quantities production of briquettes a number of problems associated with their quality and high energy consumption of the production process have been identified (Ivanova et al., 2013). The reason is a lack of sufficient information about an impact of raw material properties on the quality of solid biofuels (briquettes) as well as on energy consumption.

There are different factors that can have direct impact on the quality of final product. For example, quality can be influenced by moisture content of used raw material

(Guo et al., 2016). In some studies it was found that the working pressure of briquetting equipment affects formation of the bonds between particles of a material and as a result it has influence on the density of briquettes (Ndiema et al., 2002; Križan et al., 2014).

Temperature in a certain extent represents an important factor in the process of forming the dense structure from biomass material during pressing (Rynkiewicz et al., 2013; Križan et al., 2014).

Fraction size of feedstock material can be also considered as an important factor with influence on the durability of densified solid biofuel (Kaliyan & Morey, 2009).

Possibly, the most suitable and reliable way, which might significantly affect quality of briquettes and reduce energy consumption within briquettes' production is an optimization of fraction size of used raw material and utilization of raw materials with optimal density for a certain briquetting technology.

An important aim of the research was to investigate influence of raw materials fraction size and bulk density as well as temperature within briquetting process on the quality of briquettes with a special attention to the energy consumption of the process.

MATERIALS AND METHODS

Application of raw materials with different density for production of solid biofuel can have influence not only on the costs for transportation and storage but also on the quality of a final product. For research purposes were used raw biomass materials with different densities, i.e. low, medium and high density, such as:

– Industrial hemp (*Cannabis sativa* L.) – fibrous material with low density;
– Two varieties of miscanthus (*Miscanthus x giganteus* and *Miscanthus sinensis*) – herbaceous materials with medium density;
– Apple (wood) branches obtained after pruning – marital with high density.

Determination of bulk density of selected raw materials was performed in accordance with International standard EN ISO 17828 (using measuring container with stated volume) and calculated by following Eq. (1):

$$BD_{ar} = \frac{(m_2 - m_1)}{V}, \text{ kg m}^{-3} \quad (1)$$

where m_1 – mass of the empty container, kg; m_2 – mass of the filled container, kg; V – net volume of the measuring container, m^3.

The final result of bulk density for each type of tested material was calculated as the mean value of the duplicate determinations (performed within a short period of time, but not simultaneously), and with repeatability precision equal to a maximum 3.0%.

One of the most important parameter of raw material that can have influence on the briquetting process and the quality of solid biofuel is moisture content. Determination of moisture content was done in accordance with standard EN ISO 18134–3 (oven drying method under the temperature of 105 °C performed on general analysis test samples prepared by EN 14780:2011) using drying oven Memmert UFE 500 and determined by Eq. (2):

$$W = \frac{(m_2 - m_3)}{(m_2 - m_1)} \cdot 100, \% \quad (2)$$

where m_1 – the mass of the empty dish plus lid, g; m_2 – the mass of the dish with lid plus sample before drying, g; m_3 – the mass of the dish with lid plus sample after drying, g.

The resulting moisture content was found as the mean of duplicate determinations with respect to repeatability precision, i.e. difference between two individual results of each material was not more than 0.2% absolute.

All raw materials used for briquetting was grinded by the hammer mill SV 15 in three different fractions: 12 mm, 8 mm and 4 mm. Grinding of raw materials into fractions was performed in order to study influence of material's rheology and impact of various fractions' size on the agglomeration process. The briquetting itself was conducted using hydraulic piston briquetting press Briklis HLS 50.

During the briquetting process the temperature was measured by digital thermometer THERM 2246 in three different points (inside the pressing chamber, temperature of die and temperature of briquette). And energy consumption of briquettes' production process was determined through measuring the electric energy by electricity meter.

The main indicator of briquettes quality (strength) is mechanical durability, which was determined according to standard EN ISO 17831–2:2015 with respect to EN ISO 16559:2014, by using rotation drum and calculated as (3):

$$DU = \frac{m_A}{m_E} \cdot 100, \% \quad (3)$$

where m_A – the mass of sieved briquettes after the drum treatment, g; m_E – the mass of pre-sieved briquettes before the drum treatment, g.

Mechanical durability for each type of briquettes obtained from the studied materials grinded into different fractions was reported as the mean value from the results of the five replications.

RESULTS AND DISCUSSION

Fig. 1 below presents the values of bulk densities of four studied materials and different fractions.

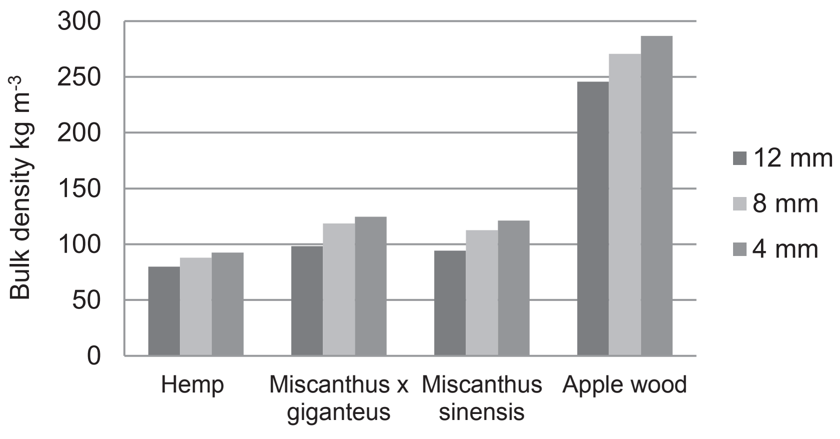

Figure 1. Bulk density of selected raw materials grinded into three different fractions.

As it is visible from the Fig. 1, the study has found that the raw material with the lowest bulk density is hemp, which shows the minimum density 79.9 kg m^{-3} for fraction 12 mm and maximum density 92.7 kg m^{-3} for fraction 4 mm. Material crushing to smaller fraction can increase the bulk density but in the same time will need more expenses for more steps of crushing (Guo et al., 2016). The highest bulk density from the studied materials has apple wood with a minimum density 245.7 kg m^{-3} for fraction 12 mm and maximum 286.8 kg m^{-3} for fraction 4 mm.

Raw materials with low bulk density applied for production of solid biofuels require more expenses for processing in comparison with raw materials with high bulk density (Havrland et al., 2011). Grinding and densification can significantly decrease volume and as a result costs for storage, transport and utilization of biomass (Guo et al., 2016). It must be also mentioned that initial bulk density of feedstock has influence on the density of final product, i.e. briquettes.

According to Havrland et al. (2011) moisture content can have significant effect on solid biofuel's proprieties, for example high moisture content of produced briquettes will decrease the calorific value, as well as high moisture content may negatively impact on densification process and briquettes storage. Moisture content of studied biomass materials is presented in Fig. 2.

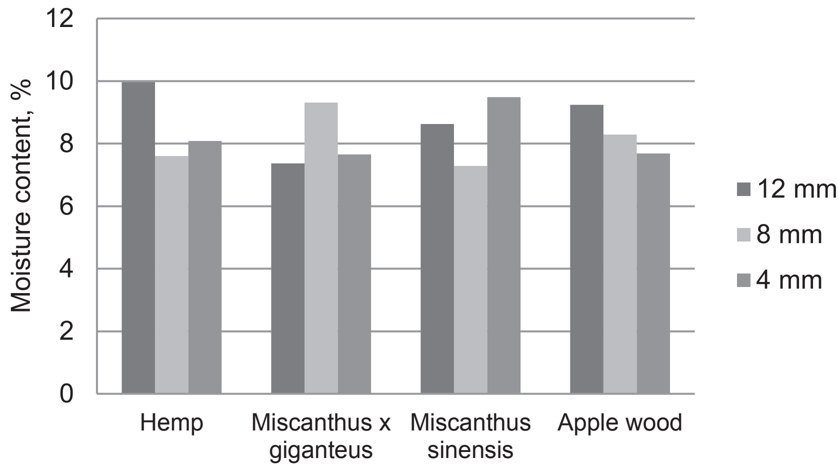

Figure 2. Moisture content of researched raw materials.

The results showed that the moisture content of raw materials used for briquetting purposes was varying between the lowest one 7.29% for *Miscanthus sinensis* with fraction 8 mm and the highest one 9.97% for hemp with fraction 4 mm (see Fig. 2). These values of moisture content are suitable for biomass briquetting (usual moisture content recommended by the producers must be not more than 12–14%, it depends on the applied briquetting technology (Havrland et al., 2011)). Moderate amount of moisture in a feedstock can positively affect the binding mechanism of biomass particles (Kaliyan & Morey, 2009). All raw materials used in the research were dried under natural conditions. Additionally, according to EN ISO 17225–3:2014 and EN ISO 17225–7:2014 in correspondence with EN ISO 17225–1:2014 moisture content of wood briquettes as well as non-woody briquettes should be 12% for A class and ≤ 15% for B class briquettes.

The briquettes of poor mechanical quality are characterised by high crumbling and that contributes to the losses during handling and transportation (Ivanova et al., 2014). The results of the main parameter of mechanical quality (mechanical durability) of obtained briquettes are illustrated in Fig. 3.

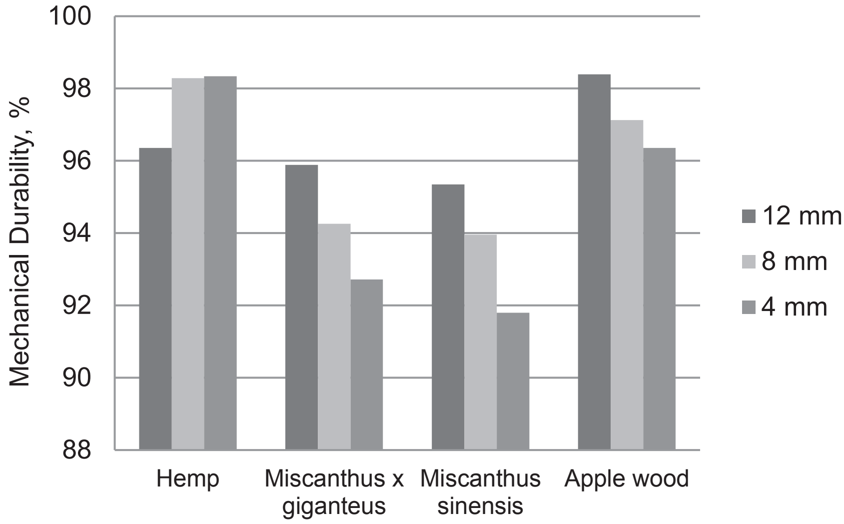

Figure 3. Mechanical durability of produced briquettes.

Based on the mechanical durability test results it was found that the briquettes obtained from hemp and apple tree wood represent the briquettes with the highest strength. The briquettes produced from *Miscanthus x giganteus* and *Miscanthus sinensis* showed lower mechanical durability. Relatively low mechanical durability of Miscanthus was also shown in another scientific works (Ivanova et al., 2014). However, as it may be seen from the Fig. 3 all the obtained briquettes had mechanical durability higher than 91%. In most cases, briquettes made from raw material with the largest fraction of 12 mm proved to be much durable than the briquettes obtained from a biomass crushed into a smallest fraction. But not in the case of hemp, which have showed an opposite trend. Different agglomeration mechanism and high strength of briquettes made of hemp can be probably explained by fibrous structure of this biomass material.

Energy consumption in the process of biomass densification is an important factor which can have an influence on the price of a final product. Today, many studies are performed in the field of briquetting in order not only to improve the quality of the final product, but also for reducing the energy consumption of the process (Kaliyan & Morey, 2009). Specific energy consumption for production of briquettes from different feedstock and fraction size is presented in Fig. 4.

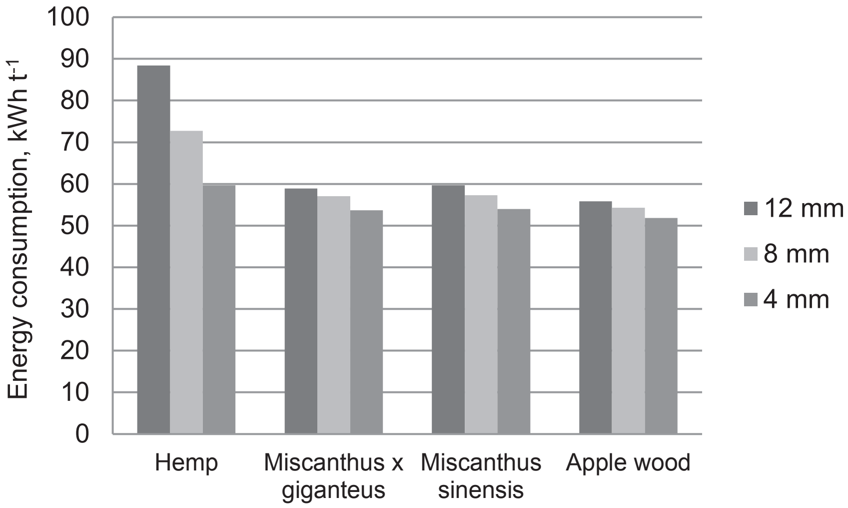

Figure 4. Energy consumption for production of 1 t of briquettes from each type of material.

Assessment of specific energy consumption has showed that pressing of all raw materials with a fraction size of 12 mm requires more energy in comparison with energy consumption for the factions 8 mm and 4 mm. Various scientific studies, for example Guo et al. (2016) proved that this may be related to lower density of the feedstock. Another factor that can hinder the effective pressing process is the effect of relaxation of the pressed material (Ndiema et al., 2002).

By some research results of densification process, specifically Kaliyan & Morey (2009) and Križan et al. (2014) it was found that the temperature produced in the briquetting process can have impact on the quality of solid biofuel. For analyzing the influence of temperature on the quality of the briquettes' formation during the briquetting process the temperatures of the pressing chamber, die and briquettes were measured. Only maximum achieved values of temperatures were registered. The research results are presented in the Table 1 below.

According to Havrland et al. (2011) increasing of the temperature values in the briquetting process happens due to the friction which appears in the process of biomass movement through the channel of the die. In the present research the highest registered temperature was 59 °C. This temperature was achieved during the briquetting of apple tree wood. This is probably related to the high density of wooden material and as a result appearance of higher friction force between densified biomass and the wall of the die.

Another important parameter of briquetting process is a working pressure developed by briquetting press. It must be mentioned that with an increasing pressing pressure increases not only density of solid biofuel (Wrobel et al., 2013; Zvicevicius et al., 2013), but also energy consumption (Havrland et al., 2011). The working pressure of hydraulic briquetting press used in the research is low (12 MPa) in comparison with another types of presses that can develop pressing pressure of 130 MPa.

Table 1. The measured temperatures in the process of biomass densification

Type of raw material	Temperature of pressing chamber, °C	Temperature of die, °C	Temperature of briquette, °C
Hemp with fractional size:			
-12 mm	29.3	44.1	31.1
-8 mm	31.9	46.6	36.5
-4 mm	34.5	51.0	40.0
Miscanthus x giganteus with fractional size:			
-12 mm	30.3	48.4	38.0
-8 mm	32.4	50.0	39.6
-4 mm	33.8	51.9	42.7
Miscanthus sinensis with fractional size:			
-12 mm	31.0	50.2	39.1
-8 mm	33.9	51.9	41.0
-4 mm	34.9	52.0	41.8
Apple wood with fractional size:			
-12 mm	30.4	54.7	41.2
-8 mm	33.7	57.7	46.2
-4 mm	39.7	59.0	47.6

CONCLUSIONS

Densified solid biofuel in the form of briquettes represents an advantageous fuel with big potential of use, but in the same time it requires more attention and further study in order to increase quality and improve the energy efficiency of its production.

In the frame of research it was found, that bulk density of initial raw material can have influence on the quality of final product and on increasing values of temperature in the process of briquetting. With decreasing particles' size of raw material (fraction) by grinding with hammer mill the bulk density increases. Also an essential can be the reduction of energy consumption in the process of biomass densification by optimization of feedstock fraction size. But in the same time grinding of biomass into very small fraction is associated with additional costs in the briquettes' production process and the quality of briquettes (mechanical durability) may be relatively low. The research showed that the durability of briquettes produced from *Miscanthus x giganteus*, *Miscanthus sinensis* and apple tree wood with fraction size 12 mm are of better quality than briquettes made from the materials with smaller fraction size 8 mm and 4 mm. Utilization of raw material with smaller fraction size affected positive only mechanical durability of briquettes made from hemp.

At the end it can be mentioned that for better understanding of an influence of initial raw material's fraction size and its proprieties on the quality of briquettes and energy efficiency of the production process much more factors should be studied.

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