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Evaluation of Physical Properties in Briquettes Made from Selected Plant Materials

Ignacy Niedziółka[1], Wojciech Tanaś[1], Mariusz Szymanek[1], Beata Zaklika[1], Józef Kowalczuk[2], Jarosław Tatarczak[2], Janusz Zarajczyk[2]

[1]Department of Agricultural Machines,
[2]Department of Horticultural and Forestry Machines,
University of Life Sciences, 28 Głęboka Street, 20-612 Lublin

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Summary. The purpose of this study was to evaluate the physical properties of briquettes made from selected plant raw materials. The research was carried out on three kinds of raw materials, i.e. wheat straw, maize stover and Sida stalks. It was found out that the plant materials used for the production of briquettes were characterized by low moisture and high calorific value and they could well undergo a process of compaction. Also, the produced briquettes were characterized by favourable properties concerning the studied parameters, i.e. length, mass, proper density and bulk density. The best results for the studied properties were obtained for the briquettes made from maize stover, and slightly worse for the briquettes made from wheat straw and Sida stalks.
Key words: plant biomass, briquetting, physical properties of briquettes.

INTRODUCTION

Energy from fossil fuel resources has been getting more and more expensive due to their depleting reserves. More and more attention has been paid to the problems of environmental protection. These phenomena have been encouraging research into alternative energy sources, among others, biomass. The greatest hopes are connected with the biomass of plant origin and this group includes the straw of cereals and other crops [Borkowska 2006, Denisiuk 2007, Grzybek 2012, Niedziółka et al. 2006, Stolarski 2008].

Virtually any type of straw from cereal, oilseed rape and buckwheat can be used for energy purposes. Due to their properties, the most often used straw is that of rye, wheat, rape and buckwheat. It is assumed that "straw" is ripe or dried plant stalks, having a high dry matter content of up to 85%, and the capacity of water and gas absorption. As a waste product it has a wide range of applications in crop production, horticulture, construction and energy. Despite the different applications of straw in agriculture it should be noted that there still remains a considerable potential of this material which has not found any rational use. Its use as an energy source has become the solution to this situation [Dreszer et al. 2003, Fiszer 2008, Kołodziej and Matyka 2012, Niedziółka and Szymanek 2010, Zarajczyk 2013].

To enhance plant biomass use for energy production, efforts have been made to improve its physical properties [Wu et al. 2011]. Lowering the moisture allows for long-term storage, while increasing the concentration of mass and energy per unit volume makes the transport, storage and dispensing easier. These favourable characteristics can be achieved by concentration of biomass in the form of briquettes, thus gaining a fuel which is competitive with conventional ones [Komorowicz et al. 2009, Lewandowski and Ryms 2013, Niedziółka 2014, Szymanek and Kachel-Jakubowska 2010].

Biomass briquetting means the increasing of energy density and improving the milling properties of the raw material. The most commonly used briquetting presses are the piston, screw and cylindrical ones. They can be used as separate devices or within an in-line process for the manufacture of compact fuel. Construction of the line is dependent on the volume of production, properties of the raw material used and specific requirements for the obtained product [Hejft 2013, Frączek 2010, Kallyan and Morey 2009]. Therefore, the production process may be more or less complicated, depending on the initial parameters of the processed materials as well as their final destination.

The aim of this study was to evaluate the physical properties of briquettes made of selected plant raw materials.

MATERIALS AND METHODS

Wheat straw, maize stover and Sida stalks were used for the production of briquettes. The relative moisture of raw materials was determined by the weight-drier method according to the PN-EN 15414-3: 2011 standard. Measurement of moisture content in the raw materials was performed in triplicate and determined by the formula (1):

$$W = \frac{m_o - m_1}{m_o} \cdot 100 , \qquad (1)$$

where:
W – humidity of the tested material (%),
m_o – mass of the sample before drying (g),
m_1 – mass of the sample after drying (g).

The net calorific value was calculated based on the gross calorific value determined using a calorimeter KL-12 Mn, in accordance with PN-EN 14918: 2010. The briquetting plant materials were pulverized using a chopper drum substation and universal hammer mill, powered by electric motors with the capacity of, respectively, 7.5 and 4.5 kW. The device used for the compaction process of the shredded plant materials was the hydraulic piston briquetting machine Junior of the POR DETA company, Poland.

After the production of briquettes their geometrical characteristics were determined: diameter and length using calipers (with accuracy of ± 0.1 mm) and mass using a laboratory scale WPT 6.3 (with accuracy of ± 0.1 g). Bulk density of the pellets was determined by freely dropping them into the measuring cylinder with the volume of 50 (dm³), in accordance with PN-EN 15103: 2010. After filling the cylinder and removing the excess strip, all the briquettes were weighed on the scales WPE 200 with accuracy of ± 0.1 g. Bulk density value was calculated as the quotient of the difference in mass of the cylinder with and without fuel pellets and the cylinder's volume, according to the formula (2):

$$\rho = \frac{m_L - m_O}{V} , \qquad (2)$$

where:
ρ – bulk density of pellets ($kg \cdot m^{-3}$),
m_L – mass of cylinder with pellets (g),
m_O – mass of the empty cylinder (g),
V – cylinder's volume (dm^3).

Photo 1 shows the tested plant materials after their shredding.

Photo 2 shows the hydraulic piston briquetting machine JUNIOR used to produce briquettes.

Photo. 2. The hydraulic piston briquetting machine JUNIOR

Table 1 presents the technical and operational parameters of the hydraulic piston briquetting machine JUNIOR.

Table 1. The technical and operational parameters of the hydraulic piston briquetting machine JUNIOR

Specification	Measurement unit	Data
Type of briquetting device	-	JUNIOR
Diameter of pellets	mm	50
Maximum length of briquettes	mm	60
Briquetting performance	$kg \cdot h^{-1}$	50
Electric motor power	kW	7.5
Maximum working pressure	MPa	15.0
Oil tank capacity	dm^3	110
Briquetting device dimensions (length x width x height)	mm	1600×1100×1500
Briquetting device weight	kg	680

a) b) c)

Photo 1. The tested plant materials after shredding: a) wheat straw, b) maize stover, c) Sida stalks

Photo 3 shows the briquettes made from the tested plant materials.

a) b) c)

Photo 3. Briquettes produced from the tested plant raw materials: a) wheat straw, b) maize stover, c) Sida stalks

RESULTS

Figure 1 shows the average moisture content of plant materials used for the production of briquettes. The lowest moisture was recorded for wheat straw (11.9%) and the highest for maize stover (14.3%). The statistical analysis showed that significant differences occurred in the moisture of all the tested materials.

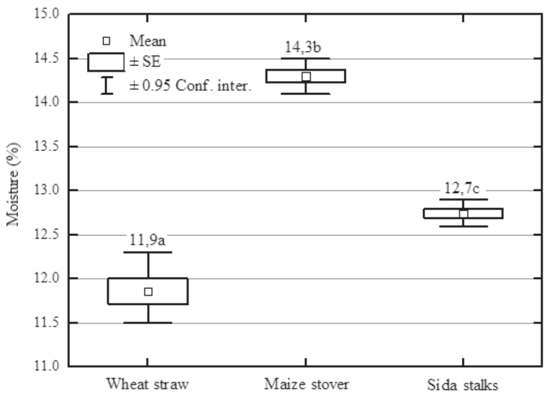

Fig. 1. Average moisture of the compacted plant raw materials

Figure 2 shows the average calorific value of the plant materials used in the manufacture of briquettes. The lowest calorific value occurred for wheat straw (16.9 MJ·kg^{-1}), slightly higher values were recorded for Sida stalks (17.1 MJ·kg^{-1}) and the highest for maize stover (17.6 MJ·kg^{-1}). The analysis showed no statistically significant differences in the calorific value of all the compacted materials.

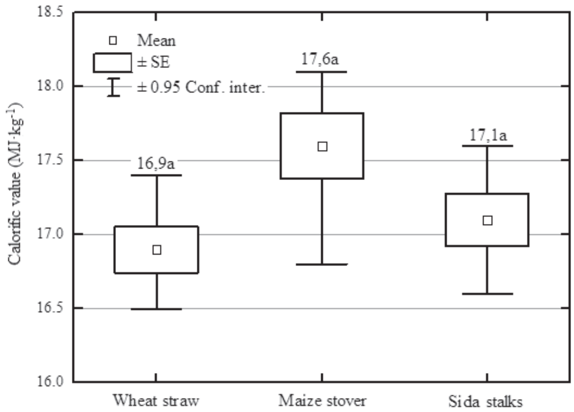

Fig. 2. Average calorific value of compacted plant materials

Figure 3 shows the results of measurements of the length of briquettes made of various plant materials. The shortest briquettes were obtained from wheat straw (38.9 mm), while the longest from Sida stalks (50.2 mm). The analysis of the results showed that statistically significant differences occurred between the length of briquettes produced from wheat straw and maize stover, and the length of briquettes made from Sida stalks. There were no statistically significant differences in the length of briquettes from wheat straw and maize stover.

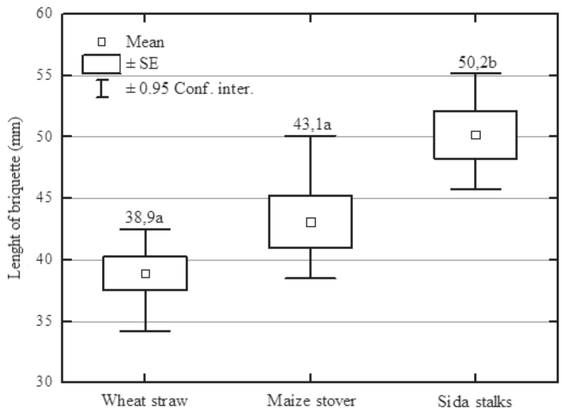

Fig. 3. Average length of briquettes made from plant materials

Figure 4 shows the results of measuring the mass of pellets made from the tested materials. The lowest average mass characterized the briquettes from wheat straw (47.9 g), slightly higher briquette mass was found for Sida stalks (52.4 g) and the highest for maize stover (61.8 g). The statistical analysis indicated that significant differences occurred between the mass of briquettes made from wheat straw or Sida stalks and that of the briquettes made from maize stover. In contrast, no statistically significant differences occurred between the mass of wheat straw and Sida stalks briquettes.

Figure 5 shows the density of briquettes depending on the type of plant raw materials used. The lowest proper density characterized the briquettes from Sida stalks (959.5 kg·m^{-3}) and the highest the briquettes from maize stover (1105.3 kg·m^{-3}). Based on the statistical analysis, it was found out that significant differences occurred between the proper density of briquettes produced from wheat straw or Sida stalks and the proper density of briquettes from maize

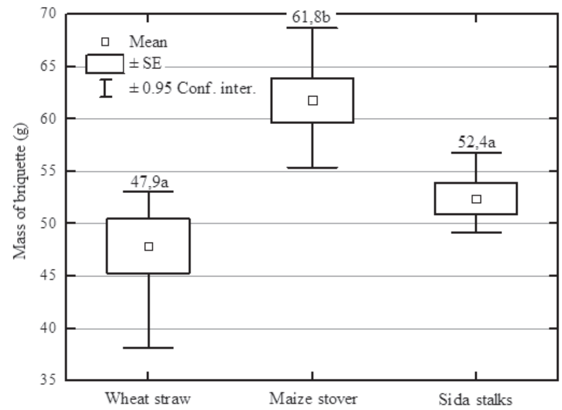

Fig. 4. Average mass of briquettes made from plant materials

stover. However, no statistically significant differences were found in the density of the pellets produced from wheat straw and Sida stalks.

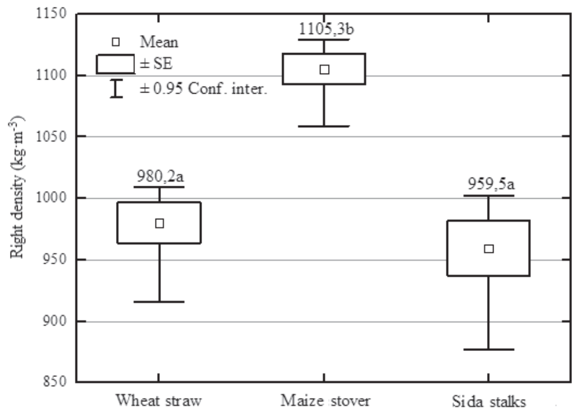

Fig. 5. Average density of briquettes produced from plant materials

The results of measurements of the average bulk density depending on the kind of raw materials used are shown in Figure 6. The lowest bulk density characterized the briquettes produced from Sida stalks (479.4 kg·m^{-3}), and the highest those produced from maize stover (567.3 kg·m^{-3}). Based on the statistical analysis it was found out that significant differences occurred between the bulk density of briquettes made from wheat straw or Sida stalks and the bulk density of briquettes made of maize stover. There were no statistically significant differences in the bulk density of briquettes made from wheat straw and Sida stalks.

CONCLUSIONS

The results of research and statistical analysis allow for the following conclusions:

1. The tested plant materials used for the production of briquettes were characterized by low moisture and high calorific value and were vulnerable for the process of compaction. Also, the produced briquettes were characterized by favourable parameters of the studied properties, i.e. length, mass proper density and bulk density.

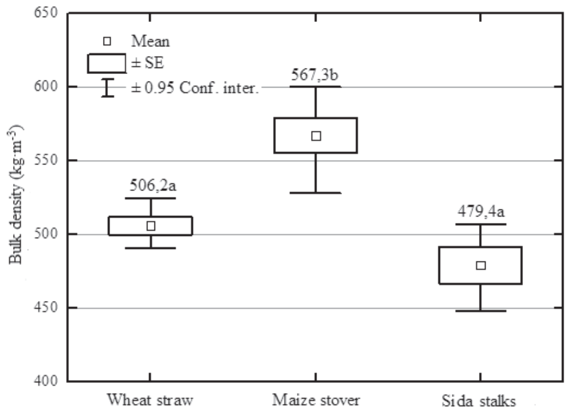

Fig. 6. Average bulk density of briquettes produced from plant materials

2. Among the compacted materials, the lowest moisture (11.9%) and heating value (16.9 MJ·kg^{-1}) was found out for the wheat straw, and the highest for the maize stover, (14.3%) and (17.6 MJ·kg^{-1}), respectively.
3. After the analysis of the results of measurements of length and mass of the produced briquettes it was found out that the shortest briquettes were obtained from wheat straw (38.9 mm), and the longest from Sida stalks (50.2 mm). In contrast, the lowest mass was recorded for the briquettes made from wheat straw (47.9 g), whereas the highest for the briquettes produced from maize stover (61.8 g).
4. Based on the analysis, the lowest values of proper and bulk density were found out for the pellets produced from Sida stalks – (959.5 and 479.4 kg·m^{-3}), respectively, and the highest values for the briquettes manufactured from maize stover – (1105.3 and 567.3 kg·m^{-3}), respectively.

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OCENA WŁAŚCIWOŚCI FIZYCZNYCH BRYKIETÓW WYKONANYCH Z WYBRANYCH MATERIAŁÓW ROŚLINNYCH

Streszczenie. Celem tego badania była ocena właściwości fizycznych brykietów wykonanych z wybranych surowców roślinnych. Badania przeprowadzono na trzech rodzajach surowców: słomie pszennej, słomie kukurydzianej i łodygach ślazowca pensylwańskiego. Stwierdzono, że materiały roślinne stosowane do wytwarzania brykietów charakteryzuje niska wilgotność i wysoka wartość opałowa i mogą one z powodzeniem być poddawane procesowi zagęszczania. Ponadto, wyprodukowane brykiety charakteryzowały się korzystnymi właściwościami w zakresie badanych parametrów, czyli długości, masy, gęstości właściwej i gęstości nasypowej. Najlepsze wyniki dla badanych właściwości uzyskano dla brykietów ze słomy z kukurydzy, a nieco gorsze dla brykietów ze słomy pszennej i łodyg ślazowca pensylwańskiego.

Słowa kluczowe: biomasa roślin, brykietowanie, właściwości fizyczne brykietów.