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ASSESSMENT OF PHYSICAL PROPERTIES OF BRIQUETTES MADE OF MIXTURES OF SELECTED PLANT RAW MATERIALS AND POST-FERMENTATION WASTE

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ABSTRACT

Searching for renewable energy sources causes the increase in the interest in obtaining and processing of plant biomass for energy purposes. One of the methods of using biomass is to converse it into solid biofuels in the form of briquettes. The research covered briquette production with the use of the following plant raw materials: straw of spring crop mixture (wheat with barley – 50/50%) and oat straw and post-fermentation waste. Samples of fragmented straw with addition of post-fermentation waste were prepared in three various weight participation i.e.: 90/10%, 80/20% i 50/50%. The paper presents an assessment of physical properties of briquettes manufactured from the investigated mixtures of plant raw materials with an addition of post-fermentation waste in the hydraulic piston briquetting machine. We determined the moisture of raw materials and waste, length, diameter and mass of manufactured briquettes as well as their specific density and mechanical strength. We found out that along with the increase of the mass participation of post-fermentation waste in the accepted mixtures of plant materials from 10 to 50% their length increased from 5 to 25% and the mass from 1 to 12%. On the other hand, specific density of briquettes increased from 18 to 24% for grain mixtures and from 3 to 7% for oat straw. Mechanical strength of briquettes was within 88.3-90.6% for grain mixture and 83.6-87.1% for oat straw.

Introduction

Around the world and in Poland, a greater emphasis is put on the use of renewable energy sources. Presently, energy from wind, solar radiation, water and geometry, and mainly from biomass is used. Followers of renewable energy sources indicate problems related to incineration of fossil fuels, which cause environment pollution, global warming and reduction of their resources (Janowicz, 2006).

Searching for alternative energy sources caused an increase of the interest in processing and obtaining biomass for energy purposes. It may be obtained from waste from agri-food industry and from annual and perennial cultivations or by-products. Surpluses and waste such as grass from permanent grasslands (hay), grain straw and straw of other plants as well as energy plants from purposeful cultivations are most often used for solid biofuels production (Kołodziej and Matyka, 2012; Stolarski et al., 2008; Terlikowski, 2012).

Plant biomass is a fuel which is difficult for use and requires appropriate processing. Mainly it is a fuel with a local scope, which is often moist, non-uniform and of low energy value in comparison to the volumetric unit. Therefore, in comparison to other energy carriers, biomass seems to be a burdensome raw material with regard to energy. However, biomass enjoys constant interest of potential recipients of electric and thermal energy as well as agricultural producers and ecologists, on account of its popularity and availability. Calorific value and physical properties of produced biofuels depend on the moisture, type and degree of biomass fragmentation (Temmerman et al., 2006; Wu et al., 2011).

Non-processed plant biomass is characterized by low density; it also causes problems with transport and storing. Constant, liquid and gas biofuels are produced from biomass, which occurs itself in various physical states. Among solid biofuels there are pellets and biofuels, for production of which, various types of plant materials are used, inter alia: sawdust, bark, chips, wood chips, energy plants etc. Straw from all types of grains, rapeseed and buckwheat is mainly used. Rye, wheat, rapeseed and buckwheat straw and corn rachis are particularly valuable (Majtkowski, 2007; Piotrowski et al., 2004).

The wheat straw is basically used as fodder and litter in animal production and its surpluses are used for energy purposes. On the other hand, rapeseed, horse bean and sunflower straw are not used in animal production and therefore it is frequently obtained for production of briquettes. Such management of straw has many advantages. The produced fuel is not harmful for environment and heating is more profitable on account of its competitive prices in comparison to conventional energy sources (Grzybek, 2003; Kościk, 2007).

Post-fermentation residue from biogas station, which is harmful to environment and require relevant technology of storing and utilization, is available. Therefore, the interest not only in biogas but also in processing post-ferment for fertilization and energy purposes increases. Particularly favourable is the use of solid post-fermentation waste for pellets or briquettes. Physical properties and chemical composition of produced biofuels depend on the substrate used for biogas production (Czekała et al., 2012; Lewandowski and Ryms, 2013; Szyszlak-Bargłowicz and Piekarski, 2009).

Thus, it is necessary to search for possibilities of rational use of by-products and waste for heating purposes, consisting in production of fuel in the form of briquettes. Production of this type of fuel may be an alternative or supplementary energy source. Such use of agricultural biomass is indicated on account of environment protection (Frączek, 2010; Kallyan and Morey, 2009; Klimiuk et al., 2012; Niedziółka, 2014).

Objective and scope of the study

The paper presents the assessment of basic physical properties of briquettes manufactured from the selected mixtures of plant materials with an addition of post-fermentation waste in the hydraulic piston briquetting machine. The scope of the study covered fragmentation of the researched plant raw materials, mixing them with post-fermentation waste in the assumed mass share and then carrying out the briquetting process.

Material and research methods

The following plant raw materials were used for research: grain mixture straw (spring wheat with spring barley – 50/50%) and oat straw as well as post-fermentation waste. Samples from fragmented raw materials were prepared in three various mass shares i.e. grain mixture and post-fermentation waste in the following composition: 90/10%, 80/20% and 50/50%, oat straw and post-fermentation waste in the following composition: 90/10%, 80/20% and 50/50%. Fragmentation degree of raw materials whose length is >3.15 mm was in case of grain mixture 75.5% of the sample mass and for oat straw it was 83.2%. And for post-fermentation waste the fragmentation degree was 55.8% of the sample mass with the length of <3.15 mm. For production of briquettes a hydraulic piston briquetting machine JUNIOR type by DETA Polska was used. Working pressure of a briquetting machine was 8 MPa.

Specific moisture of raw materials was determined with the use of a laboratory moisture balance MAX 50/1/WH by RADWAG. Samples of moist biomass (approx. 5 g) were placed in the drying chamber of the moisture balance and then dried in the temperature of 120°C to the moment of achieving constant mass. The value of moisture value of the dried raw material was read from the screen.

Water mass necessary to receive the required moisture of raw material was calculated from the formula (1):

$$m_w = \frac{w_2 - w_1}{100 - w_2} \cdot m_n \quad \text{(g)} \qquad (1)$$

where:

m_w – water mass for hydration, (g)
w_2 – required moisture of raw material, (%)
w_1 – initial moisture of raw material, (%)
m_n – mass of the moistened raw material, (g)

For briquettes produced in the piston briquetting machine measurements of physical properties included: diameter, length and mass. For measurements samples of briquettes with the mass of 1000 g ±10 g were collected and carried out in 3 iterations. We determine the geometric dimensions of briquettes with the use of a calliper with a precision of the measurement of ±1 mm, and their mass with the use of a laboratory scale with the measurement precision of ±0.1 g.

Specific density of briquettes was determined based on the measurements of physical properties of the agglomerate sample with the mass of 1000 g ±10 g, made in 3 iterations and calculated according to the following formula (2)

$$\rho_w = \frac{4 \cdot 10^6 \cdot m}{\pi \cdot d^2 \cdot l} \quad (\text{kg}\cdot\text{m}^{-3}) \qquad (2)$$

where:

ρ_w – specific density of briquette, ($\text{kg}\cdot\text{m}^{-3}$)
m – briquette mass, (g)
d – external diameter of a briquette, (mm)
l – briquette length, (mm)

We carried out measurements of mechanical strength of briquettes on the research stand according to the standard PN-EN 15210-2:2011. Rotational speed of the drum was 21 rot·min^{-1} (±0.1 rot.·min^{-1}), test time 5 min and the mass of a sample 2000 g (±100 g). After the strength test, briquettes samples were sieved on the sieve with the meshes diameter of 31.5 mm. Mechanical strength of briquettes was determined according to the formula (3):

$$D_U = \frac{m_A}{m_E} \cdot 100 \quad (\%) \tag{3}$$

where:

D_U – mechanical strength of briquettes, (%)
m_A – mass of briquettes after the strength test, (g)
m_E – mass of briquettes before the strength test, (g)

Results of measurements of physical properties of the researched briquettes were subjected to statistical analysis with the use of one-factor analysis of variance in the STATISTICA 10.0 programme. Significance of differences between averages were determined with the use of Tukey's test at the level of significance of $\alpha = 0.05$.

Research results and their analysis

Table 1 presents results of the research on the moisture of raw materials and post-fermentation waste. Initial moisture of raw materials was at the same level and amounted to 7.1-7.2% while after they were hydrated it was 17.1% for grain mixture and 16.9% for oat straw. Due to difficulties related to mixing of moist post-fermentation waste with plant raw materials they were dried to the moisture of 9.0%.

Table 1.
Moisture of raw materials and post-fermentation waste

Type of raw materials	Initial (%)	
	Moisture, w_1	After hydration, w_2
Grain mixture	7.1	17.1
Oat straw	7.2	16.9
Post-fermentation waste	65.6	9,0*/

*/ - moisture of waste after drying

Table 2 presents results of measurements of length and mass of the produced briquettes. Average length of briquettes produced from the grain mixture with addition of post-fermentation waste was within 24.2 to 29.1 mm. While, average length of briquette produced from the oat straw with addition of post-fermentation waste was within 38.3 to 48.1 mm. External diameter of briquettes was permanent and was 50 mm. Average mass of briquette produced from the grain mixture with addition of post-fermentation waste was within 42.5 to 44.6 g. Whereas the average mass of briquettes produced from oat straw with addition of post-fermentation waste was within 65.8 to 73.8 g.

Along with the increase of the post-fermentation waste share in briquettes produced from the grain mixture their length increased from 5 to 20% and the mass from 1 to 5%. On the other hand, the increase of post-fermentation waste in briquettes from oat straw caused increase of their length from 5 to 25% and mass from 3 to 12%. Statistically significant differences were determined for the length of briquettes produced from the grain mixture and post-fermentation waste in the composition of 90/10% and 80/20% and 50/50% as well as between the length of briquettes made of oat straw and post-fermentation waste in the composition of 90/10% and 80/20% and 50/50%. Contrary, statistically significant differences were reported for the mass of briquettes produced from the grain mixture and post-fermentation waste and the mass of briquettes made of oat straw and those waste. The analysis of the length and mass of briquettes prove that the addition of post-fermentation waste to compacted raw materials favourably influenced the researched parameters.

Table 2.
The list of results of the length and mass of produced briquettes

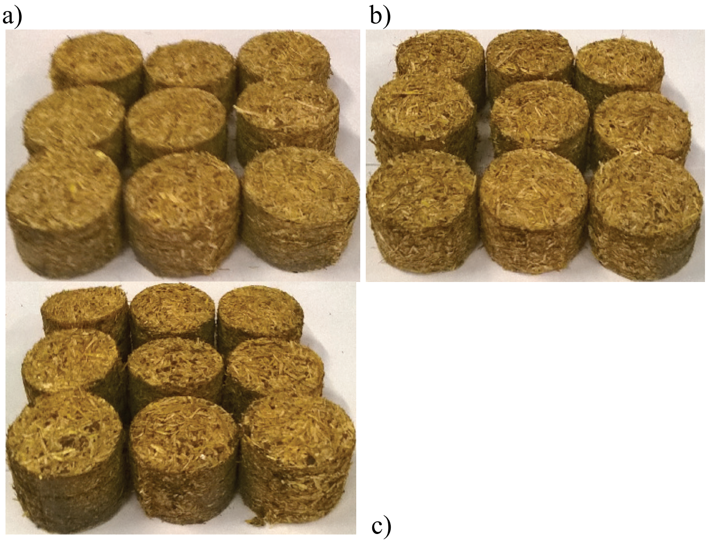
Types of mixtures	Average length of a briquette (mm)	Average mass of a briquette (g)
Grain mixture and post-fermentation waste – (90/10%)	24.2a	42.5a
Grain mixture and post-fermentation waste – (80/20%)	25.4a	42.8a
Grain mixture and post-fermentation waste – (50/50%)	29.1b	44.6a
Oat straw and post-fermentation waste – (90/10%)	38.3c	65.8b
Oat straw and post-fermentation waste – (80/20%)	40.4c	67.9b
Oat straw and post-fermentation waste – (50/50%)	48.1d	73.8b
NIR	3.77	8.62

a, b, c … – averages marked with the same letter do not differ significantly at the level of $\alpha = 0.05$

Figures 1 and 2 present briquettes produced from the researched plant raw materials and post fermentation waste.

Specific density of briquettes produced from the grain mixture with addition of post-fermentation waste was within 727-902 $kg \cdot m^{-3}$. Whereas the specific density of briquettes produced from oat straw and post-fermentation waste was within 882-940 $kg \cdot m^{-3}$ (fig. 3). Based on the statistical analysis, significant differences were reported for the specific density of briquettes from the grain mixture and post-fermentation waste in the composition of 90/10% and density of the remaining briquettes produced from the assumed composition of mixtures and post-fermentation waste and for specific density of briquettes from the grain mixture and post-fermentation waste in the composition of 80/20% and density of briquettes from oat straw and post-fermentation waste at the mass share of 50/50%. We did not report any statistically significant differences between the density of briquettes from the grain straw mixture and post-fermentation waste in the composition of 80/20% and 50/50%, and the density of briquettes made of oat straw and post-fermentation waste in the composition of 90/10% and 80/20%. Similar relations occurred between the density of briquettes made of grain straw and post-fermentation waste in the composition of 50/50%, and the density of briquettes made of oat straw and post-fermentation waste for mass share of 90/10%, 80/20% and 50/50%.

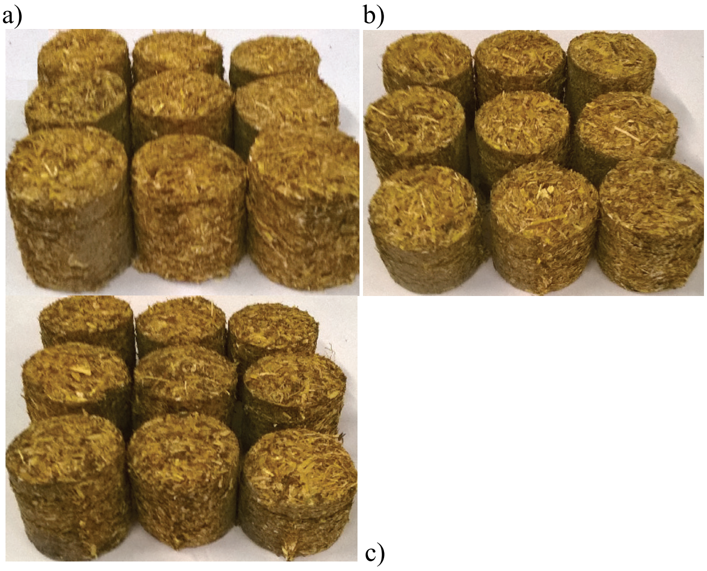
a) b)



c)

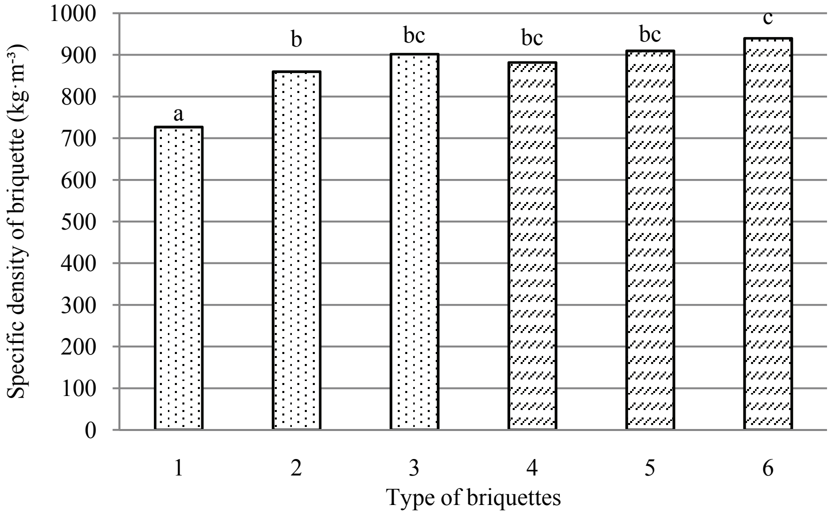
Figure 1. Briquettes produced from the grain mixture and post-fermentation waste for accepted mass share: a) – 90/10%, b) – 80/20%, c) – 50/50%

a) b)



c)

Figure 2. Briquettes produced from oat straw and post-fermentation waste for accepted mass share: a) – 90/10%, b) – 80/20%, c) – 50/50%



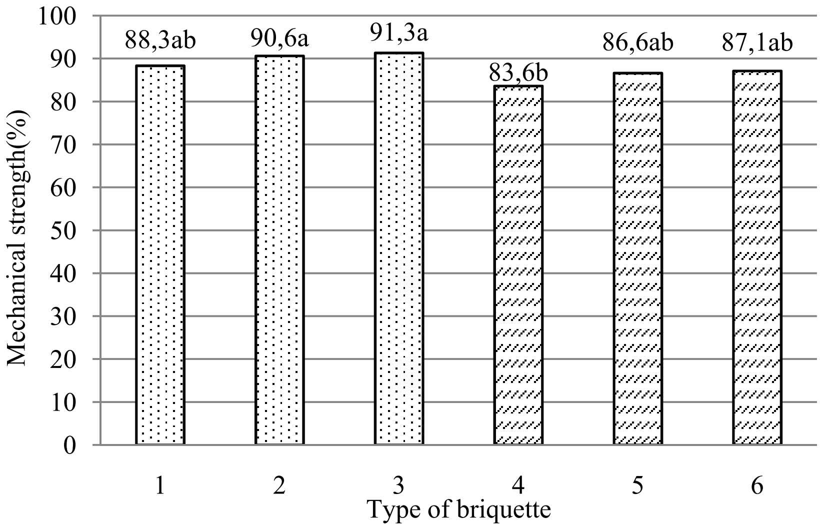
NIR = 71.8

a, b, c … – arithmetic averages denoted with the same letter do not differ significantly at the level of α = 0.05

Figure 3. Specific density of briquettes produced from the grain mixture and post-fermentation waste in the following composition: 1 – 90/10%, 2 – 80/20%, 3 – 50/50% and the oat straw and post-fermentation waste in the following composition: 4 – 90/10%, 5 – 80/20%, 6 – 50/50%

Figure 4 presents the results of the research on the mechanical strength of briquettes. Mechanical strength of briquettes produced from the grain mixture with addition of post-fermentation waste was within 88.3-91.3% whereas in case of briquettes produced from oat straw with an addition of post-fermentation waste it was within 83.6-87.1%. Statistically significant differences were reported for the mechanical strength of briquettes produced from the grain mixture and post-fermentation waste in the composition of 80/20% and 50/50% and the strength of briquettes from oat straw with an addition of post-fermentation waste in the composition of 90/10%. In the remaining cases, we did not report any statistically significant differences between the mechanical strength of briquettes produced from those raw materials.

Based on the obtained results of research, one may state that the addition of post-fermentation waste for the used plant materials in the accepted mass shares favourably influenced the researched physical properties of briquettes. Along with the increase of the share of post-fermentation waste higher parameters of the studied properties were obtained. More advantageous effects with regard to length, mass and specific density were obtained for briquettes produced from the oat straw mixtures and post-fermentation waste in comparison to briquettes produced from the grain straw mixture and used waste. Only in case of mechanical strength higher parameters were reported for briquettes made of grain straw mixture and post-fermentation waste in comparison to briquettes made of the oat straw mixture and used waste. Their improvement was influenced by a finer fraction of post-fermentation waste in comparison to fragmented plant raw materials. It is confirmed by results of research of other authors, which say that participation of finer fractions allows obtaining a product of the highest endurance (Fiszer, 2008; Hebda and Złobecki, 2012).



NIR = 5.34
a, b, c … – averages marked with the same letter do not differ significantly at the level of α = 0.05

Figure 4. Mechanical strength of briquettes produced from the grain mixture and post-fermentation waste in the following composition: 1 – 90/10%, 2 – 80/20%, 3 – 50/50% and the oat straw and post-fermentation waste in the following composition: 4 – 90/10%, 5 – 80/20%, 6 – 50/50%

Conclusions

Based on the research, which was carried out and based on the obtained results, we made the following conclusions:

1. Briquettes produced from the mixtures of agglomerated plant raw materials and post-fermentation waste had favourable parameters concerning the investigated physical properties as well as specific density and mechanical strength.
2. Briquettes produced from the grain mixture and post-fermentation waste in the composition of 90/10% were the shortest (24.2 mm) and had the lowest mass (42.5 g) and briquettes produced from the oat straw mixture and waste in the composition of 50/50% were the longest (48.1 mm) and their mass was (73.8 g).
3. Along with the participation of post-fermentation waste in the compacted plant raw materials their length increased by 5-20% and their mass by 1-5% in case of briquettes from the grain mixture and respectively by 5-25% and by 3-12% in case of briquettes made of oat straw.

4. Briquettes made of grain mixture and post-fermentation waste in the composition of 90/10% had the lowest specific density (727 $kg \cdot m^{-3}$) and briquettes made of oat straw and post-fermentation waste in the composition of 50/50% had the highest specific density (940 $kg \cdot m^{-3}$).
5. The lowest mechanical strength (83.6%) was obtained for briquettes made of oat straw and post-fermentation waste in the composition of 90/10% and the highest strength (91.3%) was reported in case of briquettes produced from the grain mixture and post-fermentation waste in the composition of 50/50%.

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OCENA CECH FIZYCZNYCH BRYKIETÓW WYTWORZONYCH Z MIESZANEK WYBRANYCH SUROWCÓW ROŚLINNYCH I ODPADÓW POFERMENTACYJNYCH

Streszczenie. Poszukiwanie odnawialnych źródeł energii powoduje wzrost zainteresowania pozyskiwaniem oraz przetwarzaniem biomasy roślinnej na cele energetyczne. Jednym ze sposobów wykorzystania biomasy jest jej konwersja na biopaliwa stałe w postaci brykietów. Badania obejmowały produkcję brykietów z wykorzystaniem następujących surowców roślinnych: słomę mieszanki zbóż jarych (pszenica z jęczmieniem – 50/50%) i słomę owsianą oraz odpady pofermentacyjne. Próby rozdrobnionej słomy z dodatkiem odpadów pofermentacyjnych przygotowano w trzech różnych udziałach masowych tj.: 90/10%, 80/20% i 50/50%. W pracy przedstawiono ocenę fizycznych cech brykietów wytworzonych z badanych mieszanek surowców roślinnych z dodatkiem odpadów pofermentacyjnych w brykieciarce hydraulicznej tłokowej. Określano wilgotność surowców i odpadów oraz długość, średnicę i masę produkowanych brykietów, a także ich gęstość właściwą i wytrzymałość mechaniczną. Stwierdzono, że ze zwiększaniem udziału masowego odpadów pofermentacyjnych w przyjętych mieszankach surowców roślinnych od 10 do 50%, wzrastała ich długość od 5 do 25% oraz masa od 1 do 12%. Natomiast gęstość właściwa brykietu zwiększała się od 18 do 24% dla mieszanki zbożowej i od 3 do 7% dla słomy owsianej. Wytrzymałość mechaniczna brykietów zawierała się w przedziale 88,3-90,6% dla mieszanki zbożowej i 83,6-87,1% dla słomy owsianej.

Słowa kluczowe: biomasa, odpady pofermentacyjne, brykiety, gęstość, wytrzymałość mechaniczna