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Pelletization of biomass waste with potato pulp content**

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A b s t r a c t. This paper presents the results of a research on the influence of potato pulp content in a mixture with oat bran on the power demand of the pelletization process and on the quality of the produced pellets, in the context of use thereof as a heating fuel. The tests of the densification of the pulp and bran mixture were carried out on a work stand whose main element was a P-300 pellet mill with the 'flat matrix-densification rolls' system. 24 h after the pellets left the working system, their kinetic durability was established with the use of a Holmen tester. The research results obtained in this way allowed concluding that increasing the potato pulp content in a mixture with oat bran from 15 to 20% caused a reduction of the power demand of the pellet mill. It was also established that as the pulp content in a mixture with oat bran increases from 15 to 25%, the value of the kinetic durability of the pellets determined using Holmen and Pfost methods decreases.

K e y w o r d s: pelletization, biomass waste, potato pulp, pellet quality

INTRODUCTION

According to Szyszlak-Bargłowicz *et al.* (2012), biomass ranks fourth worldwide as an energy source, after coal and oil. In all its forms, biomass currently covers approximately 14% of the world energy needs. Biomass is the most important source of energy in developing countries, providing 35% of their energy. In developed countries, biomass energy use is also substantial.

A rich source of energy from biomass is also the agriculture and food industry, which generates huge amounts of post-production waste (*eg* buckwheat hulls obtained during the production process of groats in grain processing plants, fruit pomace left over from the production of fruit juices, rapeseed pomace obtained during rapeseed oil production, or herbal waste).

One of the methods for managing plant biomass waste is pelletization or briquettization thereof into the form of a solid fuel (pellets, briquettes) (Hejft, 2002; Kaliyan and Morey, 2009; Laskowski and Skonecki, 2001; Skonecki and Laskowski, 2012). According to Adapa *et al.* (2010), densification can increase the bulk density of biomass from an initial bulk density of 40-200 kg m^{-3} to a final compact density of 600-1200 kg m^{-3} and a bulk density of 650 kg m^{-3}.

For the purposes of heating or as fodder, industry practice also includes densification of various types of mixtures of waste raw materials, *eg* from the agriculture and food industry, or of combinations of various types of waste materials of plant origin with other additives (also of plant origin). This includes producing heating pellets from a mixture of off-quality grain (granary waste) combined with oak sawdust and waste left over from the process of apple juice production (Stolarski, 2006); from a mixture of wheat, oat, and maize harvest waste in combination with straw, sawdust, and used edible oil (Niedziółka *et al*., 2008); from hardwoods, softwoods and grasses (Stelte *et al*., 2011); from a mixture of tobacco waste with herbal waste (Obidziński, 2012b); from compost obtained from mushroom production (Ryu *et al*., 2008); from a mixture of waste left over after trimming olive trees (Carone *et al*., 2010); from a mixture of waste wood and straw (Shaw *et al*., 2009); by pelletization of a mixture of chestnut and pine sawdust; or from a mixture of grape waste and coffee husks (Gil *et al*., 2010).

Some of the types of waste in the densified mixture can play the role of a natural binder and make the produced pellets more durable, and have a positive effect on the power demand of the pelletization process. This is confirmed by numerous research studies in which the following additives were introduced to the densified mixture: sodium hydroxide

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and maize starch as a binder in the process of biomass densification (Finney *et al*., 2009); sodium hydroxide to waste left over from the process of palm oil production (Razuan *et al*., 2011); bark and steam in the process of Scots pine sawdust pelletization (Filbakk *et al*., 2011); Pyrenean oak waste to densified olive pomace waste obtained in the process of olive oil production (Miranda *et al*., 2012a, 2012b); pine waste (sawdust) to pelletized barley straw (Serrano *et al*., 2011); industrial cork residue to vine shoots (Mediavilla *et al*., 2009); hydrolytic post-production waste obtained during the production of ethanol from lignocellulosic materials to densified biomass (Ohman *et al*., 2006); a binder (Arabic gum and Cassava starch) in the process of densification of carbonized (torrefied) forest wood waste obtained from forest production (Sotannde *et al*., 2010); maize starch or lignosulphonate (a by-product in cellulose production) in the process pelletization of poplar energy crop (Mediavilla *et al*., 2012); or shredded paper, a waste material from containers in the process of densification of forest wood waste (Kong *et al*., 2012).

One of the types of post-production waste obtained during potato starch production (*eg* in PEPEES S.A. in Łomża, Poland) is potato pulp, which consists mainly of raw fibres, starch remnants, and mineral compounds.

The heat of combustion for dry potato pulp is 16.33 MJ kg^{-1}, the calorific value is 15.41 MJ kg^{-1}, and the mean ash content is 4.42% (Obidziński, 2012a). However, this material is characterized by very high moisture levels, exceeding 88% (Obidziński, 2012a). Such moisture content is a serious problem when using pulp as a (raw) material for the production of an ecological solid fuel in the form of heating pellets or briquettes (Obidziński, 2012a). Therefore, potato pulp needs to be additionally dried before it is pelletized. The conducted tests confirmed that after drying down to the appropriate moisture level, potato pulp is a material that is easily susceptible to the process of densification .

The aim of the research described in this paper was to determine the influence of potato pulp content in a mixture with oat bran on the power demand of the pelletization process as well as on the quality of the produced pellets, in the context of use thereof as a heating fuel.

MATERIALS AND RESEARCH METHODS

This paper presents the results of a research study of the pelletization process of post-production corn waste in the form of oat bran (produced in Podlaskie Cereal Institutions S.A. in Białystok, Poland) in a mixture with potato pulp, a remnant of washing out starch from potatoes (produced in PEPEES S.A in Łomża, Poland). The moisture content of the oat bran was 6.7 % and the moisture content of the potato pulp was 85.4%.

The moisture content of the raw materials (oat bran, potato pulp, and the prepared mixtures of oat bran and pulp) before the densification process was determined pursuant to PN-76/R-64752 using a WPE 300S moisture balance with an accuracy of 0.01%. Each time the moisture content of five samples was determined. For the purpose of the measurements, samples with a mass of 5 g were taken and dried in a temperature of 105°C until the indications of the moisture balance remained unchanged in three consecutive readouts at 15 s intervals. The mean of the obtained values was adopted as the end result of the determination of the moisture content.

The tests of the densification process of the investigated mixture of potato pulp with oat bran were carried out on a SS-4 work stand, whose main component was a P-300 pellet mill with a flat matrix.

The research on the densification process comprized three stages:
– preparing the mixtures of oat bran with the appropriate potato pulp contents and determining the moisture content of the obtained mixtures (after 24 h),
– pelletization of the prepared mixtures in the working system of the pellet mill and recording the results,
– determining the kinetic durability of the obtained pellets (24 h after leaving the working system).

The tests of the densification of the mixtures of oat bran and potato pulp were conducted for a working gap between the densification roll and the matrix of h_r = 0.4 mm, at a mass velocity of the mixtures of approx. Q_s = 150 kg h^{-1} and a rotational speed of the matrix of n_m = 280 r.p.m. The diameter of the openings in the matrix used in the tests was d_o = 8 mm, while their length was l_o = 28 mm.

During the tests, the influence of the potato pulp content (z_w = 15, 20, and 25%) in the mixture with oat bran on the power demand of the engine driving the pellet mill and on the kinetic durability of the obtained pellets were determined. Recording of the results of the power demand of the pellet mill, for each of the measured parameters, started after thermal equilibrium in the working system of the pellet mill was achieved, *ie* when the temperature of the working system (as indicated by the thermal pair connected to the working system) remained constant throughout the process.

The kinetic durability of the obtained pellets was determined pursuant to PN-R-64834:1998 and according to the methodology presented in the paper by Thomas *et al*. (1996), 24 h after the pellets had left the working system, using Holmen test and Pfost test.

In the tests carried out using Holmen method, a pellet sample weighing 100 g was placed each time in the tester chamber, where it was exposed to a stream of air and, while circulating in it, it was hitting on the perforated metal walls of the tester. During the tests, the influence of the test time on the kinetic durability of the pellets was determined. The pellets were kept in the chamber for 30, 60, 90, and 120 s, respectively. After these times, the remnants of pellets from the tester chamber were placed onto the sieve, sieved, and weighed. The kinetic durability of the pellets was calculated as the ratio of the mass of the pellets after the test to the mass of the pellets before the test.

The Pfost tester (built pursuant to PN-R-64834:1998 at the Chair of Food Industry Machines and Appliances of Białystok University of Technology, Poland) is equipped with a 285x285x120 mm chamber, in which a 230x50x2 mm steel plate is placed. The tester is driven by an electric motor and a drive belt. The electric motor is connected to a frequency converter, owing to which it is possible to achieve the required rotational speed of the tester. 24 h after the completion of the pelletization process, the obtained material was sieved on a sieve with a diameter smaller by 1 mm than the diameter of the pellets, in order to remove small particles. Then, five samples of whole pellets with a mass of 500±0.5 g were weighed and subjected to a test in the tester chamber. The rotational speed of the chamber was 50 r.p.m. After 10 min of test time, each sample was again subjected to sieving. The mass of the pellets remaining on the sieve was weighed with an accuracy of ±0.5 g. The kinetic durability was determined as the ratio of the mass of the pellets after the test to the mass of the pellets before the test.

RESULTS AND DISCUSSION

Figure 1 presents the results of the tests of the influence of potato pulp content in a mixture with oat bran on the power demand of the pellet mill recorded during the densification of the mixture.

On the basis of the obtained test results (Fig. 1), it can be concluded that increasing the potato pulp content in a mixture with oat bran from 15 to 25% caused a significant reduction of the power demand of the pellet mill by approx. 41% (from 3.69 to 2.18 kW).

The reduction of the power demand of the pellet mill was caused by the significant increase in the moisture content in the mixture resulting from the increased potato pulp content (Fig. 2). The moisture content of the mixture increased from 18.50% (at a 15% pulp content in the densified mixture) to 31.33% (at a 25% pulp content in the densified mixture). Increasing the pulp content resulted in obtaining increasing amounts of the binder (in the form of a liquid produced from starch and moisture) during the pelletization process. The produced binder caused a reduction of the resistance to forcing through the openings, at the same time lowering the values of the power demand of the pellet mill (Fig. 1) and increasing the density and the kinetic durability of the obtained pellets, which in combination with the bran, after cooling and gelatinization of starch into a sticky gel, produced a dense agglomerate.

The values of the power demand of the pellet mill obtained during the densification of the mixture of potato pulp and oat bran show that the addition of pulp has a highly favourable effect on the reduction of the power demand, which is significantly lower than the corresponding demand in the case of the pelletization of bran only. Apart from this, the addition of pulp allows production of pellets of a better quality (with higher kinetic durability) than in the case of bran-only pellets.

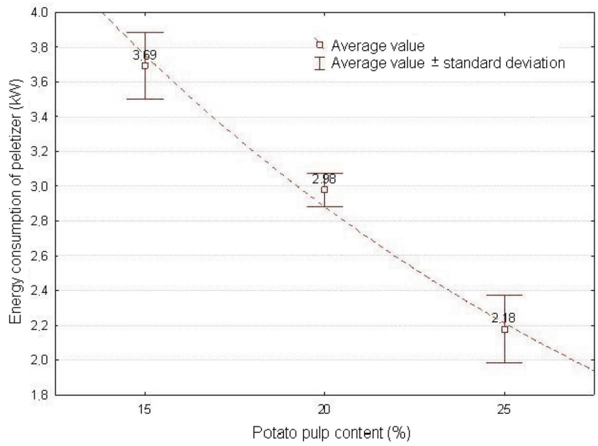

Fig. 1. The influence of potato pulp content in a mixture with oat bran on the power demand of the pellet mill.

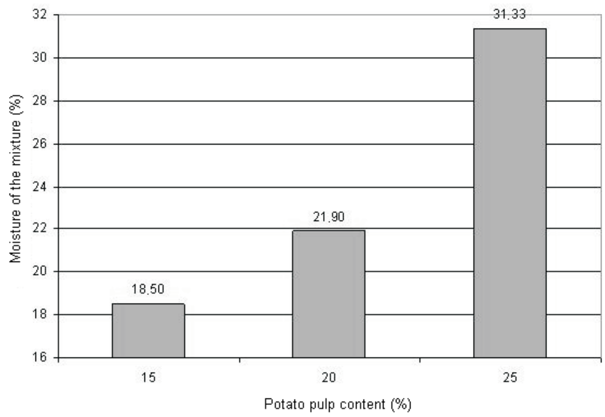

Fig. 2. The influence of potato pulp content in a mixture with oat bran on the moisture content of the mixture.

According to Kulig and Laskowski (2008), the total power demand of the process of pelletization is affected mostly by the chemical composition of the processed raw materials. Niedziółka *et al*. (2008) claim that the value of power demand during the densification process is affected to a large degree by the quantities of particular components in the plant mixtures used for pelletization. Increasing the quantity of ground wheat and sawdust in a plant mixture results in an increase in power demand from 14 to 34% compared to the power demand for mixtures with lower contents of these components.

Mediavilla *et al*. (2009) pelletized different mixtures of vine shoots and cork in a commercial pellet mill, using a 20 mm compression flat die. They discovered that with the addition of industrial cork residue to vine shoots, there was a reduction of power demand. Another paper by Mediavilla *et al*. (2012) shows that an addition of maize starch or lignosulphonate (in dosages of 2.5, 5.0 and 7.0 w.t. % (d.b.) of dry

T a b l e 1. Results of tests of the influence of the potato pulp content in a mixture with oat bran on the kinetic durability of the pellets determined using Holmen and Pfost methods

Potato pulp content (%)	Kinetic durability			
	Holmen methods the time of the test (%)			Pfost methods (%)
	t = 30 s	t = 60 s	t = 90 s	
15	98.42	95.78	95.24	96.22
20	94.42	90.77	88.55	92.85
25	76.64	65.90	52.66	67.10

additive) increased the stability of the process and reduced power demand during the pelletization process of poplar. Kaliyan and Morey (2009) also confirmed that an addition of lignosulphonate as a binder during the pelletization process improves the physical qualities of the pellets and reduces the power demand.

The influence of pulp content z_w on the power demand of the pellet mill N_g during the densification of oat bran and potato pulp in the working system of a pellet mill with a flat matrix is described by a general equation of the exponential function:

$$N_g = 8.26e^{-0.053 z_w} \quad (1)$$

where: z_w – potato pulp content in mixture (%).

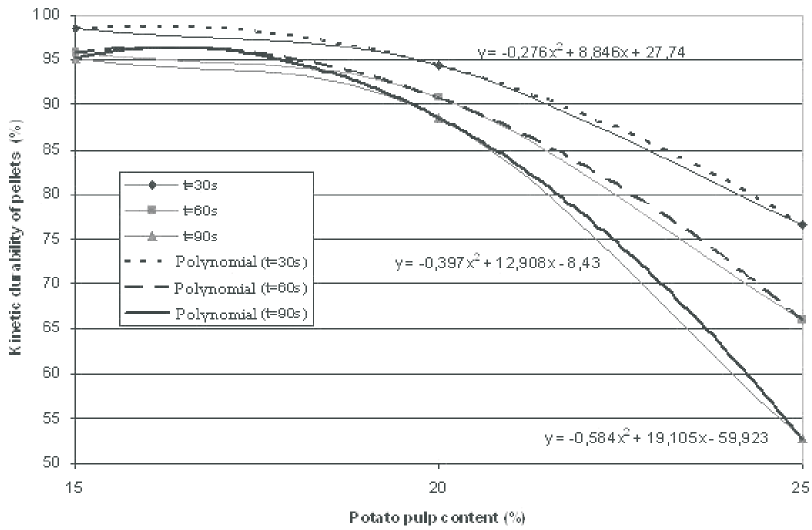

Fig. 3. The influence of potato pulp content in a mixture with oat bran on the kinetic durability of the pellets determined using Holmen method.

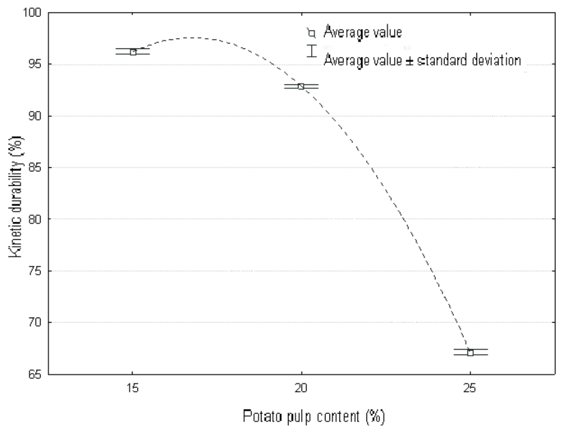

Fig. 4. The influence of potato pulp content in a mixture with oat bran on the kinetic durability of the pellets determined using Pfost method.

Table 1 and Figs 3 and 4 show the values of the kinetic durability of the pellets determined using Holmen and Pfost methods, obtained by measurements.

On the basis of the conducted tests (Table 1 and Fig. 3), it can be concluded that as the pulp content in a mixture with oat bran increases from 15 to 25%, the value of the kinetic durability of the pellets determined using Holmen method decreases. At a test time of 30 s, the kinetic durability decreases by approx. 22%, from 98.42 to 76.64%. Pursuant to PN-R-64834:1998, the appropriate test time for pellets of 8 mm in diameter is 60 s, at which the kinetic durability of the pellets decreases by approx. 31%, from 95.78 to 65.90%. Increasing the test time to 90 s results in reducing the kinetic durability by approx. 45%, from 95.24 to 52.66%.

Similar results concerning the values of the kinetic durability of the pellets to those obtained for Holmen test time of 60 s were obtained in Pfost test (Fig. 4). Increasing the pulp content in a mixture with oat bran from 15 to 25%

results in reducing the kinetic durability of the pellets determined using Pfost method by approx. 30%, from 96.22 to 67.10%.

The value of the kinetic durability of the pellets determined using Pfost method is higher by approx. 1% from the value determined using Holmen method, which allows a conclusion that both these methods may be used interchangeably in future research. Holmen method is, however, far less time-consuming.

A favourable effect of the addition of a binder to biomass in the pelletization process is confirmed by Finney *et al*. (2009), who tested the influence of the addition of sodium hydroxide and maize starch as a binder in the densification process of biomass. They concluded that the kinetic durability of the tested pellets increased significantly when small amounts (over 1%) of binder additives were added. Razuan *et al*. (2011) discovered that adding small amounts of caustic soda (1.5-2.0 w.t. %) to palm kernel cake increased the tensile strength of the obtained pellets to 3055 kPa, with their density fluctuating between 1192 and 1237 kg m^{-3}. Gilbert *et al*. (2009), who produced pellets from a mixture of switchgrass and heavy oil, concluded that heavy pyrolysis oil has a potential for use as a binder material which can significantly increase the strength and durability of the pellets.

Serrano *et al*. (2011), who produced pellets from barley straw mixed with pine waste (sawdust), observed an increase in the kinetic durability of pellets with a pine sawdust content. This is also confirmed by Ohman *et al*. (2006), who observed that it was possible to improve the quality of pellets made from biomass by adding hydrolytic post-production waste obtained during the production of ethanol from lignocellulosic materials. Sotannde *et al*. (2010) tested the influence of a binder (gum arabic and Cassava starch) in the process of densification (briquettization) of carbonized (torrefied) forest wood waste. They concluded that using either of the tested binding agents makes it possible to produce briquettes of high kinetic durability.

According to Filbakk *et al*. (2011), who tested pellets from pinewood containing 0, 5, 10, 30, and 100% of bark, concluded that pellets produced from pure bark had the best mechanical properties, in comparison with pellets produced from wood with different bark contents. They also claim that higher contents of lignin and extractives have a positive effect on binding mechanisms during the production of pellets.

Potato starch contained in potato pulp plays the role of a natural binder in a mixture with oat bran. According to Kaliyan and Morey (2010), natural binders in biomass can be expressed or activated (softened) under high pressures in the presence of moisture (*eg* water soluble carbohydrates) or, in some cases, an increased temperature (*eg* lignin, protein, starch, or fat). When the pressure is removed and the binder cools, it hardens or ‘sets up’ forming bridges, or bonds, between particles, which has the effect of binding them together and making the resulting product more durable. Furthermore, in the area of glass transition, activating (softening) the natural binding components by using moisture and temperature is essential for production of highly durable briquettes and pellets.

The relationship between the kinetic durability P_{dx} of the pellets (obtained from a mixture of oat bran and potato pulp in the working system of a pellet mill with a flat matrix) and the potato pulp content z_w in a mixture with oat bran, at each of Holmen test times, is described by a second degree polynomial. At a test time of 60 s (for the pellets diameter of 10 mm - pursuant to PN-R-64834:1998), the polynomial has the following form:

$$P_{dx} = -0.39 z_w^2 + 12.91 z_w - 8.43 \qquad (2)$$

where: z_w – potato pulp content in mixture (%),
and for Pfost test, the relationship between the kinetic durability P_{dx} of the pellets with the potato pulp content z_w is described by the following second degree polynomial:

$$P_{dx} = -0.45 z_w^2 + 14.99 z_w - 27.95 \qquad (3)$$

On the basis of the tests carried out in the working system of the pellet mill, it can be concluded that the most favourable content of pulp as an additive to oat bran, from the point of view of the power demand of the pellet mill, is 20%, as it allows to significantly reduce the power demand of the process (in comparison with the pulp content of 15%, the power demand falls by approx. 19%, from 3.69 to 2.98 kW), at the same time making it possible to achieve a satisfactory quality of the pellets (kinetic durability of over 90%). Increasing the pulp content to 25% results in, on the one hand, an additional reduction of the power demand by approx. 22%, but on the other hand, this also causes a reduction of the kinetic durability to a value below 70% (Table 1, Figs 3, 4), which renders the obtained pellet quality unsatisfactory.

The tests performed in the working system of the pellet mill allow a conclusion that the most favourable content of pulp as an additive to oat bran, from the point of view of the quality of pellets, is below 20%, as it allows obtaining high quality pellets (pellets of high kinetic durability). Increasing the pulp content above 20% (at an operational moisture content of approx. 85-88%) results in a reduction of the kinetic durability below 90%, which renders the pellets less attractive from the energetic point of view.

The pellets obtained for the pulp content of 15% are characterized by the highest durability and their surface is shiny, even, and smooth. Increasing the pulp content in a mixture with oat bran to 20% makes the surface of the obtained pellets become more uneven, and small cracks appear on it. At the pulp content of 25%, the produced pellets are completely cracked and their surface is rugged and uneven.

On the basis of the performed tests presented in this paper and subsequent research studies of the densification process of other waste materials with a potato pulp content, details concerning the course of individual operations comprising the technology of heating and fodder pellets production were developed, which resulted in a patent application made by the author (Obidziński, 2012c).

CONCLUSIONS

1. Increasing the potato pulp content in a mixture with oat bran from 15 to 20% caused a reduction of the pellet mill power demand by approx. 41% (from 3.69 to 2.18 kW).

2. Increasing the potato pulp content in a mixture with oat bran from 15 to 25% resulted in reducing the value of the kinetic durability of the pellets determined using Holmen method (at a test time of 60 s – pursuant to PN-R-64834: 1998) by approx. 31%, from 95.78 to 65.90%.

3. Increasing Holmen test time from 30 to 90 s resulted in reducing the value of the kinetic durability of the pellets.

4. Using Pfost test, similar results concerning the values of the kinetic durability of the pellets to those for Holmen test time of 60 s were obtained. Increasing the pulp content from 15 to 25% in a mixture with oat bran resulted in reducing the kinetic durability of the pellets determined using Pfost method by approx. 30%, from 96.22 to 67.10%.

5. The most favourable content of pulp as an additive to oat bran, from the point of view of the power demand of the pellet mill and the high quality of the pellets obtained, was 20%, as it allows significant reduction of the power demand of the process (in comparison with the pulp content of 15%, the power demand falls by approx. 19%, from 3.69 to 2.98 kW), simultaneously making it possible to achieve a satisfactory quality of the pellets (kinetic durability of over 90%).

6. The most favourable content of pulp as an additive to oat bran, from the point of view of the quality of pellets, was 15%, as it allows obtaining high quality pellets (with a kinetic durability of over 95%).

7. The dependence of the kinetic durability of the pellets (produced from a mixture of oat bran and potato pulp in the working system of a pellet mill with a flat matrix) on the potato pulp content in a mixture with oat bran was described by a second degree polynomial, while the influence of the pulp content on the power demand of the pellet mill was described by a general equation of the exponential function.

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