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THE INFLUENCE OF MATERIAL AND PROCESS PARAMETERS AND CONSTRUCTION PARAMETERS ON THE DENSITY OF PELLETS FROM OF WASTE PLANT MATERIALS

Summary

This paper presents the results of tests of the influence of material and process, and construction parameters on maximum densifying pressures and density of pellets obtained in the process of densification of a mixture of plant waste in the form of unshredded buckwheat hulls, and a mixture of buckwheat hulls and potato pulp. The tests of densification of buckwheat hulls were conducted on an SS-3 stand with an "open chamber – densification piston" working system, according to the Hartley experiment plan. On the basis of the conducted tests it was found out that buckwheat hulls are a material with a low susceptibility to densification. Shredding buckwheat hulls considerably increase their susceptibility to densification. An addition of potato pulp to buckwheat hulls reduces the densifying pressures necessary to obtain pellets of high quality of mixture of buckwheat hulls and potato pulp. As far as the obtained pellets density is concerned, an addition of 15% of potato pulp is the most beneficial quantity added to buckwheat hulls.
***Key words**: pelletizing, potato pulp, buckwheat hulls, density*

WPŁYW PARAMETRÓW MATERIAŁOWO-PROCESOWYCH I KONSTRUKCYJNYCH NA PRZEBIEG PROCESU GRANULOWANIA ODPADOWYCH MATERIAŁÓW ROŚLINNYCH

Streszczenie

W pracy przedstawiono wyniki badań procesu zagęszczania mieszaniny odpadów otrębów owsianych i wycierki ziemniaczanej. Badania wstępne zagęszczania otrębów owsianych przeprowadzono na stanowisku SS-3, z układem roboczym „otwarta komora zagęszczania-tłok zagęszczający", używając komory otwartej o średnicy 8 mm i długości 47 mm, natomiast badania właściwe procesu zagęszczania przeprowadzono w układzie roboczym granulatora P-300 z układem „płaska matryca-rolki zagęszczające". W badaniach określono energochłonność procesu granulowania oraz jakość uzyskanego granulatu (gęstość i wytrzymałość kinetyczną). Oznaczanie wytrzymałości kinetycznej granulatu otrzymanego w układzie roboczym granulatora wykonano zgodnie z Polskimi Normami metodą Holmena. Wyniki przeprowadzonych badań pozwoliły stwierdzić, że dodatek wycierki ziemniaczanej do otrębów owsianych spowodował zwiększenie podatności mieszanki na zagęszczanie i obniżenie zapotrzebowania granulatora na moc. Dodatek wycierki do ok. 20% pozwala na uzyskanie granulatu o wysokiej jakości stanowiącego pełnowartościowe paliwo stałe.
***Słowa kluczowe:** granulowanie, wycierka ziemniaczana, łuska gryki, gęstość*

1. Introduction

Pelletizing and briquetting are the basic methods of utilization of various types of waste of plant origin in the form of a solid fuel (pellets, briquettes) [1, 5, 9, 11].

The product (pellets) obtained in the course of the process of pelletizing should be characterized by an appropriate durability (a certain kinetic durability) resulting from transport, storage, or the physiology of animal feeding (in the case of fodder pellets) [15, 26]. This is, however, in the opinion of numerous researchers, extremely difficult, due to the large number of factors that influence the process.

According to many scientists [6, 7, 8, 9, 10, 13, 14, 23, 25], an influence on course of pressure agglomeration process and quality of received products (pellets or briquetts) has many factors:

– chemically – biological factors – factors related to the feedstock (chemical composition of condensed material, biological structure of particles),
– material factors – related to preparation of material for process of condensing relate (the moisture of material, temperature of material, granulometric composition of particles of condensed material),
– equipment factors – construction (matrix diameter, diameter and number of densification rolls, diameter, length and condition of surface of slots in matrix, size of slot between matrix and roll, etc.),
– process factors – related to the course of process of condensing (condensing pressure, intensifying of flow of condensed material, speed of condensing, temperature of process, conditioning).

It is confirmed by Gilbert et al. [7] and numerous other scientist [2, 4, 12, 20, 21, 22, 24] who claim that the pellet quality depends on the properties of the feedstock – in terms of biomass type, moisture content and particle fibre size; and quality management of the manufacturing process – in terms of operating conditions, pelletiser type and binding agent. According to Kaliyan and Morey [10], a binder (or additive) can be a liquid or solid that forms a bridge, film, matrix, or causes a chemical reaction to make strong inter-particle bonding. Selection of binders mainly depends on cost and environmental friendliness of the binders.

One of the types of waste raw materials obtained from processing buckwheat into groats are buckwheat hulls witch can be use as a material to the pellets production.

On the basis of the conducted initial tests of the process of densification of unshredded buckwheat hulls, it was found out that buckwheat hulls are a material with a low susceptibility to densification. At different values of the length of matrix opening and different tested temperatures of the densification process, agglomerate of a sufficient quality was not be obtained. Hence, a decision was made to shred the hulls prior to the densification process. However, even after shredding the obtained densities of pellets were not satisfactory. The pellets crumbled easily when pressed lightly by hand. It was therefore decided that a binder should be used, in the form of potato pulp.

2. Purpose of the research

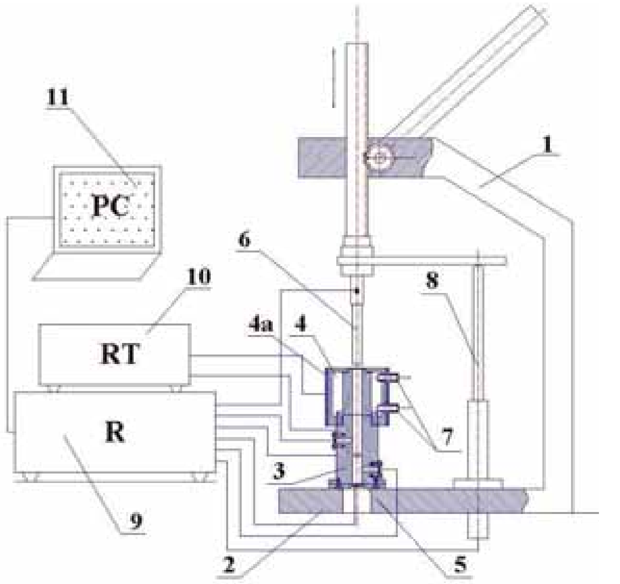
The aim of the research was to determine the most beneficial values of material and process, and construction parameters on the maximum densifying pressures and the density of pellets obtained from a mixture of buckwheat hulls and binder in the form of potato pulp in the aspect of the use of the obtained pellets as fodder or heating fuel.

3. Research methods

In the course of the tests, buckwheat hulls produced in Podlaskie Zakłady Zbożowe S.A. in Białystok and potato pulp produced in PEPEES S.A in Łomża which is waste obtained during flushing out of starch from potatoes were used as research materials.

In the course of the tests, the susceptibility of unshredded buckwheat hulls, a mixture of shredded buckwheat hulls and potato pulp, and unshredded buckwheat hulls and potato pulp to densification, by determining the maximum pressures densifying the raw material and the density of the obtained pellets.

The tests of densification of buckwheat hulls were conducted on an SS-3 stand (fig. 1), with an "open densification chamber – densifying piston" [16, 17, 18].



Source: Own study / Źródło: opracowanie własne

Fig. 1. Scheme of the stand SS-3: 1 - press, 2 - base, 3 - densification chamber, 4 - thermostatic element, 4a - heating band, 5 - chamber bottom, 6 - densifying piston, 7 - connection pipe, 8 - movement sensor, 9 - multichannel recorder, 10 - temperature controller, 11 - computer

Rys. 1. Schemat stanowiska SS-3: 1 - praska, 2 - podstawa, 3 - komora zagęszczania, 4 - element termostatujący, 4a - opaska grzejna, 5 - dno komory, 6 - tłok zagęszczający, 7 - króćce, 8 - czujnik przemieszczenia, 9 - rejestrator wielokanałowy, 10 - regulator temperatury, 11 - komputer

The stand consists of hand press 1, on whose base 2 an open densification chamber 3 (with an opening of 9 mm in diameter) is fixed to which the tested material was poured. The densification chamber 3 is heated, owing to which it is possible to control the process temperature. Heating of chamber 3 can be realized by means of heating band 4a put from above on special thermostatic element 4, or by means of thermostatic element 4 alone, supplied with water through connection pipes 7, from an ultrathermostat. The set value is obtained using temperature controller 10 coupled with heating band 4a. Densification of the material was performed by means of piston 6, with a tensometric sensor, allowing to record the forces the piston is subjected to.

Signals from the set of tensometers stuck on the densifying piston 6, from the smaller side pistons, and from movement sensor 8 were provided to Spider 8 multichannel recorder 9 with computer 11 and recorded in the form of binary files, which were then further processed.

A due time before commencing the proper measurements, the densification chamber was being heated until the adequate set temperature was achieved. Prior to the recording of results was started, several trial runs were performed, until the pressure force was set.

The tests of densification of a mixture of unshredded buckwheat hulls and potato pulp, and a mixture of shredded buckwheat hulls and potato pulp were conducted according to the PS/DS-P: Ha4 Hartley experiment plan, where the input quantities were the material, process, and construction ones:

$x_1 = z_w$- potato pulp content (15, 20 and 25%),
$x_2 = t_p$ - process temperature (50, 70 and 90°C),
$x_3 = l_m$ - length of matrix opening (32, 37 and 42 mm),
$x_4 = m_p$ - mass of densified sample (0.3, 0.6 and 0.9 g).

In the course of the tests, 20 samples were subjected to densification (for each of the points of the adopted experiment plan) in an open chamber with a diameter of 8 mm.

Shredding of buckwheat hulls was performed by means of a WŻ-2 laboratory shield shredder.

The division of the shredded buckwheat hulls into appropriate fractions was performed on an LPz-2e vortex mixer by Multiserv Morek with a set of 6 sieves with the following dimensions of the side of a square opening: 2 mm; 1 mm; 0.5 mm; 0.25 mm, 0.125 mm and 0.063 mm. After weighing a 100 g sample of shredded buckwheat hulls, it was placed on the upper sieve of a set of previously cleaned sieves. Then the set of sieves was set on the top piece of the vortex mixer and subjected to the process of sieve analysis. The time of operation of the vortex mixer was 5 minutes at a set amplitude of vibrations. After the sieving was finished, each of the fractions was weighed in order to determine the proportional contents of each of the fractions in the tested material. After weighing each of the fractions, the vortex mixer was started each time for 20 s and each sieve was carefully cleaned.

The density of pellets was determined immediately after they left the densification chamber. In the course of measurements, the height and diameter of pellets were measured by means of a calliope with an accuracy of ±0.02 mm, while their mass was determined by means of a WPS 360 laboratory balance with an accuracy of ±0.001 g. Density of the agglomerate was calculated as mass of pellets to sum of their volumes ratio.

4. Results of the tests

On the basis of the conducted tests, it was concluded that buckwheat hulls are characterized by a low bulk density of approx. 186 $kg \cdot m^{-3}$. This is connected with the shape of individual hulls, which create a kind of capsule that is empty inside. The shredding process has a beneficial influence on the bulk density of hulls, owing to which the individual hulls (capsules) lose their shape. After shredding a hull with the WŻ-2 shredder, its bulk density increases to approx. 357 $kg \cdot m^{-3}$.

Table 1 shows results of the tests of the densification process of a mixture of unshredded and shredded buckwheat hulls and potato pulp, according to the PS/DS-P: Ha4 Hartley experiment plan.

Tab. 1. Results of the tests of the densification process of a mixture of unshredded and shredded buckwheat hulls and potato pulp, according to the PS/DS-P Ha4 Hartley experiment plan
Tab. 1. Wyniki badań procesu zagęszczania mieszaniny nierozdrobnionej i rozdrobnionej łuski gryki i wycierki ziemniaczanej, zgodnie z planem eksperymentu Hartleya PS/DS-P Ha4

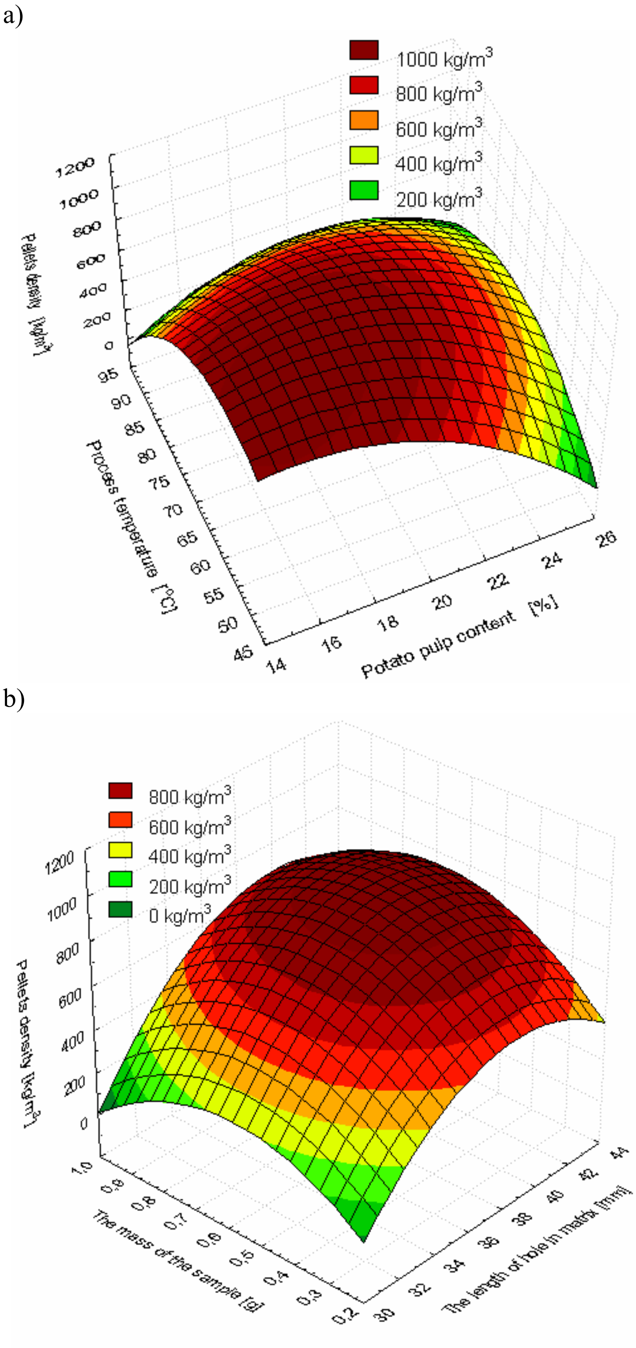
N \ x_i	Independent variables				Dependent variables (determined)			
					Unshredded hulls		Shredded hulls	
	$x_1=w_0$ [%]	$x_2=t_p$ [°C]	$x_3=l_m$ [mm]	$x_4=m_p$ [g]	Max. densifying pressures [MPa]	Pellets density [kg/m^3]	Max. densifying pressures [MPa]	Pellets density [kg/m^3]
1	25	50	32	0,3	10,57	334,45	9,56	825,83
2	15	90	32	0,3	11,28	315,51	47,87	1118,66
3	15	50	42	0,3	65,68	855,68	115,23	1032,34
4	25	90	42	0,3	14,31	339,45	15,15	819,23
5	25	50	32	0,9	8,78	333,54	15,34	813,26
6	15	90	32	0,9	3,47	211,85	79,13	1135,45
7	15	50	42	0,9	89,87	1045,15	95,16	1181,94
8	25	90	42	0,9	11,35	339,41	17,18	868,45
9	15	70	37	0,6	86,39	1085,33	97,56	1165,78
10	25	70	37	0,6	11,63	330,47	18,34	912,16
11	20	50	37	0,6	38,47	1025,23	52,06	1134,82
12	20	90	37	0,6	9,66	328,15	21,14	951,65
13	20	70	32	0,6	24,68	835,25	36,25	965,89
14	20	70	42	0,6	55,63	968,93	63,56	1074,53
15	20	70	37	0,3	23,37	832,16	48,69	1095,63
16	20	70	37	0,9	42,53	997,82	45,37	1034,41
17	20	70	37	0,6	34,19	960,67	48,29	1035,87

Source: Own study / Źródło: opracowanie własne

Fig. 2 shows the results of tests of the influence of material and process factors (potato pulp content and process temperature) on the density of pellets obtained in the process of densification of a mixture of unshredded buckwheat hulls and potato pulp in an open chamber.

On the basis of tab. 1 and fig. 2a it can be stated that as potato pulp content increases from 15 to 25%, there is a significant reduction of pellets density. This reduction is to a large extent connected with the significant increase of the moisture content of the densified mixture. The moisture content of the buckwheat hulls mixture increased from 18.63% (at a 15% pulp content in the densified mixture) to 26.23% (at a 25% pulp content in the densified mixture). Increasing the pulp content in the densified mixture resulted in obtaining bigger and bigger amounts of binder (in the form of a sticky liquid produced from starch and moisture) during the densification process. The increasing content of the produced binder had the effect of "lubrication" of the surface of the densification chamber and of a reduction of resistance to forcing through the densification chamber. This causes a reduction of densifying pressures and, in consequence, results in a reduction of pellets density.

a)



Source: Own study / Źródło: opracowanie własne

Fig. 2. The influence of material and process, and construction factors on the density of pellets obtained in the process of densification of a mixture of unshredded buckwheat hulls and potato pulp in an open chamber: a) the influence of potato pulp content and process temperature, b) the influence of the length of a matrix opening and the mass of the densified mixture
Rys. 2. Wpływ czynników materiałowo-procesowych i konstrukcyjnych na maksymalne naciski zagęszczające uzyskane podczas zagęszczania mieszaniny nierozdrobnionej łuski gryki i wycierki ziemniaczanej w komorze otwartej: a) wpływ zawartości wycierki ziemniaczanej i temperatury procesu, b) długość otworu w matrycy i masa zagęszczanej próbki

Increasing the process temperature from 50 to 70˚C causes an increase of the density of the obtained pellets. A further increase of temperature from 70 to 90˚C causes a significant reduction of the density of the obtained pellets. This may be caused by the increase of steam produced from the moisture contained in the densified mixture, which influences the degree of expansion of the obtained pellets immediately after they leave the densification chamber in comparison with the degree of expansion at a lower temperature, which in effect causes a reduction of the density of the obtained pellets. At a temperature of 90°C, within the whole range of potato pulp content values, pellets of a satisfactory quality was not obtained. The pellets crumbled easily when pressed lightly by hand.

The influence of potato pulp content z_w and process temperature t_p on the density of pellets obtained in the process of densification of a mixture of unshredded buckwheat hulls and potato pulp in an open chamber was described by the following equation:

$$\rho_g = -1455,58+174,56z_w+38,73t_p-8,31z_w^2+1,73z_w \cdot t_p - 0,59\, t_p^2 \quad (1)$$

where:

z_w – potato pulp content [%],

t_p – temperature of densification process [˚C].

On the basis of the conducted tests (tab. 1 and fig. 2b), it can be noticed that as the length of the densification chamber increases from 32 do 42 mm, irrespective of the mass of the densified sample, there is an increase of the density of the obtained pellets. This increase is connected with the increasing resistances to forcing of the densified material in the open chamber, arising as a result of increasing the length of matrix openings, which results in an increase of the real surface area of friction between the densified mixture and the walls of a matrix opening. This causes an increase of the densifying pressures that occur when the pellets are being produced, and a significant increase of pellets density.

Increasing the mass of the densified sample within the range of 0.3 to 0.6 g causes an increase of the density of the obtained pellets. This is connected with the increase of the surface areas of contact of the densified waste with the matrix surface, increasing when the amount of the densified material within a single cycle increases. The increase of the amount of densified waste causes a reduction of resistances to forcing and, in consequence, an increase of densifying pressures, which is reflected in the increase of pellets density. However, a further increase of the mass of a sample from 0.6 to 0.9 g causes a reduction of densifying pressures. When densifying a 0.9 g sample mass, it was necessary to perform initial densification of the waste fed to the chamber, as such mass was to great to fit into the chamber. This caused a reduction of the real surface area of friction between the material and the matrix surface, which reduced the values of resistance to forcing, and in consequence a reduction of the density of the obtained pellets. The highest density of pellets from unshredded buckwheat hulls, approx. 1085 $kg \cdot m^{-3}$, was obtained at a length of matrix opening of 37 mm and a mass of the densified sample of 0.6 g.

The influence of the length of matrix opening l_m and the mass of the densified sample m_p on the density of the obtained pellets in the process of densification of a mixture of unshredded buckwheat hulls and potato pulp in an open chamber is described by the following equation:

$$\rho_g = -9169,82+490,61l_m+1144,39m_p-6,42\, l_m^2+24,5l_m*m_p-1639,49m_p^2 \quad (2)$$

where:

l_m – length of densification chamber [mm],

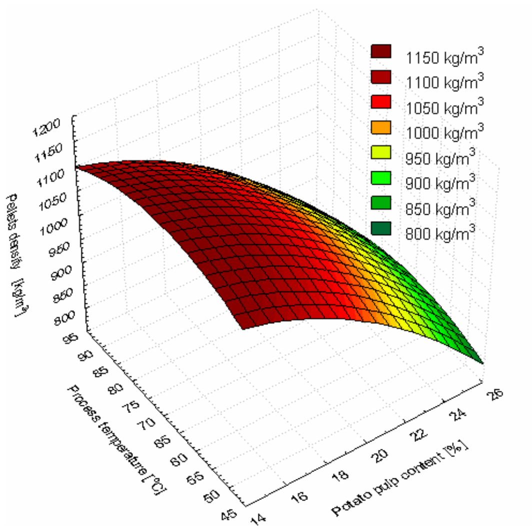
m_p – mass of densified sample [g].

Densification of shredded hulls with potato pulp

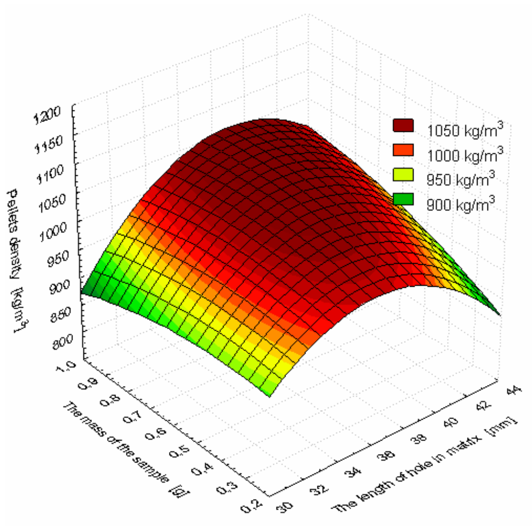
The tests of the process of densification of a mixture of buckwheat hulls and potato pulp were repeated at identical material and process parameters using shredded buckwheat hulls.

Tab. 1 and fig. 3 show the results of tests of the influence of material and process factors (potato pulp content and process temperature) on the density of pellets obtained in the process of densification of a mixture of shredded buckwheat hulls and potato pulp in an open chamber.

a)



b)



Source: Own study / Źródło: opracowanie własne

Fig. 3. The influence of material and process, and construction factors on the density of pellets obtained in the process of densification of a mixture of shredded buckwheat hulls and potato pulp in an open chamber: a) the influence of potato pulp content and process temperature, b) the influence of the length of a matrix opening and the mass of the densified mixture

Rys. 3. Wpływ czynników materiałowo-procesowych i konstrukcyjnych na maksymalne naciski zagęszczające uzyskane podczas zagęszczania mieszaniny rozdrobnionej łuski gryki i wycierki ziemniaczanej w komorze otwartej: a) wpływ zawartości wycierki ziemniaczanej i temperatury procesu, b) długość otworu w matrycy i masa zagęszczanej próbki

Increasing the pulp content in the densified mixture from 15 to 25%, within the whole tested range of temperatures, causes a reduction of pellets density. This is to a large extent connected with the increase of lubricating properties of the film of liquid created from the pulp moisture present between the material and the matrix walls, due to which there is a reduction of the coefficient of friction between the material and the matrix walls. This causes the appearance of lower values of densifying pressures in the course of the densification process, which in effect causes a reduction of the density of the obtained pellets.

Shredding buckwheat hulls considerably causes an increase of the density of the obtained pellets (tab. 1). For instance, the density of pellets obtained at a potato pulp content of 25%, process temperature of 50°C, length of densification chamber of 32 mm, and mass of densified sample of 0.3 g, increased from 334.45 $kg \cdot m^{-3}$ (at unshredded buckwheat hulls) to 825.83 $kg \cdot m^{-3}$ (at shredded buckwheat hulls).

During the densification of a mixture of shredded buckwheat hulls and potato pulp in an open chamber, it was noticed that increasing the process temperature causes a slight increase of pellets density. However, at a temperature of 90 °C, a slight reduction of the density of the obtained pellets was noticed.

The influence of potato pulp content z_w and process temperature t_p on the density of the obtained pellets in the process of densification of a mixture of shredded buckwheat hulls and potato pulp in an open chamber is described by the following equation:

$$\rho_g = 652{,}15+31{,}25z_w+10{,}92t_p - 1{,}49z_w^2 + 0{,}01z_w \cdot t_p - 0{,}08t_p^2 \quad (3)$$

Increasing the matrix length (tab. 1 and fig. 3b) causes an increase of pellets density. This tendency is the most evident within the range of the mass of the densified mixture of 0.6–0.9 g. This is connected with the time period for which the material is actually remaining in the matrix, which is becoming longer as the length of the matrix is longer, which makes the influence of temperature on the material more pronounced, and intensifies the biological and chemical processes that occur in a pellet, which become more intense the longer the time of remaining in the matrix is (at an increased matrix length). This causes an increase of the forces biding pellet particles, which in turn increases the density of the obtained pellets.

As the mass of a densified sample is increasing within the range of 0.3–0.9 g, there is a slight reduction of pellets density.

The influence of the length of matrix opening l_m and the mass of densified sample m_p on the density of the obtained pellets in the process of densification of a mixture of shredded buckwheat hulls and potato pulp in an open chamber is described by the following equation:

$$\rho_g=-1888.59+162.04l_m-387.03m_p-2.29l_m^2+16.22l_m \cdot m_p-138.09m_p^2 \quad (4)$$

The performed tests allow to conclude that shredding buckwheat hulls and adding binder in the form of potato pulp significantly improves the susceptibility of hulls to densification and the density of the obtained pellets.

Shredding buckwheat hulls prior to the densification process decreased their tendency to slide on the surface of a matrix opening and facilitated their binding within a pellet with starch from the pulp, jellifying under the influence of temperature and moisture. Shredding buckwheat hulls allowed to obtain pellets with a density (from approx. 813.26 kg/m^3 to over 1181.94 $kg \cdot m^{-3}$) greater by up to approx. 26% in comparison with the density of pellets obtained from unshredded buckwheat hulls in a mixture with potato pulp (from approx. 311.85 to approx. 1085.33 $kg \cdot m^{-3}$).

The positive influence of the increase of the degree of shredding on the density of pellets is confirmed by other studies by the author presented in the paper [19], as well as studies by Carone and fellow researchers [3] who concluded, after conducting tests of densification of olive tree waste, that the density of the obtained pellets increases as the size of a particle of the material is becoming smaller.

From the point of view of energy consumption of the process, the most beneficial temperature at which the process of densification of the tested mixture of waste materials should be carried out is 90°C. At this temperature the maximum densifying pressures are low, while the density of pellets is satisfactory. However, from the point of view of quality (density of the obtained pellets), the most beneficial process temperature is 70°C. The most beneficial mass of a densified sample is 0.6 g.

5. Conclusions

1. Densified buckwheat hulls is a material characterized by low susceptibility to pelletizing (in order to obtain high quality pellets, high densifying pressures are needed).
2. Shredding buckwheat hulls considerably improves their susceptibility to densification and density.
3. Shredding buckwheat hulls allowed to obtain pellets with a density (from approx. 813.26 $kg \cdot m^{-3}$ to over 1181.94 $kg \cdot m^{-3}$) greater by up to approx. 26% in comparison with the density of pellets obtained from unshredded buckwheat hulls in a mixture with potato pulp (from approx. 311.85 to approx. 1085.33 $kg \cdot m^{-3}$).
4. An addition of potato pulp causes a reduction of densifying pressures necessary to obtain high quality pellets from a mixture of buckwheat hulls and potato pulp.
5. The most beneficial amount of potato pulp added to buckwheat hulls, owing to the achieved pellets density, is 15%.
6. The most beneficial temperature of the densification process is 70°C, whereas the most beneficial mass of a densified sample is 0.6g.

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