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INFLUENCE OF SPEED OF DENSIFICATION PISTON AND PARTICLE SIZE OF DENSIFIED MATERIAL ON THE VALUE OF DENSIFYING PRESSURES AND PELLETS DENSITY

Summary

The article presents tests of influence of speed of densification piston (50, 100, 150 mm/min) and size of densified particle (1, 1.5, and 2 mm) on the values of maximum densifying pressures and the density of pellets obtained from a mixture of shredded oat bran with a 20% addition of potato pulp. The tests were performed in an "open densification chamber – densification piston" working system, at a process temperature of 70^{o}C, with the use of a matrix with diameter of 8 mm and length of 47 mm. Increase in speed of progression of the densification piston has an influence on a slight increase in maximum densifying pressures and a slight increase in pellets density, whereas increasing the diameter of particles of densified mixture causes a reduction of both the densifying pressures and pellets density.
***Key words**: densification, pressures, speed of piston, density*

WPŁYW PRĘDKOŚCI TŁOKA ZAGĘSZCZAJĄCEGO I WIELKOŚĆI CZĄSTKI ZAGĘSZCZANEGO MATERIAŁU NA WARTOŚCI NACISKÓW ZAGĘSZCZAJĄCYCH ORAZ GĘSTOŚĆ GRANULATU

Streszczenie

W artykule omówiono badania wpływu prędkości tłoka zagęszczającego (50, 100, 150 mm/min) oraz wielkości zagęszczanej cząstki (1, 1,5 oraz 2 mm) na wartości maksymalnych nacisków zagęszczających oraz gęstość granulatu uzyskanego z mieszaniny rozdrobnionych otrębów owsianych z 20% dodatkiem wycierki ziemniaczanej. Badania przeprowadzono w układzie roboczym „otwarta komora zagęszczania- tłok zagęszczający", przy temperaturze procesu 70^{o}C, wykorzystując matrycę o średnicy 8 mm i długość 47 mm. Zwiększenie prędkości przesuwu tłoka zagęszczającego wpływa na nieznaczny wzrost maksymalnych nacisków zagęszczających i nieznaczny wzrost gęstości granulatu, natomiast zwiększenie średnicy cząstek zagęszczanej mieszanki powoduje spadek zarówno nacisków zagęszczających jak i gęstości granulatu.
***Słowa kluczowe**: zagęszczanie, naciski, prędkość, tłok, granulat, gęstość*

1. Introduction

Trying to obtain high quality products of pressure agglomeration should be the producers' principal aim. In practice, it is often difficult to achieve, due to the influence of numerous factors, which can be divided into the following groups [5]:

- biological and chemical factors (chemical composition of the densified material, biological structure of particles),
- material factors – connected with preparation of material for the densification process (moisture content of the material, temperature of the material, granulometric composition of particles of the densified material),
- equipment factors – construction (matrix diameter; diameter and number of densification rolls; diameter, length, and condition of the surface of matrix openings, size of the gap between the matrix and the roll, etc.),
- process factors – connected with the course of the densification process (densifying pressures, flow rate of the densified material, speed of densification, process temperature, conditioning).

Among the key factors influencing the course of the densification process and the quality of the product are the size of the densified particle and the rate of agglomeration.

According to many researchers [4, 9], the diameter of particles of the fodder used for pelletisation cannot exceed 2-3 mm, as large-size particles may undergo shredding during the agglomeration process, which contributes to an increase of the energy consumption of the process, whereas their presence in the agglomerate may cause fractures and crumbling. Apart from this, small particles are more easily susceptible to the process of conditioning owing to their larger specific surface area (a better interpenetration of moisture and heat, and a more intense action of steam).

Grochowicz and his team [4], who tested the influence of the moisture content and the degree of shredding of lupine meal on the energy necessary for its densification into a constant volume (in the piston – open matrix system), concluded that lower values of densification energy are characteristic of meal whose degree of shredding is higher. Ekielski [3] informs that a reduction of the average length of chopped straw from 40 mm to 10 mm causes an increase of the efficiency of the process by over 50% (from 800 kg/h to 1750 kg/h). The tendency of an increasing process efficiency as a result of a reduction of the size of particles of the densified material is confirmed by Hejft [5].

Mani and his team [11] claim that an appropriate particle size distribution in the densified material has an influence on the quality of the obtained pellets. This is confirmed by Kaliyan and Morey [7] who list the moisture content and the particle size of the densified material as two of the most important factors that influence the value of forces during the process of densification and the stability of the obtained pellets. Serrano and his team [21], when assessing the mechanical durability and the density of pellets from barley straw and from barley straw mixed with pine waste (sawdust) produced in a ring matrix, did not observe negative effects of the increase of the size of particles of barley straw on the densification process and the quality of pellets. According to Laskowski [9], the average particle diameter has a visible influence on the work of friction, extrusion, and agglomeration of material, and the kinetic durability of pellets. Carone and his team [2], when testing mechanical properties (density and stability) of pellets produced on a piston press from olive tree waste, concluded that the density of the obtained pellets is increasing as the size of material particle is decreasing. These tests were carried out using material with particle sizes of 1, 2, and 4 mm. Shaw and his team [22, 23], who analyzed the influence of the particle size of the densified material (in the range of 0.8-3.2 mm) on the density and mechanical durability of pellets produced on a laboratory piston press from wheat straw and poplar sawdust, concluded that for all the tested parameters a reduction of particle size has an influence on the increase of the density and the mechanical durability of the obtained pellets. These tests were performed at two levels of temperature (70 and 100°C) and two levels of moisture content (9 and 15%).

Scholz and Fürll [5] when briquetting volume mixtures (with a straw content) concluded that a reduction of the average size of particles in the mixture from 75% to 25% causes an increase of agglomerate density by approx. 150 kg/m^3 and an increase of its kinetic durability by approx. 4.5%. Research by Ekielski [3] shows that a reduction of the average length of chopped straw from 40 mm to l0 mm causes an increase of the density of briquettes by approx. 200 kg/m^3, and the kinetic durability by 15%.

According to Skonecki and Laskowski [25], an increase of the average particle size causes a reduction of the susceptibility of material to densification and a decrease in the quality of the obtained agglomerate.

In the case of the rate of densification, its influence on the energy consumption of the process and the kinetic durability of the agglomerate, according to Hejft [5] has not been determined unambiguously. According to Skonecki and Laskowski [24], tests of densification of various materials are carried out at different speeds of travel of the piston. Most tests are carried out at speeds of 5 to 100 mm/min [24, 20]. Therefore, as Skonecki and Laskowski [24] show, determination of the influence of the speed of the piston is an important issue in the aspect of creating standardized conditions for densification tests.

According to Li and Liu [10], who densified oak sawdust at increasing speeds of densification, the density of agglomerate measured 2 minutes after densification decreases as the speed of densification increases. Laboratory tests of cyclic forcing of a fodder mixture (with a straw content) through a single opening, performed by by Hejft [5], show that the speed of densification does not have a significant influence on a change of the values of densifying pressures.

One of post-production waste obtained in the processing of food and agricultural materials obtained when oats is processed into oatmeal, flour, or other materials, is oat bran. It is obtained through shredding, repeated sorting, and separation of fractions rich in dietary fiber from floury endosperm parts [26]. Oat bran is used as fodder additive [26], owing to its high protein and dietary fiber content it is used as an ingredient of many diets [1, 14, 15]; as a substitute of wheat flour in the production of bread [8].

Earlier research studies of the densification of oat bran conducted by the author and his team [18, 19] show it to be material of low susceptibility to densification. The slippery oat hulls and the low quantity of endosperm remaining in the bran, as well as the low moisture content, result in the bran, during the densification process, being forced through the matrix opening at low densifying pressures, while the density of the produced pellets is very low. Therefore, oat bran should be shredded, which would lower its tendency to slide on the surface of the matrix opening and increase the moisture content of bran before the process of densification; or a binder additive may be used [19]. Other research studies by the author and his team [16, 17, 18] show that potato pulp can be a very good binder material. According to these studies, a potato pulp content of up to 20% in a mixture with oat bran allows to obtain satisfactory densities of pellets, which then constitute a fuel of full value conforming to the norms for norms in force for non-wood pellets [18].

2. Purpose of the research

The aim of the research was to assess the influence of the degree of shredding of the tested oat bran mixed with a 20% addition of potato pulp, and the speed of the densifying piston on the values of unitary densifying pressures and the density of the obtained pellets.

3. Research methods

A mixture of post-production waste in the form of shredded oat bran (produced in w Podlaskie Zakłady Zbożowe S.A. in Białystok) with a potato pulp content of 20% from Zakład PEPEES S.A in Łomża was used for the tests. The tested pulp is obtained as post-production waste during the production of potato starch. The pulp used in the tests was sampled from several places on the heap that it was stored on in the yard in Zakłady Pepees S.A. in Łomża.

The moisture content of the oat bran used in the tests was 5.09%, while the moisture content of the potato pulp was 85.6%. The moisture content of the mixture of oat bran with a 20% pulp content was 20.5%.

The tests were performed in an "open densification chamber – densification piston" working system on a test stand presented in fig. 1.

The main element of the stand is special densification chamber (10), placed on lower table for compression (8) of HT-9501 type universal testing machine with a maximum pressure of 200 kN.

Densification chamber 10 has an opening with a diameter of 8 mm, into which the tested material is poured to be densified.

Heating band 20 is put on special thermostat element of the chamber 10. The set process temperature is achieved by means of temperature controller 22 coupled with heating band 20. This solution enables the control of process temperature and makes it possible to heat the chamber to a temperature of over 100^{o}C. Densification of the tested material in chamber 10 is enacted by piston 13, fixed by means of a special holder mounted in upper table 16 of the press.

The HT-9501 machine consists of movable bar (18) controlled through the UP/DOWN buttons on the control panel. The position of the bar depends on the length of the tested sample and the selected method – compression or expansion. Encoder movement sensor (3) is connected to movable table (8) and records displacement of the hydraulic cylinder sending signals indicating real displacement.

Pressure transducer (7) is mounted in the middle part of the hydraulic cylinder. The pressure transducer records pressure changes inside the cylinder and these values are converted from analogue to digital showing the values of forces exerted on the cylinder. The force sensor is mounted in the movable part of the table. The machine is calibrated in a manner that enables the measurement of real forces exerted on the cylinder. Hydraulic cylinder (2) is a source of force acting on the tested samples. The upper limit of displacement is in the upper part of the cylinder.

The electric-hydraulic support consists in the control of the speed of travel of the lower bar, which has a decisive impact on the constancy of some of the parameters during the test, e.g.: position, speed, and the constant value of the acting force. The basic upwards and downwards motion is controlled from the software level.

Rotating motor shaft (5) drives the pressure pump, which is decisive in the operation of the pressure cylinder. A pressure control valve is located in the vicinity of the pump.

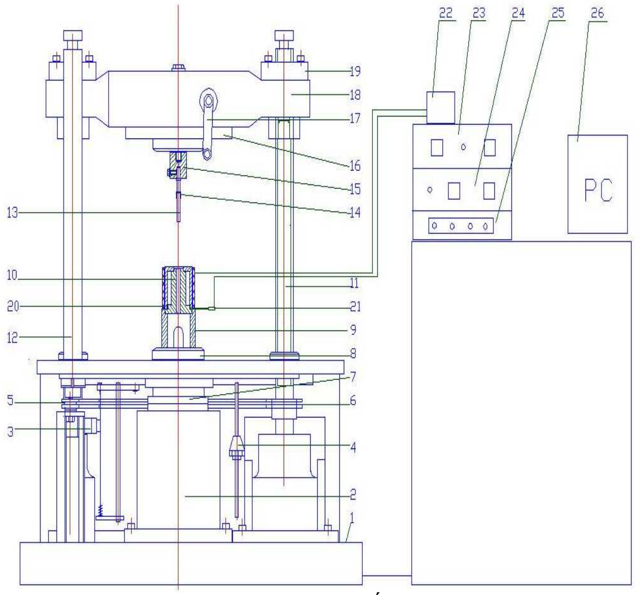

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Fig. 1. Scheme of the stand for tests of densification process of plant materials: 1- base, 2- cylinder, 3- encoder, 4- safety limits, 5- engine, 6- chain, 7- pressure transducer, 8- lower table for compression, 9- matrix base, 10- measurement matrix, 11- leading screw, 12- column, 13- piston, 14- distance sleeve, 15- piston-mounting holder, 16- upper table for compression, 17- clamp holder, 18- lower bar, 19- nut, 20- heating band, 21- type 361 wired temperature sensor, 22- R-700 temperature controller, 23- control panel, 24- elements controlling the speed of operation, 25- elements for the measurement of electric values. 26- computer

Rys. 1. Schemat stanowiska do badania procesu zagęszczania materiałów roślinnych : 1- podstawa, 2- cylinder, 3- encoder, 4- limity bezpieczeństwa, 5- silnik, 6- łańcuch, 7- przetwornik ciśnienia, 8- stolik dolny do ściskania, 9- podstawa matrycy, 10- matryca pomiarowa, 11- śruba prowadząca, 12- kolumna, 13- tłoczek, 14- tulejka dystansowa, 15- uchwyt mocujący tłok, 16- stolik górny do ściskania, 17- uchwyt zaciskowy, 18- belka dolna, 19- nakrętka, 20- opaska grzejna, 21- przewodowy czujnik temperatury typ361, 22- regulator temperatury R-700, 23- pulpit sterowniczy, 24- elementy sterujące prędkością pracy, 25- elementy do pomiaru wartości elektrycznych. 26- komputer

The densification chamber used for the tests (fig. 2) enables the control of the process temperature (it is possible to heat the chamber to a temperature of over 100 ^{o}C), owing to the temperature controller coupled with the heating band.

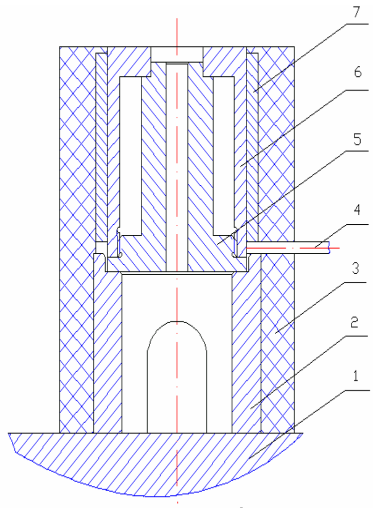

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Fig. 2. Densification chamber: 1- lower table of the universal testing machine, 2- base of the densification chamber, 3- insulation (mineral wool), 4- 361 type thermal pair, 5- internal part of the densification chamber, 6- thermostat element, 7- heating band

Rys. 2. Komora zagęszczania: 1- stolik dolny maszyny wytrzymałościowej, 2- podstawa komory zagęszczania, 3- izolacja (wełna mineralna), 4- termopara typu 361, 5- wewnętrzna część komory zagęszczania, 6- element termostatujący, 7- opaska grzejna

The analysis of the recorded curves of forces occurring during the densification was performed with the use of Statistica 10.0Pl software.

The tests of densification of the mixture of oat bran and potato pulp were performed at changing material and process parameters: the diameter of particles of a fraction of a mixture of oat bran and potato pulp (1, 1.5, and 2 mm), and the speed of travel of the densification piston (50, 100, and 150 mm/min).

The tests were performed at a temperature of 70^{o}C, using a matrix with a diameter opening of 8 mm and length of 47 mm. During the tests, 20 samples of material with a mass of 1 g were subjected to densification (for each of the points of the test plan).

The potato pulp was shredded in two stages. The pulp, preliminarily shredded by means of a spoon, was put on a sieve with a mesh diameter of 1 mm and placed on a WU-3 laboratory shaker. As a result of shaker action, particles with a diameter of approx. 1 mm and less were produced from the tightly packed matter, which allowed for an adequate course of the process of mixing with oat bran.

The determination of the moisture content of the tested waste was performed pursuant to PN-76/R-64752 by means of a WPE 300S moisture balance. Each time, the moisture content of five samples with a mass of 5 g, dried in a temperature of 105°C until a constant mass was achieved, was determined. An average value from the obtained results was adopted as the final result.

The determination of density was carried out by measuring the height and diameter of 15 pellets using a caliper with an accuracy of ±0.02 mm, and determining their mass by means of a laboratory balance with an accuracy of ±0.001 g. The density of the agglomerate was calculated as the relationship between the mass of the pellets and the sum of their volumes.

4. Results of the tests

The results of the tests of the influence of the diameter of particles of a fraction of the densified mixture of potato pulp and oat bran, and the speed of travel of the densification piston on the maximum densifying pressures and the quality of the obtained pellets are presented in table 1, fig. 4, and fig. 5.

Table 1. Test results of influence of the diameter of particles of a fraction of the potato pulp and oat bran densified mixture, and the progression speed of densification piston on the course of densification process and quality of obtained pellets
Tab. 1. Wyniki badań wpływu średnicy cząstek frakcji zagęszczanej mieszanki wycierki ziemniaczanej w mieszaninie z otrębami owsianymi oraz prędkość przesuwu tłoka na przebieg procesu zagęszczania i jakość uzyskanego granulatu

x_i	Particle diameter $x_1= d_f$ [mm]	Piston speed $x_2= v_t$ [mm/min]	Maximum densifying pressures p_{max} [MPa]	Pellets density ρ_g [kg/m^3]
1	1	50	42.89	1043.70
2	1.5	50	36.99	1014.03
3	2	50	16.23	876.78
4	1	100	46.26	1085.83
5	1.5	100	41.37	1067.81
6	2	100	17.32	900.93
7	1	150	48.56	1115.67
8	1.5	150	44.59	1085.45
9	2	150	17.81	918.51

Source: own work / Źródło: opracowanie własne

An example curve of the maximum force under the piston as a function of the travel of the piston (print screens from the software operating the universal testing machine) obtained at different parameters are shown in fig. 3.

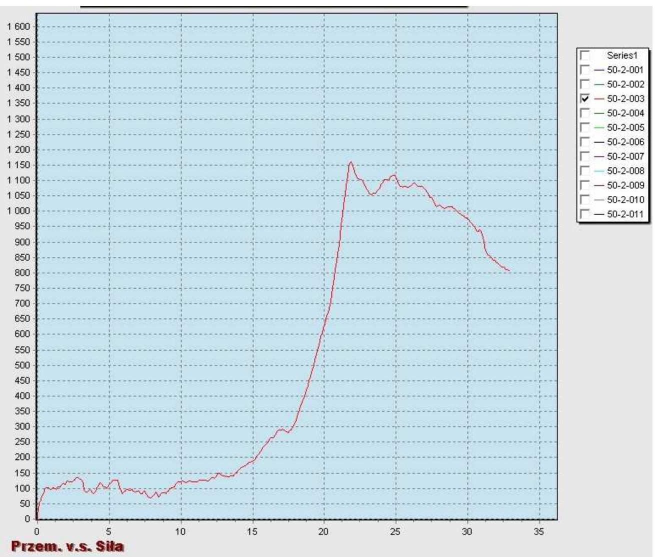

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Fig. 3. The curve of the maximum force under the piston as a function of the progression of the piston (print screens from the software operating the universal testing machine) obtained at the following parameters: v_t=50 mm/min, t_p=70^{o}C, d_f=2 mm
Rys. 3. Przebieg zależności maksymalnej siły pod tłokiem w funkcji przemieszczenia tłoka (zrzuty ekranów z programu obsługującego maszynę wytrzymałościową) uzyskane przy parametrach: v_t=50 mm/min, t_p=70^{o}C, d_f=2 mm

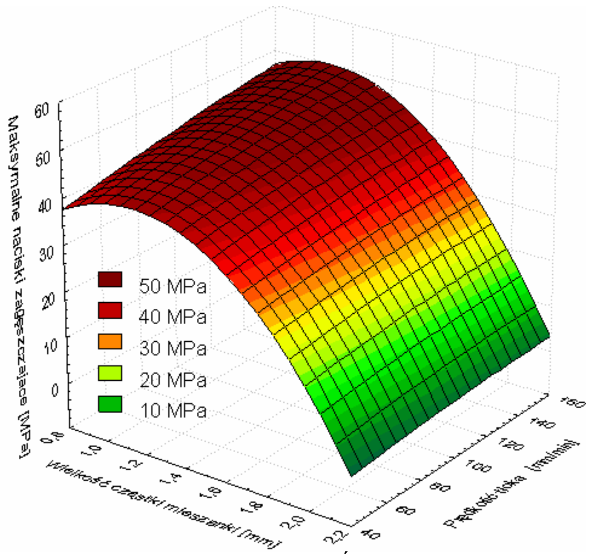

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Fig. 4. Influence of diameter of particles of a fraction of the potato pulp and oat bran densified mixture, and speed of progression of piston on the maximum values of densifying pressures
Rys. 4. Wpływ średnicy cząstek frakcji zagęszczanej mieszanki wycierki ziemniaczanej w mieszaninie z otrębami owsianymi oraz prędkość przesuwu tłoka na wartości maksymalnych nacisków zagęszczających

On the basis of the performed tests (tab. 1 and fig. 4), it can be concluded that increasing the diameter of particles of a fraction of the densified mixture of potato pulp and oat bran causes a reduction of the maximum densifying pressures, whereas an increase of the speed of travel of the densification piston influences a slight increase of the maximum vales of densifying pressures. For example, increasing the diameter of particles of a fraction of the densified mixture of potato pulp and oat bran from 1 to 2 mm (at a speed of the densification piston of 50 mm/min) causes a reduction of the maximum densifying pressures from 42.89 MPa to 16.23 MPa.

On the other hand, increasing the speed of travel of the densification piston from 50 to 150 mm/min (at a particle size of the densified material of 1 mm), for example, influences a slight increase of the maximum densifying pressures from 42.89 MPa to 48.56 MPa. The explanation for this increase is the addition of potato pulp, which caused the occurrence of binder material (in the form of a sticky liquid created from starch and moisture) in the densified mixture during the process of pelletization at a temperature of 70 ^{o}C. This occurs despite the shorter time the mixture remains in the opening, which is connected with the shortening of the time of relaxation of stresses in the formed pellets [5] as a result of the increase of the speed of the densification piston. However, the presence of the resultant sticky liquid caused, in the case of oat bran, an increase of the resistance to forcing, in comparison with the densification of oat bran alone. In consequence, the increase of the resistance to forcing resulted in an increase of the maximum densifying pressures. During the densification of oat bran alone, the slippery oat hulls and the low quantity of endosperm remaining in the bran, in addition to the low moisture content, resulted in the bran's tendency to slide on the surface of the matrix opening and being forced through the matrix opening at low densifying pressures [18]. An addition of pulp of 20% caused an increase of the moisture content of the densified mixture of up to approx. 20.5% and a reduction of the tendency to slide on the surface of the matrix opening and an increase of the densifying pressures. This level of addition allows to obtain pellets of a satisfactory quality (the density of the obtained pellets from aprox, 900 to 1115.67 kg/m^3), which makes them a solid fuel of full value.

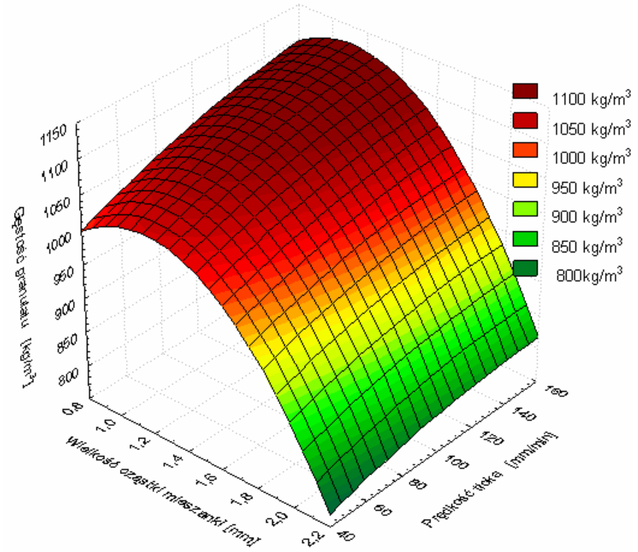

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Fig. 5. Influence of diameter of particles of a fraction of the potato pulp and oat bran densified mixture, and the speed of progression of piston on the pellets density

Rys. 5. Wpływu średnicy cząstek frakcji zagęszczanej mieszanki wycierki ziemniaczanej w mieszaninie z otrębami owsianymi oraz prędkość przesuwu tłoka na gęstość granulatu

On the basis of the performed tests (tab. 1 and fig. 5), it was concluded that an increase of the diameter of particles of a fraction of the densified mixture of potato pulp and oat bran causes a reduction of the density of pellets, whereas an increase of the speed of travel of the densification piston influenced a slight increase of the density of the obtained pellets. For example, a reduction of the diameter of particles of a fraction of the densified mixture of potato pulp and oat bran from 2 to 1 mm (at a speed of the densification piston of 50 mm/min) caused an increase of the density of the obtained pellets from 876.78 to 1043.70 kg/m^3. According to Zawiślak [27] this was caused by the fact that the insufficient shredding of the material failed to make use of the gluing effect of starch, which resulted in a lowering of the stability of pellets. This is also confirmed in research by Mani et al. [12] who claim that a reduction of particle size of densified corn straw (from 3.2 mm through 1.6 mm to 0.8 mm) influences an increase of pellets density from 5 to 16%. Similar results were obtained by Kaliyan and Morey [6], who by reducing the size of corn straw particles from 0.80 to 0.66 mm obtained an increase of the density of briquettes by 5 to 10%. In the case of densification of grasses, a reduction of particle size from 0.64 to 0.56 mm did not have a significant influence on pellets density [6].

On the other hand, an increase of the speed of travel of the densification piston from 50 to 150 mm/min (at a particle size of the densified material of 1 mm), for example, influenced a slight increase of the density of the obtained pellets from 1043.70 to 1115.67 kg/m^3.

This increase is not caused by the increasing values of densifying pressures, which increase together with the increasing speeds of travel of the densification piston. The increasing resistance to forcing and the action of the sticky liquid that is a mixture of moisture and potato starch contained in the pulp caused an increase of the density and the kinetic durability of the obtained pellets, which, after cooling and settling, together with the bran, formed stable and durable pellets.

5. Conclusions

1. An increase of the diameter of particles of a fraction of the densified mixture of potato pulp and oat bran from 1 to 2 mm influences the reduction of the maximum densifying pressures and the reduction of pellets density.
2. Increasing the speed of travel of the densification piston from 50 to 150 mm/min influences a slight increase of the maximum values of densifying pressures, and a slight increase of the density of the obtained pellets.
3. An addition of potato pulp of 20% in a mixture with oat bran allows to obtain pellets of a satisfactory quality, which makes them a solid fuel of full value.

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