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AGGLOMERATION OF STRAW AND HARD COAL WITH AN ADDITIVE OF POTATO PULP – EXPERIMENTAL STUDY

Summary

The paper presents experimental investigations on pressure agglomeration of straw with 20% hard coal addition at various potato pulp contents and at varying process temperatures. Compaction was carried out on a laboratory stand with an open compaction chamber. The experiment was performed at potato pulp contents of 15, 20 and 25% and at temperatures of 40, 50, 70 and 90°C. The effect of densification temperature and potato pulp content on medium and maximum compacting pressures, average compaction force, compaction work and density of obtained granulate was determined. The use of the binder and increase the process temperature have resulted in a reduction in the value of maximum agglomeration pressures and a reduction in the density of the obtained pellets.

***Key words**: granulate, binder, agglomeration pressures, granulate density*

ZAGĘSZCZANIE SŁOMY I WĘGLA KAMIENNEGO Z DODATKIEM WYCIERKI ZIEMNIACZANEJ – BADANIA EKSPERYMENTALNE

Streszczenie

Opisano eksperymentalne badania nad ciśnieniowym zagęszczaniem słomy z 20% dodatkiem węgla kamiennego przy różnych zawartościach wycierki ziemniaczanej oraz w zmiennych temperaturach prowadzenia procesu. Zagęszczanie przeprowadzono na stanowisku laboratoryjnym z otwartą komorą zagęszczającą. Doświadczenie wykonano przy zawartości wycierki ziemniaczanej wynoszącej 15, 20 i 25% oraz w temperaturach 40, 50, 70 i 90°C. Określono wpływ temperatury zagęszczania i zawartości wycierki na średnie i maksymalne naciski zagęszczające, średnią siłę zagęszczającą, pracę zagęszczania oraz gęstość otrzymanego granulatu. Zastosowanie dodatku do wytwarzania granulatu oraz wzrost temperatury procesu wpłynęły na zmniejszenie wartości maksymalnych nacisków zagęszczających oraz na obniżenie gęstości uzyskanego pelletu.

***Słowa kluczowe**: granulat, lepiszcze, naciski zagęszczające, gęstość granulatu*

1. Introduction

A wide range of organic and inorganic substances contained in various plant materials makes that every material subject to pressure agglomeration should be analyzed individually in terms of its susceptibility to granulation and briquetting [1]. According to Berghel and co-workers [2], one way to improve the quality of pellets is to use additives in the course of its production, giving, for example lignin from packing paper. During their experiments on a small industrial press they added 1 to 4% lignin. They found that the increase in the amount of lignin increases the mechanical strength and length of the pellet. Stahl and Berghelbada [3] produced fuel pellets from a mix of sawdust and post-production turnip waste produced in the production of turnip oil. They found that along with the increase in the content of turnip waste in the agglomerated mixture, the energy consumption of the pelleting process decreases, as well as the mechanical strength and the density of the obtained granulate decreases. Sotannde and co-workers [4] conducted research on the influence of binder (arabic gum and manioc starch) in the process of agglomeration (briquetting) charred (torrefied) at a temperature of up to 450°C wood waste from forestry production. The obtained results showed that the use of both binder materials allows obtaining briquettes of high quality (high kinetic strength and high calorific value). Mediavilla and co-workers [5] show that addition of corn starch or lignosulfonate (in the amount of 2,5; 5,0 and 7,0% dry matter) increases the process stability and decreases the energy demand during pelleting poplars. According to Grochowicz [6] and other researchers [7, 8] starch has the unique ability to convert its crystalline structure into a viscous gel (during the baroterm process), which dissolves in a large volume with other particles. After passing through the matrix and cooling the granulate, the starch begins to crystallize, becoming a hard and solid structure. Finney and others [9], assessed the temperature and impact of the addition of caustic soda and corn starch as a binder in the biomass compaction process, claiming that the quality of granules (pellets) could increase by agglomerating at elevated temperatures (45-75°C), in which lignin softening (one of the biomass components - a natural binder) would occur. Obidziński and others [10] applied potato pulp in the process of post-harvest tobacco waste agglomeration, obtaining high-quality pellets using an addition of 15% potato pulp. Other studies carried out by Obidziński and others [11] show that the addition of binder in the form of 5% potato pulp to nettle waste allows it to agglomerate. The high moisture content contained in potato pulp limits its direct application to the production of solid fuels [12]. According to Nielsen and co-workers [13] during the pelleting process the temperature of the pelleting process and the moisture of the raw material are the key parameters affecting the susceptibility to pelleting sawdust and hardness of the obtained granulate. With the increase in the process temperature of the pelleting process and the moisture of the raw material. With the increase of the process temperature and moisture of the raw material, there is a reduction in the energy demand for the pelleting process. Increasing the temperature significantly increases the strength of the granulate, while increasing the moisture content of the raw material reduces the strength of the granulate due to the lowering of frictional resistance against the matrix wall. Razuan and others [14] investigated the impact of densification pressure, temperature, biomass moisture and the effect of binder addition on the density and strength of the granulate made from palm parenchyma. In their research, they found that with the granulation temperature ranging from 20 to 40°C, the granulate strength ranged from 358 kPa to 914 kPa. In this temperature range, the density of granules increased slightly from 1157 $kg \cdot m^{-3}$ to 1200 $kg \cdot m^{-3}$. The optimum granulation temperature is 80-100°C. Above the temperature of 100°C, the granules' expansion effect occurred due to evaporation of moisture contained in the material, which in turn causes a decrease in density and strength of the granulate. According to Czekała and others [15], the introduction of a waste recycling system for solid fuels in production plants is beneficial both in economic and ecological terms.

The following paper presents experimental investigations of compaction of a mixture of straw and hard coal with an addition of potato pulp in an open agglomeration chamber. At the same time, the effect of densification temperature and potato pulp content on medium and maximum compacting pressures, average compaction force, compaction work and density of the obtained granulate was determined.

2. Aim of the study

The aim of the research is to analyze the structural problems in plant materials granulators for small and medium production plants.

3. Materials and methods

The examination of the rye straw agglomeration process with the addition of hard coal was carried out on the SS-3 test stand (Fig. 1).

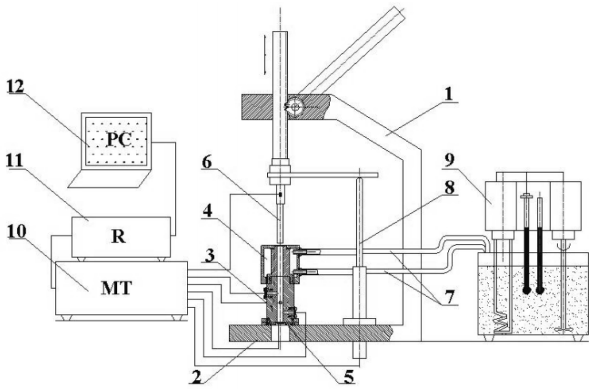


Fig. 1. Scheme of the SS-3 test stand for testing the agglomeration process [16]: 1 - press, 2 - base, 3 - compaction chamber, 4 - thermostatic element, 5 - chamber bottom, 6 - compacting piston, 7 - stub pipes, 8 - displacement sensor, 9 - ultrathermostat, 10 - strain gauge bridge, 11 multichannel recorder, 12 - computer

Rys. 1. Stanowisko SS-3 do badania ciśnieniowej aglomeracji [16]: 1 - praska, 2 - podstawa, 3 - komora zagęszczania, 4 - element termostatujący, 5 - dno komory, 6 - tłok zagęszczający, 7 - króćce, 8 - czujnik przemieszczenia, 9 - ultratermostat, 10 - mostek tensometryczny, 11 - rejestrator wielokanałowy, 12 - komputer

The open agglomeration chamber 3 is the basic element of the test stand. The heating of the agglomeration chamber is carried out by a heating band 4a, temperature regulation is enabled by the temperature controller 10. Agglomeration of the material takes place by means of the compaction piston 6, on which a strain gauge has been placed allowing to register the forces. In the form of an electrical voltage, the signal is transferred to the recorder 9, the binary signal is converted to digital and sent to the computer 10. The mass of a single sample was 0,6 g, the height of the agglomeration chamber was equal to 47 mm.

x_1 = tp – process temperature (30, 50, 70 and 90°C)

The moisture determination was carried out according to [10] using a moisture analyzer WPE - 300S allowing to determine the humidity with an accuracy of 0.01%.

x_2=w – potato pulp content (10, 15, 20%).

As dependent variables were included:

– medium force under the piston F,
– maximum agglomeration pressures p_{max},
– medium agglomeration pressures p_{av},
– work of agglomeration L_z,
– density of obtained granulate ρ_g.

Density of the obtained product was determined after 24 hours by measuring granules geometric dimensions using a caliper with an accuracy of ± 0.02 mm. From the obtained dimensions, the volume of obtained granules was calculated. The granules were then weighed using a WPE - 300S scale with an accuracy of ± 0.01 g. The granulate density ρ_g was calculated as:

$$\rho_g = \frac{m_g}{V_g}\left[\frac{kg}{m^3}\right], \tag{1}$$

where:
m_g – granulate mass [kg],
V_g – granulate volume [m^3].

The agglomeration work for the obtained granulate was calculated from the formula:

$$L_z = F \cdot l[J], \tag{2}$$

where:
F – average agglomeration force under the piston [N],
l – displacement of the piston during agglomeration [m].

The material used for the research consisted of a mixture of ground cereal straw with the addition of 20% crushed hard coal (4 : 1 ratio). Potato pulp was added to the mixture with concentrations mentioned before in the paper.

4. Results

This chapter presents the results of tests for agglomeration of rye straw with the addition of hard coal.

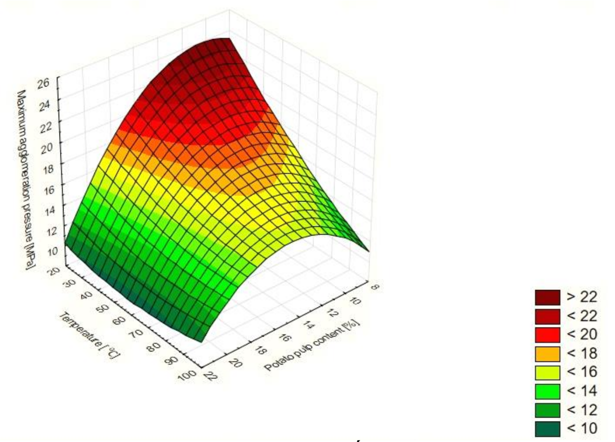
Analyzing the obtained test results (Tab. 1, Fig. 2), it can be noticed that as the process temperature rises from 30 to 90°C, the maximum agglomeration pressure decreases.

For example, an increase in temperature from 30 to 90°C (at the content of a 10% potato pulp) resulted in a decrease in the maximum agglomeration pressures from 23,1 to 15,5 MPa. A similar tendency occurs at the content of 15% potato pulp, when the maximum agglomeration pressures slightly decrease from 19,29 to 18,88 MPa, and at 20% potato pulp content - the maximum agglomeration pressures fall from 13,38 to 9,71 MPa.

Table 1. Results of the agglomeration process of rye straw with 20% of hard coal and potato pulp
Tab. 1. Wyniki badań procesu aglomeracji słomy żytniej z udziałem 20% węgla kamiennego i wycierki ziemniaczanej

No	Independent variables		Dependent variables				
	x_1=t_p [°C]	x_2=w [%]	Average force under the piston [N]	Maxiumum agglomeration pressures [MPa]	Avrerage agglomeration pressures [MPa]	Work of agglomeration [J]	Pellet density [kg·m^{-3}]
1.	30	10	491,17	23,10	7,80	18,17	1117,36
2.	30	15	444,06	19,29	7,05	16,43	947,55
3.	30	20	285,85	13,38	4,54	10,58	623,72
4.	50	10	611,58	22,45	9,71	22,63	1174,64
5.	50	15	379,18	15,94	6,02	14,03	898,67
6.	50	20	335,86	15,26	5,33	12,43	695,24
7.	70	10	297,39	10,81	4,72	11,00	1104,96
8.	70	15	545,85	18,36	8,66	20,20	888,51
9.	70	20	373,82	14,13	5,93	13,83	677,56
10.	90	10	505,51	15,50	8,02	18,70	936,92
11.	90	15	607,65	18,88	9,49	22,48	867,04
12.	90	20	266,67	9,71	4,23	9,71	576,73

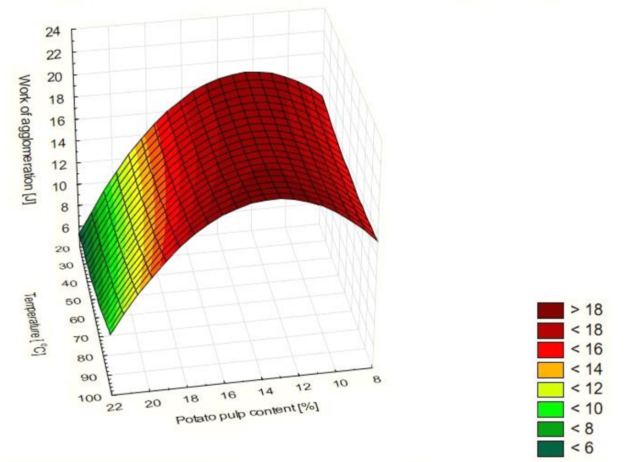
Source: own work / Źródło: opracowanie własne



Source: own work / Źródło: opracowanie własne
Fig. 2. The influence of material and process factors on the maximum compaction pressures obtained during the compaction of straw with hard coal and potato pulp
Rys. 2. Wpływ czynników materiałowych i procesowych na maksymalne naciski zagęszczające uzyskane podczas zagęszczania słomy z udziałem węgla kamiennego i wycierki ziemniaczanej

Increasing the potato pulp content from 10 to 20% causes a decrease in the maximum agglomeration pressures (at the process temperature of 30°C - from 23,1 to 13,38 MPa, at 50°C - from 22,45 to 15,26 MPa). At a temperature of 70°C, an increase in the content of potato pulp from 10 to 15% results in an increase in maximum compaction pressures from 10,81 to 18,36 MPa, while further increasing the content of pulp from 15 to 20% resulted in a decrease in agglomeration pressure to 14,13 MPa. At temperature of 90°C, increasing the content of pulp from 10 to 15% caused an increase in the maximum agglomeration pressures from 15,5 to 18,88 MPa, while a with a further increase in the content of pulp from 15 to 20% the maximum agglomeration pressures decrease to 9,71 MPa.

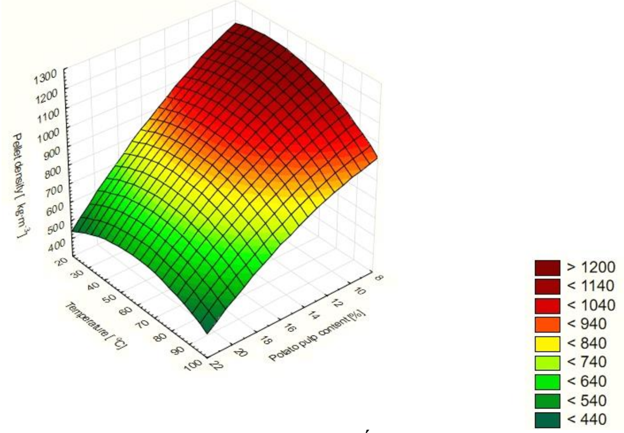
On the basis of the obtained test results (Fig. 3 and Tab. 1), it can be concluded that along with the increase in the compactness from 10 to 15%, the agglomeration work increases, whereas with a further proportion of potato pulp content of 20%, the agglomeration work decreases. The recorded drop is caused by the improvement of the lubricating properties of the material, which results in a decrease in the transfer resistance resulting in a reduction in agglomeration work.



Source: own work / Źródło: opracowanie własne
Fig. 3. The influence of material-process factors on the work of agglomeration obtained during the compaction of straw with hard coal and potato pulp
Rys. 3. Wpływ czynników materiałowych i procesowych na pracę zagęszczania uzyskaną podczas zagęszczania słomy z udziałem węgla kamiennego i wycierki ziemniaczanej

For example, with the process temperature ranging from 30 to 90°C (at 10% pulp content), there is a slight increase in the agglomeration work from 18,17 to 18,7 J. With a 15% pulp content (when the temperature rises from 30 to 90°C) there is an increase in the agglomeration work from 16,43 to 22,48 J, while at the highest content of potato pulp - 25%, in the same temperature range, the work of agglomeration slightly decreases from 10,58 to 9,71 J.

Increasing the content of the pulp from 10 to 20% in the mixture agglomerated at 30°C results in a reduction of the agglomeration work from 18,17 to 10,58 J. Increasing the process temperature from 30 to 50°C and increasing the content of potato pulp from 10 to 20% reduces the agglomeration work from 22,63 to 12,43 J. When the content of pulp is increased from 10 to 15%, at a process temperature of 70°C, the agglomeration work increases from 11 J to 20,2 J. With further increasing the content of pulp from 15 to 20% the agglomeration work is reduced to 13,83 J. At the highest temperature of 90°C with an increase in the content of pulp from 10 to 15%, the agglomeration work increases from 18,7 to 22,48 J, and with a further increase in the content of potato pulp from 15 to 20% it decreases to 9,71 J.



Source: own work / Źródło: opracowanie własne

Fig. 4. The influence of material-process factors on the density of granules obtained during the compaction of straw with hard coal and potato pulp

Rys. 4. Wpływ czynników materiałowych i procesowych na gęstość granulatu uzyskanego podczas zagęszczania słomy z udziałem węgla kamiennego i wycierki ziemniaczanej

Source: own work / Źródło: opracowanie własne

Fig. 5. View of the granulate from a mixture of straw and hard coal with a 20% addition of a potato pulp, obtained at a temperature of 70°C

Rys. 5. Widok granulatu z mieszaniny słomy i węgla kamiennego z dodatkiem 20% wycierki ziemniaczanej, otrzymanego przy temperaturze 70°C

Source: own work / Źródło: opracowanie własne

Fig. 6. View of the granulate from a mixture of straw and hard coal with a 15% addition of a potato pulp, obtained at a temperature of 70°C

Rys. 6. Widok granulatu ze mieszaniny słomy i węgla kamiennego z dodatkiem 15% wycierki ziemniaczanej, otrzymanego przy temperaturze 70°C

Analyzing the obtained test results (Table 1, and Fig. 4), it can be noticed that with the increase in the content of potato pulp in the mixture from 10 to 20%, the density of the granulate decreases. A similar tendency (decrease in granulate density) occurs with the increase in process temperature from 30 to 90°C.

When the process temperature increases from 30 to 90°C (at 10% of potato pulp), the granulate density decreases from 1130,14 to 936,92 kg·m^{-3}, with a 15% pulp concentration in the same temperature range, granulate densities decrease from 947,55 to 867,04 kg·m^{-3}. At 25% content of pulp, the density also decreases from 623,72 to 576,73 kg·m^{-3}.

When the content of potato pulp is increased from 10 to 20%, at 30°C, the density of the granulate decreases from 1117,36 to 947,55 kg·m^{-3}. At a temperature of 50°C there is also a decrease from 1184,63 to 696,92 kg·m^{-3}. A similar decrease in density occurs at 70°C (for 70 ° C the density is from 1111,48 to 677,88 kg·m^{-3}), and at 90°C the density also falls from 951,23 to 578,04 kg·m^{-3}. Granules with the highest density of 1184,64 kg·m^{-3} were obtained for 10% pulp content in the mixture, at a process temperature of 50°C. At the highest content of the pulp (20%), the starch contained in the potato pulp caused sticking of the thickened material to the walls of the agglomeration chamber, which caused the granules leaving the chamber to have an uneven, strongly frayed surface (Fig. 5).

At 15% content of potato pulp, an uneven, fuzzy surface of the obtained granulate is also observed, the reason is, similarly to the 20% addition of the pulp, i.e. a large amount of "adhesive" (viscous gel) produced from potato pulp and moisture, which causes sticking of material to the wall of the agglomeration chamber (Fig. 6).

At the lowest content of added pulp (10%), granules with a compact, even surface as well as the highest density were obtained (Fig. 7). It can be concluded that the added amount of pulp is the most advantageous in terms of the density of the obtained granules.

Source: own work / Źródło: opracowanie własne

Fig. 7. View of the granulate from a mixture of straw and hard coal with a 15% addition of a potato pulp, obtained at a temperature of 30°C

Rys. 7. Widok granulatu z mieszaniny słomy i węgla kamiennego z dodatkiem 20% wycierki ziemniaczanej, otrzymanego przy temperaturze 30°C

5. Conclusions

On the basis of conducted agglomeration tests of a mixture of straw and hard coal with the addition of potato pulp, the following conclusions were made:

1. Increasing the content of potato pulp in a thickened mixture of straw and coal from 10 to 15% and increasing the temperature from 30 to 90°C caused a decrease in agglomeration pressures, compaction work and density of the obtained product.

2. The addition of potato pulp to the mixture, as a binder, resulted in a decrease in agglomeration pressures and enabled the product to obtain a similar density at lower agglomeration pressures, which indicates an increase in susceptibility of the tested mixture to compaction.
3. Granules with the highest density from a mixture of straw and coal with the addition of potato pulp were obtained at a 10% addition of potato pulp, at a process temperature of 50°C.

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