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RESEARCH OF THE DENSIFICATION PROCESS OF POST-HARVEST TOBACCO WASTE

Summary

This paper presents the results of tests of the densification process of a mixture of plant-type post-harvest tobacco waste and a mixture of post-harvest tobacco waste and a binder in the form of potato pulp. Initial densification tests were carried out on a modernized SS-3 stand, with a working system of the "open densification chamber-densifying piston" type, employing an open chamber with a diameter of 8 mm. During the tests, susceptibility to densification of shredded tobacco waste and a mixture of shredded tobacco waste with potato pulp were assessed, by determining the maximum densifying pressures for the material and the density of the obtained pellets. On the basis of the performed tests, it was concluded that the tested tobacco waste is characterized by a high susceptibility to densification, as indicated by the obtained low values of maximum densifying pressures during its densification. Adding potato pulp to tobacco waste had a positive impact on the mixture's susceptibility to densification and an increase in the quality of pellets. The tested pellets from tobacco waste are a material of high energy qualities.
***Key words**: densification, tobacco waste, binder, potato pulp, density*

BADANIA PROCESU ZAGĘSZCZANIA POZBIOROWYCH ODPADÓW TYTONIOWYCH

Streszczenie

W pracy przedstawiono wyniki badań procesu zagęszczania mieszaniny roślinnych pozbiorowych odpadów tytoniu oraz mieszaniny pozbiorowych odpadów tytoniu i lepiszcza w postaci wycierki ziemniaczanej. Badania wstępne zagęszczania przeprowadzono na zmodernizowanym stanowisku SS-3, z układem roboczym „otwarta komora zagęszczania-tłok zagęszczający", używając komory otwartej o średnicy 8 mm. W trakcie badań określono podatność na zagęszczanie rozdrobnionych odpadów tytoniowych oraz mieszaniny rozdrobnionych odpadów tytoniowych i wycierki ziemniaczanej, poprzez określenie maksymalnych nacisków zagęszczających surowiec oraz gęstości uzyskanego granulatu. Na podstawie przeprowadzonych badań stwierdzono, że badane odpady tytoniowe są materiałem charakteryzującym się wysoką podatnością na zagęszczanie, o czym świadczą uzyskane niewielkie wartości maksymalnych nacisków zagęszczających w trakcie jego zagęszczania. Zastosowanie dodatku wycierki ziemniaczanej do odpadów tytoniowych, wpłynęło na polepszenie podatności mieszanki na zagęszczanie oraz poprawę jakości granulatu.
***Słowa kluczowe**: zagęszczanie, odpady tytoniowe, lepiszcze, wycierka ziemniaczana, gęstość*

1. Introduction

In the coming years, among the most prospective sources for the production of clean, ecological energy there will be post-production waste materials obtained in during processing agricultural and food materials, e.g. buckwheat hulls obtained during the production of groats [27], rapeseed pellets obtained during the production of rape oil [10, 23], potato pulp which is a byproduct of starch production [17], corn bran obtained during the production of flour and other corn products [20, 26], fruit pomace obtained during the production of fruit juice [25] and many more.

One of the types of waste material obtained during the production of tobacco leaves for the needs of tobacco plants are tobacco stalks left over in the fields.

According to Gwiazdowski and his colleagues [6], Poland is the second biggest, after Italy, European producer of tobacco. In the years 2006-2009 Poland produced from 39.500 to 43.000 tonnes of the tobacco material a year. The size of tobacco harvest in 2012 was 31,600 tonnes, while 39.500 tonnes were contracted for the year 2013. The average yield for the years 2011-2012 was approx. 2 tonnes of tobacco from 1 ha of cultivation [6].

According to Czerwińska and her colleagues [4], tobacco stalks contain up to 40% of cellulose, while their mass constitutes up to 45% of the total dry mass of the overground part of the plant. This means that 17.500 to 19.000 tonnes of stalk can be utilized each year.

To a small extent, waste in the form of stalks is partly utilized. According to many authors [3, 13] tobacco stalks are treated as solid waste and disposed of, put into stacks and burnt, or used as litter.

The high bulk of stalks and their cellulose content give possibilities of utilization in the paper industry [2, 11, 15, 24] or in production of furniture boards [4, 15]. This is confirmed by Hepworth and Vincent [9] who claim that tobacco stalks and the middle parts of tobacco leaves can be used for the production of paper and cardboard.

Another method of utilization of tobacco waste consists in its use as a component for the production of light structural concretes [21], or as raw material for the production of ethanol [15].

Tobacco stalks and the middle parts of leaves are also used as substrate for button mushroom cultivation [16]. Tobacco waste is used for the production of reconstituted tobacco [28] and due to the relatively high content of K and N, can also be used as a substitute for mineral fertilizers [16].

According to Peševski and his colleagues [22], the calorific value of briquettes is ≥18.000 $kJ \cdot kg^{-1}$, which is rather high. This important characteristic indicates that, in a technological sense, the material can be used for an industrial-scale production of briquettes. Peševski and his colleagues [22] claim that nicotine content in dried tobacco stalks is 0.53%, while smoke produced during their combustion is minimal (0.005%), which means that using briquettes for energy production is ecologically allowable.

According to research carried out by Li and colleagues [13] tobacco stalks can be used for producing coal with high absorption properties by means of microwave radiation. Liu and his colleagues [14], on the other hand, used tobacco stalks as a material for the process of pyrolysis.

One of the many methods for utilizing different types of plant waste is its briquetting or pelleting into the form of a solid fuel (pellets, briquettes) [1, 5, 7, 8, 19].

2. The aim of the research

The aim of the paper is to determine the most beneficial values of material and process and construction parameters of the process of densification of post-harvest tobacco waste and a mixture of post-harvest tobacco waste with a binder in the form of potato pulp in the aspect of using the produced pellets as a heating fuel.

The study of densification of the mixture of tobacco waste with potato pulp will determine the parameters for the initial implementation of the pelletisation process of tobacco waste in the working system of the pelletizer with flat matrix.

3. Research methodology

Post-harvest tobacco waste obtained from a private farmstead in the Augustów area cultivating tobacco was used as test material in the study. The waste was harvested in September, in the form of rather long (approx. 30 cm) stalks. Then, these stalks were manually crushed into 10-20 mm long particles and dried. Then the waste was shredded by means of the "Bąk" H-111/1 type beater shredder into approx. 5 mm fractions.

In the course of the tests of the densification process, determined were: the susceptibility to densification of shredded tobacco waste and of a mixture of shredded tobacco waste with potato pulp, by determining the maximum pressures densifying the material and the density of the obtained pellets.

Tests of the densification process were carried out on a SS-3 stand, with the "open densification chamber-densifying piston" working system presented in the papers [17, 18, 20].

The stand was modernized (fig. 1) by using heating band 6 (put on an open densification chamber 7), coupled with temperature controller 3 for temperature control. Densification of the material was carried out by means of piston 5 equipped with tensometric sensor 4 allowing to record forces acting on piston 5.

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

The tests of densification of post-harvest tobacco waste were carried out at two input values, i.e.:

- $x_1 = w_o$ - waste moisture content (12, 15 and 18%),
- $x_2 = t_p$ - process temperature (50, 70 and 90°C).

The tests were carried out at a length of matrix openings of l_m = 47 mm by densifying waste samples with a mass of m_p = 0.7g.

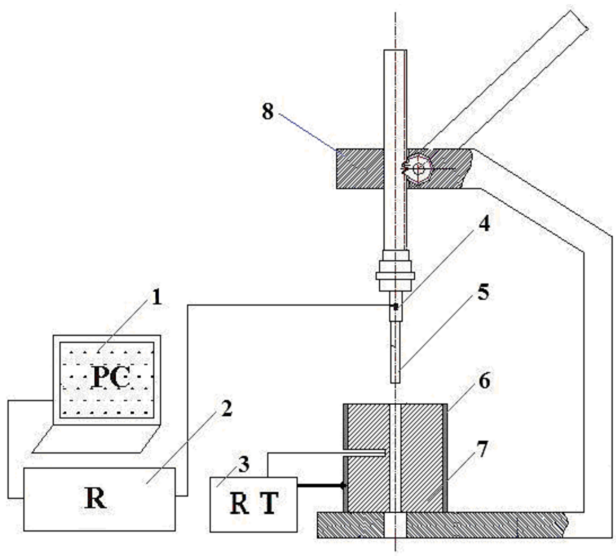


Fig. 1. Scheme of a modernized SS-3 stand papers [17, 18, 20]: 1 - computer, 2 - Spider 8 multichannel recorder, 3 - temperature controller, 4 - tensometric sensor, 5 - densifying piston, 6 - heating band, 7 - densification chamber, 8 - press

Rys. 1. Schemat zmodernizowanego stanowiska SS-3 [17, 18, 20]: 1 – komputer, 2 – rejestrator wielokanałowy Spider 8, 3 – regulator temperatury, 4 – czujnik tensometryczny, 5 – tłok zagęszczający, 6 – opaska grzejna, 7 – komora zagęszczania, 8 – praska

The tests of densification of a mixture of post-harvest tobacco waste and potato pulp, on the other hand, were carried out in accordance with the Hartley PS/DS-P: Ha4 experiment plant, where the input values were: material, process and construction parameters:

- $x_1 = z_w$ - pulp content (15, 20 and 25%),
- $x_2 = t_p$ - process temperature (50, 70 and 90°C),
- $x_3 = m_p$ - mass of the sample (0.5, 0.7 and 0.9g),
- $x_4 = l_m$ - matrix opening length (37, 42 and 47 mm).

The granulometric distribution of tobacco waste was determined with the use of a LPz-2e laboratory vortex mixer by Multiserv Morek, in accordance with the methodology presented in the paper [20], among others, using a set of 7 sieves with the following dimensions: 4mm, 2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.125 mm and 0.063 mm.

Determination of pellets density was performed (24 hours after the densification) by measuring the height and diameter of pellets by means of a caliper with an accuracy of ±0.02 mm and determining their mass by means of a WPS 360 laboratory scale with an accuracy of ±0.001 g. Density was calculated as the ratio of the mass of pellets to the sum of their volumes.

Determination of the moisture content of materials (tobacco waste and the prepared mixtures of pulp and tobacco waste) prior to the densification process was performed pursuant to PN-76/R-64752 by means of a WPE 300S moisture balance with an accuracy of 0.01%, in accordance with the methodology presented in the papers [17, 18].

4. Results of tests

Initial tests allowed to conclude that the tested post-harvest tobacco waste is characterized by a low bulk density of approx. 264 $kg \cdot m^{-3}$.

The performed sieve analysis of waste (after the shredding process) allowed to conclude that the fractions with the highest proportional contents were the fraction with a size of 1 mm (35.4%), the fraction with a size of 0.5 mm, comprising 21,8%, while the fraction with a size of 2 mm comprised 15.5%, the fraction with a size of 0.25 mm comprising 13.1%.

Table 1 shows the results of tests of the densification process of post-harvest tobacco waste, while table 2 shows the results of densification of a mixture of tobacco waste and potato pulp, in accordance with the Hartley PS/DS-P Ha4 experiment plan.

Tab. 1. Results of tests of the densification process of post-harvest tobacco waste

Tab. 1. Wyniki badań procesu zagęszczania pozbiorowych odpadów tytoniu

Independent variables			Dependent variables	
	Moisture content of waste $x_1=w_0$ (%)	Process temp. $x_2=t_p$ (˚C)	Max. densifying pressures (MPa)	Pellets density ($kg \cdot m^{-3}$)
1.	12	50	0.66	544.67
2.	12	70	3.98	842.63
3.	12	90	0.36	545.54
4.	15	50	2.94	848.21
5.	15	70	11.71	890.72
6.	15	90	1.46	736.48
7.	18	50	36.99	1173.01
8.	18	70	17.23	1143.18
9.	18	90	14.86	1056.64

Source: own work / Źródło: opracowanie własne

Tab. 2. Results of tests of the densification process of a mixture of post-harvest tobacco waste and potato pulp, in accordance with Hartley PS/DS-P Ha4 experiment plan

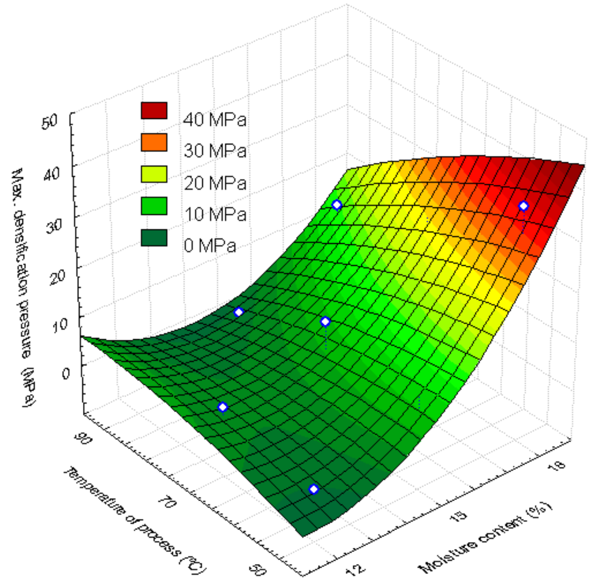
Tab. 2. Wyniki badań procesu zagęszczania mieszaniny pozbiorowych odpadów tytoniu i wycierki ziemniaczanej, zgodnie z planem eksperymentu Hartleya PS/DS-P Ha4

Independent variables					Dependent variables	
	$x_1=z_w$ (%)	$x_2=t_p$ (˚C)	$x_3=m_p$ (g)	$x_4=l_m$ (mm)	Max. densifying pressures (MPa)	Pellets density ($kg \cdot m^{-3}$)
1.	25	50	0.5	37	12.39	974.90
2.	15	90	0.5	37	0.17	495.71
3.	15	50	0.9	37	8.32	824.67
4.	25	90	0.9	37	10.04	962.48
5.	25	50	0.5	47	19.61	950.53
6.	15	90	0.5	47	0.43	580.57
7.	15	50	0.9	47	38.18	1155.39
8.	25	90	0.9	47	12.49	1049.61
9.	15	70	0.7	42	0.38	500.96
10.	25	70	0.7	42	11.64	1086.98
11.	20	50	0.7	42	41.76	1120.29
12.	20	90	0.7	42	14.20	1123.90
13.	20	70	0.5	42	9.57	1041.61
14.	20	70	0.9	42	12.66	1114.66
15.	20	70	0.7	37	9.17	1018.79
16.	20	70	0.7	47	13.11	1115.82
17.	20	70	0.7	42	16.44	1075.81

Source: own work / Źródło: opracowanie własne

Fig. 2 shows the results of tests of the influence of material and process parameters (moisture content of waste and process temperature) on the maximum densifying pressures obtained during the densification of tobacco waste in an open chamber and pellets density.

a)



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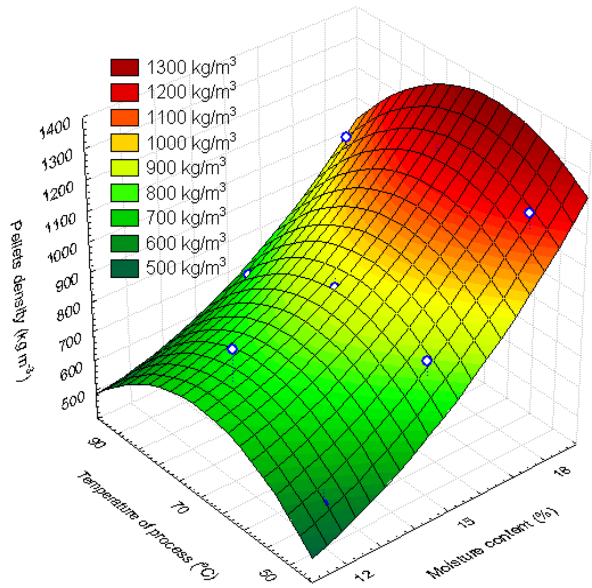


Source: own work / Źródło: opracowanie własne

Fig. 2. Influence of material and process factors (moisture content of waste and process temperature) on: a) maximum densifying pressures obtained during densification of tobacco waste in an open chamber, b) pellets density

Rys. 2. Wpływ czynników materiałowo-procesowych (wilgotność odpadu i temperatura procesu) na: a) maksymalne naciski zagęszczające uzyskane podczas zagęszczania odpadów tytoniowych w komorze otwartej, b) gęstość granulatu

On the basis of the performed tests (fig. 2a and table 1), it can be observed that as the moisture content of tobacco waste increases from 12 to 18%, the values of maximum densifying pressures increase from 0.36 MPa to 36.99 MPa, which has a considerable impact on the energy consumption of the densification process. This increase results from the appearance of additional resistances to pumping, together with an increased moisture content. During densification, at a lower moisture content, the material tended to slide on the surface of matrix openings, while the obtained densifying pressures were extremely low. Increasing the moisture content of waste resulted in the appearance of a resistance to pumping of the densified waste and a reduction of the effect of waste sliding on the surface of matrix openings.

On the basis of the performed tests (fig. 2a and table 1), it can be concluded that increasing the process temperature (at moisture content of waste of 12 and 15%) from 50 to 70°C causes an increase of maximum densifying pressures, while a further increase of temperature from 70 to 90°C causes a reduction of the obtained densifying pressures. At a moisture content of 18%, increasing the process temperature from 50 to 90°C causes a reduction of the obtained densifying pressures. The lowest values of densifying pressures were observed at the maximum process temperature (90°C), regardless of the moisture content of waste. Such a process temperature enables the activation of additional biochemical processes in the densified material and causes the appearance of a lubricant liquid, which has an influence on a reduction of the coefficient of friction between the densified material and the matrix walls. The highest values of densifying pressures (36.99 MPa) were obtained at a waste moisture content of 18% and a process temperature of 50°C.

Increasing the process temperature from 50 to 70°C causes an increase in pellets density (fig. 2b and table 1). For instance, at a process temperature of 50°C, increasing the moisture content of the material from 12 to 18% causes an increase in pellets density from 544.67 to 1173.01 kg·m^{-3} (by approx. 53%). A further increase in temperature from 70 to 90°C causes a reduction in pellets density: by approx. 35%, from 842.63 to 545.54 kg·m^{-3} (at a moisture content of 12%); by 17%, from 890.72 to 736.48 kg·m^{-3} (at a moisture content of 15%); and by 7.6% (from 1143.18 to 1056.64 kg·m^{-3}), at a moisture content of 18%. The observed reduction in density, together with the increase in temperature from 70 to 90°C is connected with expansion of pellets, occurring due to the high pressure and high temperature inside the densification chamber, increasing together with temperature.

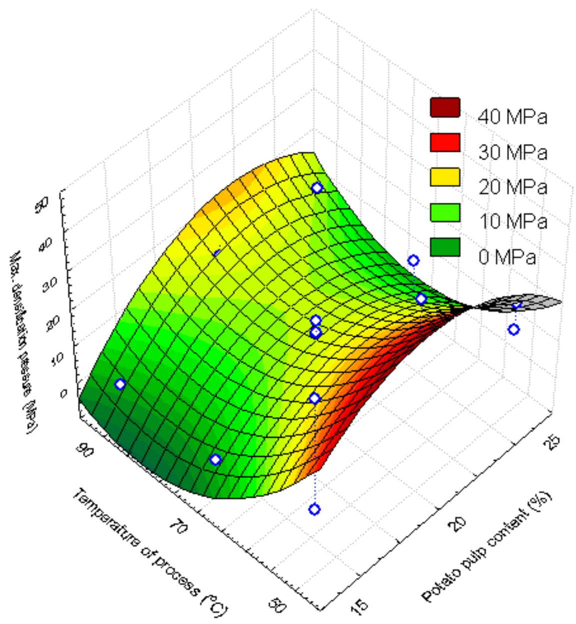
The highest density of the obtained pellets of 1173.01 kg·m^{-3} was observed at a moisture content of 18% and a temperature of 50°C.

On the basis of the performed tests of the densification process of tobacco waste, it was concluded that the material in question is characterized by a high susceptibility to densification. However, when a temperature of the densification process of 70°C was exceeded, an agglomerate of insufficient quality was obtained. The pellets crumbled and spilled easily at a slight manual pressure. It was thus decided that a binder in the form of potato pulp should be used, which would result in an improvement in the quality of pellets obtained in higher temperatures.

Table 2 and fig. 3 show the results of tests of the influence of material and process factors on the maximum densifying pressures obtained during the densification of a mixture of tobacco waste and potato pulp in an open chamber.

Analyzing fig. 3 and table 2, an increase in densifying pressures together with increasing potato pulp content in the mixture from 15 to 20% can be observed. This is caused by the fact that as the content of potato pulp is increasing, additional resistances to pumping appear (similarly to when tobacco waste alone is densified), in comparison to resistances during the densification of a mixture with a lower moisture content, which "slid" on the surface of matrix openings. The additional resistances were caused by the increasing moisture content in the densified material (together with the introduction of potato pulp) which resulted in an increase in densifying pressures.

a)



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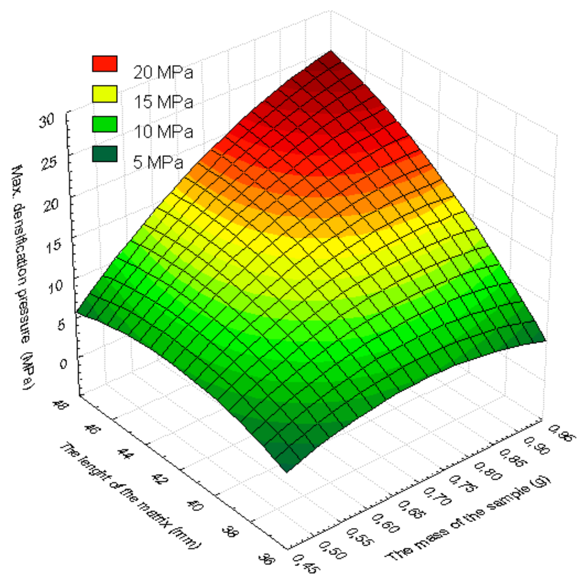

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Fig. 3. Influence of material and process factors on the maximum densifying pressures obtained during the densification of a mixture of tobacco waste and potato pulp in an open chamber: a) influence of pulp content and process temperature, b) influence of the mass of the densified sample and the length of matrix openings

Rys. 3. Wpływ czynników materiałowo-procesowych na maksymalne naciski zagęszczające uzyskane podczas zagęszczania mieszanki odpadów tytoniowych i wycierki ziemniaczanej w komorze otwartej: a) wpływ zawartość wycierki i temperatura procesu, b) wpływ masy zagęszczanej próbki i długości otworów w matrycy

A further increase in potato pulp content from 20 to 25% caused a reduction in maximum densifying pressures. This was caused by the excessively high increase in the moisture content of the mixture (by as much as 25.6 % at a pulp content in the mixture with tobacco waste of 25 %). A high increase in the moisture content causes an increase in the amount of liquid in the contact area between the mixture and chamber walls, which causes a reduction in value of the coefficient of friction and translates into a reduction in densifying pressures.

On the basis of the performed tests (fig. 3a and table 2), it can be observed that as process temperature increases, a reduction in densifying pressures occurs (at each of the tested values of pulp content in the mixture). Together with the increase in temperature, the process of gelatinization of starch contained in the pulp is activated, which contributes to the creation of a higher content of a viscous gel created from starch and water, which causes a reduction of the coefficient of friction between the mixture and the chamber walls, and a reduction in densifying pressures.

The highest value of densifying pressures (41.76 MPa) was obtained at: a matrix opening length of 42 mm, a sample mass of 0.7 g, a potato pulp content of 20%, and a process temperature of 50°C. The lowest value of densifying pressures of 0.17 MPa was obtained at: a matrix opening length of 37 mm, a sample mass of 0.5 g, a pulp content of 15%, and a process temperature of 90°C.

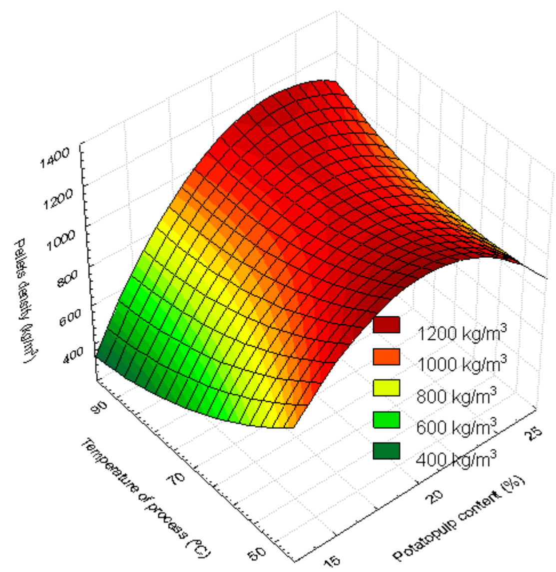
Table 2 and fig. 4 show the results of tests of the influence of material and process factors on the density of pellets obtained during the densification of tobacco waste and potato pulp in an open chamber.

Increasing the potato pulp content from 15 to 20% causes a significant increase in pellets density. For instance, at a process temperature of 70°C, increasing the potato pulp content from 15 to 20% (at a sample mass of 0.7 g and a length of matrix openings of 42 mm) causes an increase in pellets density by 53% (from 500.96 to 1075.81 kg·m^{-3}). At a further increase in potato pulp content in the mixture up to 25%, a slight reduction in pellets density was observed. This reduction is largely connected with the significant increase in the moisture content of the densified mixture.

As the process temperature increases from 50 to 70°C, a reduction in density of the obtained pellets occurs, by approx. 39% (from 824.67 to 500.96 kg·m^{-3}) at a potato pulp content of 15%, and by approx. 7% (from 1120.29 to 1041.61 kg·m^{-3}) at a pulp content of 20%. Only at a potato pulp content of 25%, together with an increase in temperature from 50 to 70°C, an increase in pellets density by 13% (from 950.53 to 1086.98 kg·m^{-3}) was observed. The increase in density is connected with changes occurring in the material as a result of the action of temperature. A further increase in temperature from 70 to 90°C causes a reduction in pellets density. The observed reduction in density, together with an increase in temperature from 70 to 90°C, is connected with an increased content of steam produced and then released from the pellets after leaving the chamber, which has an influence on pellets expansion and, in effect, on the reduction in its density.

Pellets of the highest quality (of the highest density – 1155.39 kg·m^{-3} and a smooth, shiny surface) was obtained at a pulp content of 15%, a process temperature of 50°C, a length of matrix openings of 47 mm, and a mass of the densified sample of 0.9 g.

a)



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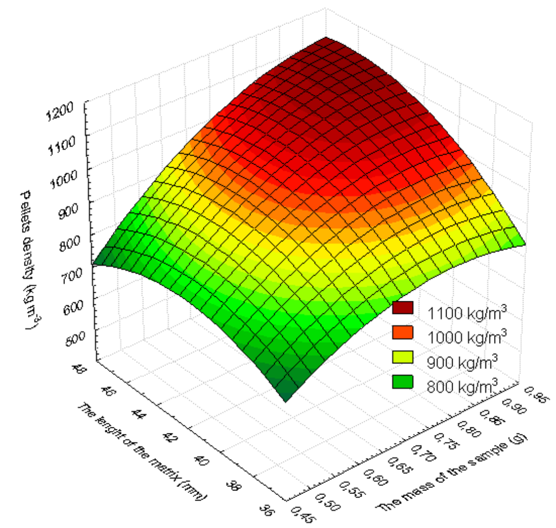

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Fig. 4. Influence of material and process factors on the density of pellets obtained during the densification of a mixture of tobacco waste and potato pulp in an open chamber: a) influence of pulp content and process temperature, b) influence of mass of the densified sample and length of matrix openings

Rys. 4. Wpływ czynników materiałowo-procesowych na gęstość granulatu uzyskanego podczas zagęszczania mieszanki odpadów tytoniowych i wycierki ziemniaczanej w komorze otwartej: a) wpływ zawartość wycierki i temperatura procesu, b) wpływ masy zagęszczanej próbki i długości otworów w matrycy

Increasing the length of matrix openings from 37 to 47 mm causes an increase in pellets density (at each of the masses of the densified samples). This tendency is the most visible in the mass range of 0.7 to 0.9 g. The observed increase in pellets density is connected with increasing resistances to pumping of the densified material in an open densification chamber, appearing as a result of the increase of the real surface of friction between the densified mixture sample and the matrix walls, which has an influence on the increase in densifying pressures at which pellets are created, which also causes an increase in pellets density. In addition, this is connected with the real time the material stays in the matrix for, which increases together with the increase in the length of matrix openings. This increases the influence of temperature on the densified mixture as well as the intensity of biochemical processes taking place in the pellets (e.g. starch gelatinization), which at a longer stay time (at an increased length of matrix openings) take place in an intense manner, which has an impact on the increase of the forces binding pellet particles, and in turn on the increase in density of the obtained pellets.

The obtained pellets produced from a mixture of tobacco waste (agricultural waste) and potato pulp (waste from agricultural and food industry plants) can be successfully used as a solid fuel of full quality.

5. Summary

On the basis of the performed tests, the following conclusions have been formulated:

- Densified post-harvest tobacco waste is a material highly susceptible to densification, which is confirmed by the obtained low values of maximum densifying pressures during its densification. However, exceeding a process temperature of 70ºC makes it impossible to obtain pellets of a satisfactory quality. In order to obtain good quality pellets, a binder should be used.
- Using an addition of potato pulp as a binder in the process of densification of tobacco waste had an influence on improving of the mixture's susceptibility to densification and the quality of pellets.
- Increasing the potato pulp content from 15 to 25% and the temperature of the densification process from 50 to 90ºC has an influence on the increase of the values of unit densifying pressures obtained during the densification of a mixture of tobacco waste and potato pulp.
- Increasing the length of matrix openings from 37 to 47 mm causes an increase in density of the obtained pellets (at each of the masses of the densified samples). This tendency is the most visible in the range of the mass of the densified mixture of 0.7 to 0.9 g.
- A temperature of 70ºC is the most beneficial temperature of the process of densification of tobacco waste, and a mixture of tobacco waste with potato pulp from the point of view of the energy consumption of the process and the density of the obtained pellets.
- Pellets of the highest quality (with the highest density of approx. 1155 $kg \cdot m^{-3}$) were obtained at a potato pulp content of 15%.
- The study of densification of the mixture of tobacco waste with potato pulp allowed to determine the parameters of the initial implementation of the pelletisation process of tobacco waste in the working system of the pelletizer with flat matrix.

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