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# THE INFLUENCE OF THE DENSITY OF THE MASS FLUX OF THE DENSIFIED MATERIAL AND THE ROTATIONAL SPEED OF THE MATRIX ON THE POWER CONSUMPTION OF THE PELLET MILL AND THE QUALITY OF OBTAINED PELLETS

*Summary*

*The article presents tests of the influence of the density of the mass flux of the densified material (5.29, 6.80, and 8.31 kg/m$^2$·s) and the influence of the rotational speed of the matrix (280, 330, and 380 r·min$^{-1}$) on the power consumption of the pellet mill and the quality of obtained pellets. The tests were carried out on a SS-2 stand with a working system of a pellet mill with a rotating matrix. On the basis of performed tests it was concluded that an increase in density of the mass flux of densified material and an increase in rotational speed of the matrix cause an increase in power consumption of the device and a reduction of the density and kinetic durability of obtained pellets.*
***Key words**: densification, mass flux, pellets, density, fodder*

# WPŁYW GĘSTOŚCI STRUMIENIA MASY ZAGĘSZCZANEGO SUROWCA ORAZ PRĘDKOŚCI OBROTOWEJ MATRYCY NA ZAPOTRZEBOWANIE GRANULATORA NA MOC ORAZ JAKOŚĆ OTRZYMANEGO GRANULATU

*Streszczenie*

*W artykule opisano badania wpływu gęstości strumienia masy zagęszczanego surowca (5,29 6,80 i 8,31 kg/m$^2$·s) oraz wpływ prędkości obrotowej matrycy (280, 330 i 380 obr·min$^{-1}$) na zapotrzebowanie granulatora na moc oraz jakość otrzymanego granulatu. Badania przeprowadzono na stanowisku SS-2 z układem roboczym granulatora z pierścieniową obrotową matrycą. Na podstawie przeprowadzonych badań stwierdzono, że zwiększenie gęstości strumienia masy zagęszczanego materiału oraz zwiększenie prędkości obrotowej matrycy powoduje wzrost zapotrzebowania urządzenia na moc oraz spadek gęstości i wytrzymałości kinetycznej otrzymanego granulatu.*
***Key words**: densification, mass flux, pellets, density, fodder*

## 1. Introduction

In professional literature devoted to the subject matter of pelletisation, the quantity of material passing through the densifying working system and its influence on the course of the process and the quality of the obtained product is one of the most important and most often described process parameters. Among the most commonly adopted measures of the quantity of material passing through the working system there are [7, 13]:

- process efficiency (the mass of product obtained at the output of the working system per time unit),
- efficiency per one opening (the mass of product obtained at the output of the working system per time unit per one matrix opening),
- mass flux density (the mass of product obtained at the output of the working system per time unit per a unit of the working surface area of the matrix).

Grover and Mishra [4] suggest that one of the most important parameters connected with the course of the densification process is the size of the stream of the passing material. Hejft [6], when comparing the efficiency of the process per one opening and the efficiency per surface unit for which the unitary energy consumption of the process in the working system is minimal, concluded that it may be assumed that efficiency per surface unit is the indicator of the course of the process for a given material. Research by Ekielski [3] show that densification of agglomerate can be achieved at various pressures. This is caused by the fact that the times the material remains (exposition) in densification chambers differ. A reduction of the unitary flow rate of the material (for the required density of agglomerate) enables the use of lower working pressure limits, as a result of which the energy consumption of the densification process is reduced. This is confirmed in research by Obidziński [15, 16] concentrated on the densification of buckwheat hulls and potato pulp, which show that increasing the rate of the mass flux of the mixture through the working system of the pellet mill from 50 to 100 kg/h caused a significant increase of the power consumption of the pellet mill [15] and a reduction of both the density and the kinetic durability of pellets [16]. According to Laskowski and Skonecki [11], increasing the mass of the densified material causes a reduction of the density of the material in the chamber as well as the density of the obtained agglomerate. On the basis of the obtained results, Laskowski and Skonecki [11] concluded that the parameters of pellets from post-extraction rapeseed meal indeed depend on the mass of the sample and the diameter of the matrix chamber, and that similar relationships pertain to the densification of wheat [11] and lupine [12] grains.

Another important parameter influencing the course of the densification process and the quality of the obtained product is the speed of the rotating elements of the densifying working system (the densification rolls or the matrix), which is confirmed in many publications [10, 7, 20]. Tamuluru [21] claims that the speed of the matrix considerably influences the quantity of the densified material, the energy required for its densification, and the kinetic durability. These changes are connected with the change of the time the material remains in the matrix. Research by Czaban [1] shows that an increase of the rotational speed of the matrix of the pellet mill causes an increase of the unitary power consumption of the process and a reduction of product density. According to Stevens [18] increasing the rotational speed of the matrix from 150 to 268 rpm, when densifying grain fodder mixtures for pigs, did not influence the kinetic durability of pellets. Thomas and his team [20] claim that high matrix speeds (approx. 10 m/s) are recommended for low-diameter pellets (3–6 mm), whereas lower speeds (approx. 6–7 m/s) are recommended for pellets of greater diameter and volume. According to Heinemans [5] low rotational speeds of matrices (4–5 m/s) are recommended when densifying material of low density, in which case high amounts of air it contains must be removed during the densification process.

Hill and Pulkinen (1988) observed that industrial pellet mills can work in a range of rotational speeds of the matrix of 60–500 rpm. In the case of densification of algae, the optimum rotational speed of the matrix is 187 rpm [8]. This is confirmed in research by Tabil and Sokhansanj [19] as they failed to obtain pellets of a satisfactory quality from algae at rotational speeds in the range of 501 to 565 rpm. According to them, the optimum rotational speed of the matrix when densifying algae is 250 rpm [19]. According to Pietsch [17], the typical speeds of densification rolls are 1–16 rpm or 0.01–1.5 m/s). Inghelbrecht and Remon [9], on the other hand, when densifying lactose powder, used speeds of the densification rolls in the range of 3–13 rpm. Yoshida and his team [24] observe that as the circumferential speeds of the cylinders densifying wood chips is reduced from 18.3 to 0.6 m/min (from 17.4 to 0.6 rpm), the density of the obtained product increases.

## 2. Purpose of the research

The aim of the research was to assess the influence of the density of the mass flux of the densified material and the rotational speed of the matrix on the power consumption of the pellet mill and the quality of the obtained pellets.

## 3. Research methods

For the tests, DK-Finiszer all-mash feed mixture with a moisture content of 16% was used.

The tests were performed in industrial scale, on SS-2 stand, presented in papers [13, 14], whose main element is the working system of the pellet mill with a rotating ring matrix. The SS-2 test stand enabling measurement and recording of the: rotational speed of matrix, rotational speed of densification roll and power consumption of motor driving the working system.

Feeding screw of the stand is driven by motor connected to frequency converter. Owing to this, the mass flux of the fed material is controlled by means of an infinitely variable change of the rotational speed of the feeding screw. In the working system (between rotating matrix and densification rolls) the material is densified and leaves the system in the form of pellets. The smooth change of the rotational speed of motor driving matrix through a belt is achieved through the use of frequency converter.

The matrices used during the tests had 1017 openings with a diameter of 4.8 mm. The density of the mass flux of the material densified in the matrix openings was defined as:

$$Z = \frac{Q}{F_c} = \frac{Q}{F_{otw} \cdot n} \quad [kg/m^2 \cdot s] \qquad (1)$$

where:
$F_c$ – total surface area of the flux of the material [m$^2$],
$F_{otw}$ – surface area of a single matrix opening [m$^2$],
n – number of openings in the matrix.

During the tests assessed were the influence of the rate of the mass flux of the mixture (350, 450, and 550 kg/h, which caused changes of the density of the mass flux of the densified material of, respectively, 5.29, 6.80, and 8.31 kg/m$^2$·s) and the influence of the rotational speed of the matrix (280, 330, and 380 rpm) on the power consumption of the pellet mill and the quality of the obtained pellets.

The tests were performed at a working gap between the densification roll and the matrix of 0.4 mm, and at a length of matrix openings of 52.5 mm.

The determination of the density and the kinetic durability of pellets were performed 24 hours after densification.

The determination of the density of pellets was performed by measuring the height and diameter of fifteen pellets by means of a calliper with an accuracy of ±0.02 mm and determining their mass by means of a laboratory balance with an accuracy of ±0.001 g. Density was calculated as the relationship between the mass of the pellets and the sum of their volumes.

The tests of the kinetic durability of the pellets with the use of Pfost's method were performed pursuant to PN-R-64834:1998, and according to the methodology presented in papers [20, 22, 23]. During the test, the tester chamber was rotating with a rotational speed of 50 rpm. The duration of the test was 10 min. The kinetic durability $P_{dx}$ of the obtained pellets was determined as the relationship between the mass of pellets after test completion and sieving of crumbled parts, and the mass of pellets before the test.

## 4. Results of the tests

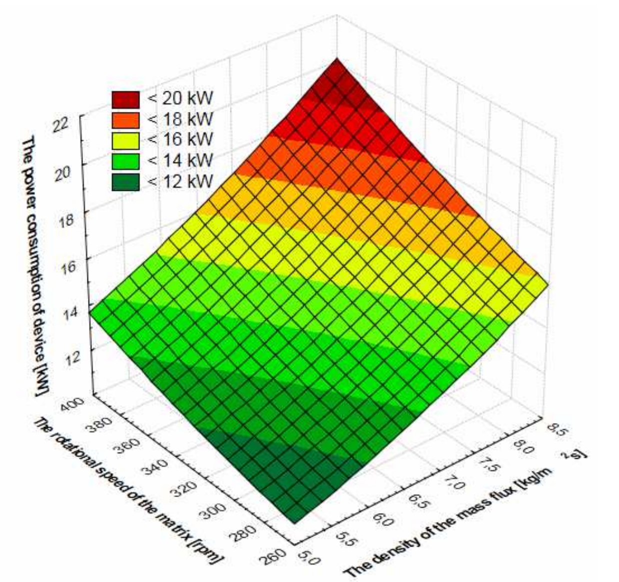
Fig. 1 shows the relationship between the power consumption of the device and the density of the mass flux (the rate of flow of the material), and the rotational speed of the matrix.

Increasing the density of the mass flux from 5.29 to 8.31 kg/m$^2$s (the rate of flow of the material from 350 to 550 kg/h) causes an increase of the power consumption. For example. At a rotational speed of 280 rpm, the power consumption of the device increases by 3.68 kW; at a rotational speed of the matrix of 330 rpm, an increase of the power consumption by 4.56 kW occurs; while at a rotational speed of the matrix of 380 rpm, the power consumption increases by 5.44 kW.

The increase of the power consumption caused by the increase of the density of mass flux (the rate of flow of the material) is caused by the thickening of the layer of material between the roll and the matrix in a single densification cycle, which causes an increase of the torque of the matrix.

Increasing the rotational speed of the pellet mill from 280 rpm to 380 rpm causes an increase of the power consumption of the device. For example, at a density of the mass flux of 5.29 kg/m$^2$s (the rate of flow of the material of 350 kg/h), the power consumption increases by1.01 kW (from 12.67 kW to 13.68 kW); at a density of the mass flux of 6.80 kg/m$^2$s (the rate of flow of the material of 450 kg/h), the power consumption increases by 1.89 kW; while at a density of the mass flux of 8.31 kg/m$^2$s (the rate of flow of the material of 550 kg/h) – by 2.77 kW.

On the basis of the performed tests, it was concluded that the maximum value of the power consumption in the tested range of independent variables is 26.91 kW, while the minimum value is 12.67 kW.

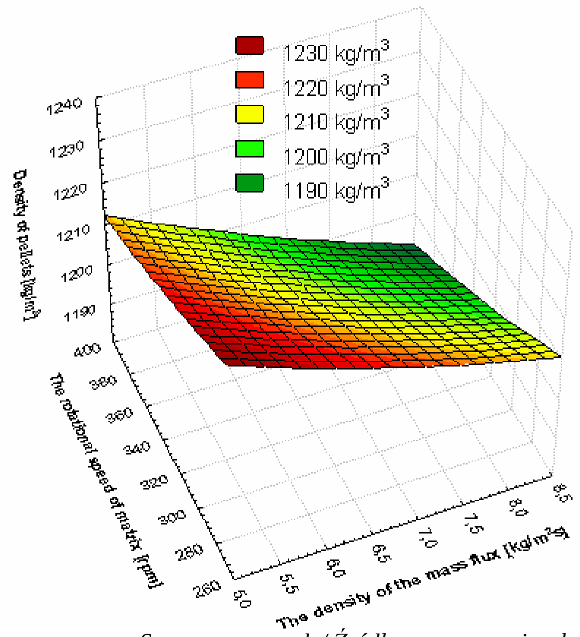



*Source: own work / Źródło: opracowanie własne*

Fig. 1. The relationship between power consumption of device and density of the mass flux (rate of flow of the material), and rotational speed of the matrix

*Rys. 1. Zależność zapotrzebowania urządzenia na moc od gęstości strumienia masy (natężenia przepływu surowca) i prędkości obrotowej matrycy*

Fig. 2 shows the relationship between the density of pellets and the density of the mass flux (the rate of flow of the material), and the rotational speed of the matrix.




*Source: own work / Źródło: opracowanie własne*

Fig. 2. The relationship between density of pellets and density of the mass flux (rate of flow of the material), and rotational speed of the matrix

*Rys. 2. Zależność gęstości granulatu od gęstości strumienia masy (natężenia przepływu surowca) i prędkości obrotowej matrycy*

Increasing the density of the mass flux from 5.29 to 8.31 kg/m$^2$s (the rate of flow of the material from 350 kg/h to 550 kg/h) causes a reduction of the density of pellets. For example, at a rotational speed of the matrix of 280 rpm, the density of pellets is reduced form 1245.91 kg/m$^3$ to 1221.53 kg/m$^3$. At a rotational speed of the matrix of 330 rpm, the density of pellets is reduced from 1234.29 kg/m$^3$ to 1206.6 kg/m$^3$, while at a rotational speed of the matrix of 380 rpm, the density is reduced by 11.07 kg/m$^3$ (from 1221.53 kg/m$^3$ to 1195.28 kg/m$^3$).

The reduction of pellets density as the density of the mass flux (the rate of flow of the material) increases is caused by the shortening of the time the mixture portion remains in a matrix opening. The time of the action of high temperature on the mixture is shortened, which has a negative influence on the creation of stable bindings in the produced agglomerate. The shorter time the mixture remains in the opening is also connected with the reduction of the time of relaxation of stresses in the formed pellets, which has a negative influence on their density.

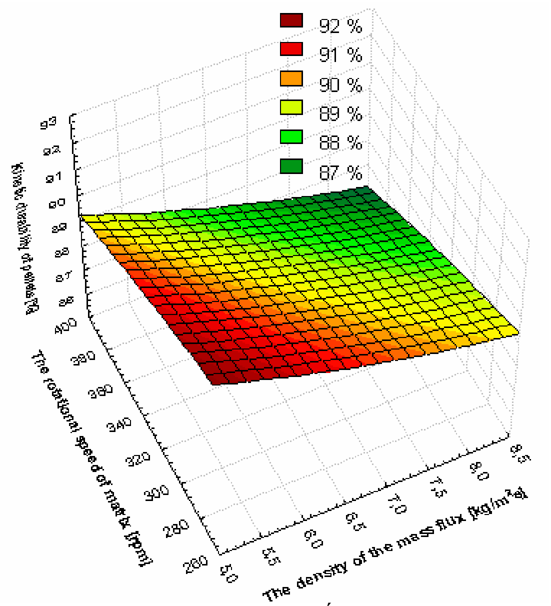
Increasing the rotational speed of the matrix of the pellet mill from 280 rpm to 380 rpm causes a reduction of the density of the obtained pellets. This reduction is connected with the fact that as the rotational speed increases, the elementary portion that is fed into a matrix opening in a single densification cycle is reduced. As the rotational speed increases, the number of layers in the created pellet increases, lowering its density. For example, increasing the rotational speed from 280rpm to 380 rpm at a density of the mass flux of 5.29 kg/m$^2$s (the rate of flow of the material of 350 kg/h) causes a reduction of the density by 24.39 kg/m$^3$ (from 1245.91 kg/m$^3$ to 1221.53 kg/m$^3$).

The maximum value of the density of pellets in the tested range of variables is 1286.75 kg/m$^3$, while the minimum value is 1195 kg/m$^3$.

Fig. 3 show the relationship between the coefficient of kinetic durability and the density of the mass flux (the rate of flow of the material), and the rotational speed of the matrix.

On the basis of the performed tests (fig. 3) it can be concluded that an increase of the density of the mass flux (the rate of the mass flux of the material) and the value of the rotational speed of the matrix cause a reduction of the coefficient of kinetic durability of pellets.

The value of the coefficient of kinetic durability of pellets decreases as the density of the mass flux increases from 5.29 to 8.31 kg/m$^2$s (the rate of flow of the material from 350 kg/h to 550 kg/h). Hence, at a rotational speed of the matrix of 280 rpm the coefficient of kinetic durability of pellets decreases from 93.68% to 90.93% (a reduction of 2.75%). At a rotational speed of the matrix of 330 rpm, the coefficient of kinetic durability of pellets decreases from 91.93% to 89.16%, while at a rotational speed of the matrix of 380 rpm – from 90.34% to 87.57%. The reduction of the coefficient of kinetic durability of pellets as the density of the mass flux (the rate of flow of the material) increases is caused by the shortening of the time a mixture portion remains in matrix openings. This has a negative influence on the creation of stable bindings in the produced agglomerate, and thus its kinetic durability is reduced. The shorter time the material remains in the opening is also connected with the reduction of the time of relaxation of stresses in the formed pellets, which has a negative influence on their kinetic durability. This is confirmed in research by Tamuluru [21] and Czabana [1].




*Source: own work / Źródło: opracowanie własne*

Fig. 3. The relationship between coefficient of kinetic durability and density of the mass flux (rate of flow of the material), and rotational speed of the matrix

*Rys. 3. Zależność współczynnika wytrzymałości kinetycznej granulatu od gęstości strumienia masy (natężenia przepływu surowca) i prędkości obrotowej matrycy*

The performed tests shown that the highest reduction of the coefficient of kinetic durability of pellets is connected with the increase of the rotational speed of the matrix. For example, increasing the rotational speed of the matrix of the pellet mill from 280 rpm to 380 rpm causes a reduction of the coefficient of kinetic durability of pellets by 3.34%, from 93.68% to 90.34% (at a density of the mass flux $Z$=5.29 kg/m$^2$s). At a density of the mass flux $Z$=6.31 kg/m$^2$s (the rate of flow of the material of 450 kg/h) the kinetic durability of the pellets decreases from 92.12% to 88.77% (by 3.35%), while at a density of the mass flux of 8.31 kg/m$^2$s (the rate of flow of the material of 550 kg/h), the coefficient of kinetic durability is reduced by 3.36% (from 90.93% to 87.57%).

The reduction of the coefficient of kinetic durability of pellets as a result of the increase of the rotational speed of the matrix is connected with the reduction of the elementary portion of material fed into a matrix opening in a single densification cycle. This increases the number of layers in the produced pellet (the number of surfaces of pellet division increases), which lowers its durability properties.

## 5. Conclusions

1. Increasing the density of the mass flux of the densified material from 5.29 to 8.31 kg·$^{-2}$s$^{-1}$ and increasing the rotational speed of the matrix from 280 to 380 r·min$^{-1}$ cause an increase of the power consumption of the device and a reduction of the density and the coefficient of kinetic durability of the obtained pellets.
2. The maximum value of power consumption in the tested range of independent variables is 26.91 kW, while the minimum value is 12.67 kW.
3. The highest reduction of the density and the coefficient of kinetic durability of pellets is connected with the increase of the rotational speed of the matrix.
4. The maximum value of the density of pellets in the tested range of variables is 1286.75 kg·m$^{-3}$, while the minimum value is 1195 kg·m$^{-3}$.
5. The density of the mass flux of the material may be accepted as one of the more important measures of the quantity of pellets flowing through the working system of the pellet mill.

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