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DETERMINING THE GRIP ANGLE IN A GRANULATOR WITH A FLAT MATRIX

WYZNACZANIE KĄTA CHWYTU W GRANULATORZE Z PŁASKĄ MATRYCĄ*

The article addresses the new concept of determining the grip angle in a roll – a flat matrix working arrangement. It was verified experimentally with the exemplary use of composite fuels. For this purpose, a methodology has been developed and the external and internal friction coefficients for several fuel blends have been determined. Knowing them enables one to determine the grip angle which has a significant influence on the efficiency of the granulator. Then, pressure granulation tests with selected blends were carried out. The test results and the calculations are presented in the article. The comparison of the experimental grip angle and the one determined on the basis of a theoretical equation testifies to the correspondence between the theory and the actual physical situation. The determined friction coefficients also determine the selection of an adequate diameter and width of the roller as well as the shape of its working surface. It is of essential importance for ensuring the correct operation of a press with a flat matrix.

***Keywords**: pressure granulation, composite fuels, grip angle, external and internal friction coefficient.*

W artykule zwrócono uwagę na nową koncepcję określania kąta chwytu w układzie roboczym rolka - płaska matryca. Poddano ją weryfikacji eksperymentalnej na przykładzie paliw kompozytowych. W tym celu opracowano metodykę i wyznaczono współczynniki tarcia zewnętrznego oraz wewnętrznego kilku mieszanek paliw. Ich znajomość umożliwia określenie kąta chwytu mającego istotny wpływ na wydajność granulatora. Następnie przeprowadzono próby granulacji ciśnieniowej wybranych mieszanek. Wyniki badań oraz obliczeń przedstawiono w artykule. Porównanie doświadczalnego kąta chwytu oraz wyznaczonego z równania teoretycznego świadczy o zbieżności teorii z rzeczywistą sytuacją fizyczną. Wyznaczone współczynniki tarcia determinują również dobór odpowiedniej średnicy i szerokości rolki, a także kształtu jej powierzchni roboczej. Ma to istotne znaczenie dla prawidłowej eksploatacji prasy z płaską matrycą.

***Słowa kluczowe**: granulacja ciśnieniowa, paliwa kompozytowe, kąt chwytu, współczynnik tarcia zewnętrznego i wewnętrznego.*

1. Introduction

Pressure granulation most often uses granulators with a ring matrix or a flat matrix [6,7] and structures combining the advantages of granulators and roll presses, which are used mainly to consolidate materials of mineral origin and post-production waste. A granulator with a flat matrix is a solution which offers great development potential. The key factors of structural nature which have an influence on the course of the pressure granulation process in a granulator with a flat matrix include the diameter, the roller width, the shape of its working surface, the matrix height and the geometry of the moulding forms [1, 2, 3, 12, 13]. The sources present experiments in the area of selecting some structural parameters of the working elements of the granulator obtained on a laboratory and industrial scale [1, 6, 8, 12]. These works focus on selecting the structural features of the matrix. The results of laboratory tests and operational tests have been found to provide a data base which is sufficient to make their proper selection.

To ensure a proper course of the pressure granulation process, it is important that the consolidated material is forced through the holes in the matrix, and most of all, that the condition of gripping the material being condensed in the roller-matrix arrangement is fulfilled. The issue of determining the grip angle in the working arrangement of the granulator has not been addressed in a complex way so far. Only one paper [6] presents considerations aimed at comparing the efficiency of a granulator with a flat matrix and a ring matrix, on the assumption that the grip angle is the same. Many more publications concern modelling of the process of condensing in a closed matrix [4, 14], a screw press [10, 11] and in a roll press in which material is consolidated in a way similar to that in a granulator with a flat matrix [5, 9]. There is, however, a shortage of knowledge about the phenomena which occur during the flow of material in the roll-flat matrix zone [7, 15]. Therefore, the geometrical dimensions of the roll, which have a significant influence on the course of the press operation, are selected in an experimental way, with the use of the trial and error method. This way of proceeding is time-consuming, expensive and does not enable determining the influence of the change of the feed properties on the granulation process. This inspired undertaking relevant own research. It was carried out with the exemplary use of composite fuels because the development of their production technology is innovative both in the field of science and technique [16].

2. Objective of the paper

The issue of fundamental importance for the proper operation of a granulator with a flat matrix is introducing a proper amount of material into the roller-flat matrix zone, its stable flow and forcing through the holes of the matrix. The grip angle [6] is of great importance here, similar to the case of a roll press [9]. A theoretical analysis has been carried out and used to develop a concept of determining the material grip angle in a granulator with a flat matrix [2]. Its innovative nature

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl*** required that its correctness had to be checked. The objective of the research studies, the results of which are presented in the present article, was to verify experimentally the hypothesis on determining the grip angle in the working arrangement of the granulator on the basis of the knowledge of external and internal friction coefficients. This required building proper laboratory stations, developing a methodology and carrying out tests as well as carrying out pressure granulation trial tests with the exemplary use of composite fuels.

3. Determining the grip angle in a press working arrangement

A new concept of determining the material grip angle in the roller – matrix working arrangement has been presented in the paper [2]. It considers conditions of balance of an elementary section of the volume of material between the roller and the matrix. It has been assumed that the indispensable condition of a correct condensation process is to eliminate internal skids of material which may occur within the compaction zone. Focus was laid on its beginning, that is, the place where the working surface of the roller comes in contact with the material. The scheme of the material compaction arrangement in the roller – flat matrix zone is presented in Fig. 1.

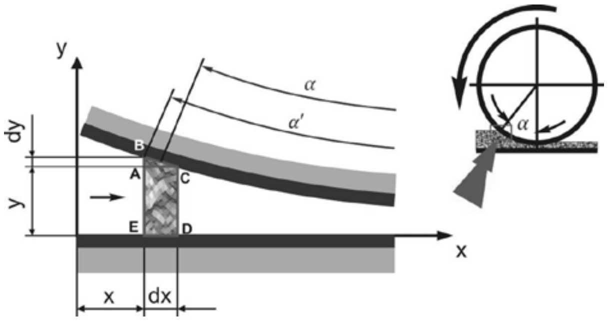

Fig. 1. Scheme of the material condensation arrangement in the roller – flat matrix zone [2]

The result of theoretical considerations is the dependence (1) determining the grip angle value α' which is presented below:

$$\alpha' \leq \arctan\left(\frac{1}{2}(\xi - \mu)\right) \quad (1)$$

Where: ξ– internal friction coefficient,
μ – external friction coefficient.

The considerations show that the grip angle in the working arrangement of the granulator can be determined theoretically if the internal and external friction coefficients are known. It is of essential importance for the correct selection of geometrical structural parameters of the roller and the shape of its working surface. Considering the theoretical nature of the considerations, it was decided that the presented hypothesis needed to be verified. It required laboratory tests to be carried out.

4. Experimental determination of external and internal friction coefficients

The external and internal friction coefficients of the feed were determined on the station presented in Fig. 2. It consists of a support structure on which a rotational base unit and an arm with a discharge trough are set. Before starting the measurements, the station is levelled with the use of adjustment screws. The trough is inclined to the level at an angle which makes it possible for the feed to freely slide down the trough. It is fed in a continuous manner while simultaneously reducing the inclination angle.

The external friction coefficient of the feed – steel frictional couple is the tangent of the angle at which the trough is inclined to the level at which the feed no longer continues to move. Then, such a position of the trough is determined which makes the feed pour down along the axis of the rotating base unit. It lasts until a regular cone is formed. Its height and mass are used to determine the internal friction method and the bulk density of the feed. Three trial tests were carried out for each case. The internal friction coefficient tests were carried out at the test station in which no consolidation of the material being condensed occurs because it features no cohesion at the moment when the roller grips the material. Table 1 contains results of measurements of the external friction coefficient, the internal friction coefficient and the bulk density of lignite, straw, miscanthus, plastifier and their blends under gravitational pressure. The presented results constitute an average of three measurements.

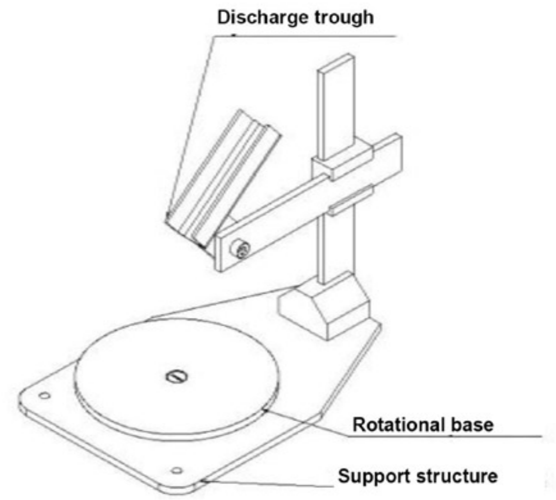

Fig. 2. Scheme of a test station designed to determine the external friction coefficient, the internal friction coefficient and the bulk density of fuel blends

Table 1. Friction coefficient and bulk density measurement results

Name	Internal friction coefficient	External friction coefficient	Bulk density [kg/m^3]
Lignite	0.74	0.34	650
Straw	1.23	0.32	110
Miscanthus	1.12	0.29	210
M1	0.98	0.32	371
M2	0.95	0.31	381
M3	0.92	0.36	401
M4	0.88	0.34	448
M5	0.8	0.31	542
WB 45 plastifier	0.78	0.39	1020

The tests proved that the highest internal friction coefficient is shown by grinded <3 mm plant biomass in the form of straw and miscanthus. It falls within the range from 1.12 to 1.23. However, the lowest external friction coefficient among the tested materials is 0.74 and it is shown by the <3 mm lignite whereas the WB45 plastifier features a slightly higher value. As expected, the blends had the friction coefficient dependent on the content of components. A higher content of lignite results in a reduced internal friction coefficient. Compositions of individual blends marked as M1 to M5 and their moistures are provided in table 2.

5. Composite fuel pressure granulation laboratory research tests

The tests of the pressure granulation of blends containing miscanthus, lignite and plastifier were carried out with the use of a laboratory granulator with a flat matrix, presented in Fig. 3. It is equipped with a matrix which is 25 mm thick and has a diameter of 120 mm. It has 36 cylindrical holes with a diameter of 8 mm which are disposed in a ring with an internal diameter of 52 mm and the external diameter of 100 mm. In the top part of the hole, there are conical 2.5 mm deep undercuts with a 60° flare angle. The granulator is equipped with two condensing rollers which are 40 mm thick and have a diameter of 64 mm. On the cylindrical surface of the rolls, there are 30 prismatic cuts with a width and depth of 3 mm. The rotational speed of the matrix is 300 rpm. The granulator is powered with a three-phase motor with the power output of 2.2 kW. The distance of the rollers from the matrix is set to be 0.1 mm. Before carrying out the measurements, the matrix and the rollers were heated up to the temperature of approximately 70°C by means of a mixture consisting of bran-water-oil-corundum powder.

The initial preparation of components of the blends consisted in drying lignite and miscanthus, then grinding them to a grain size below 3 mm. Immediately before starting the tests, the blend compositions, which are specified in table 2, were prepared. After blending the components exactly, the moisture of the blends, their bulk density, external and internal friction coefficients were measured. Then, the blend granulation tests were performed during which the weight of the obtained granules, their quality and the process duration were determined. The data obtained in the experimental research was used to calculate the experimental grip angle on the basis of the measurement of the granulator efficiency and the density of fuel blends which underwent pressure granulation. However, the theoretical grip angle was obtained from the dependence (1), using the experimentally determined external and internal friction coefficients. The results of the tests and calculations are presented in table 2. They point at a regularity which consists in that the experimental grip angle is bigger than the theoretical one. The average difference between them is 6.21 %. Fig. 4 shows selected results of tests and calculations in the form of a dependence of the experimental and theoretical grip angle on the granulator efficiency, obtained in the course of the composite fuel blend consolidation tests.

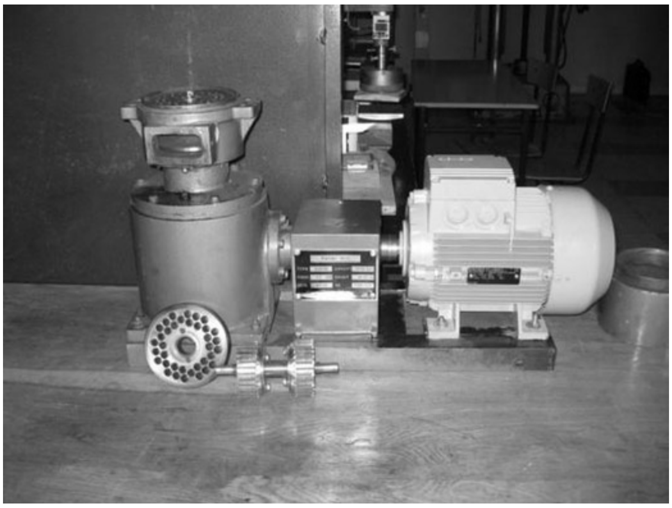

Fig. 3. Laboratory granulator

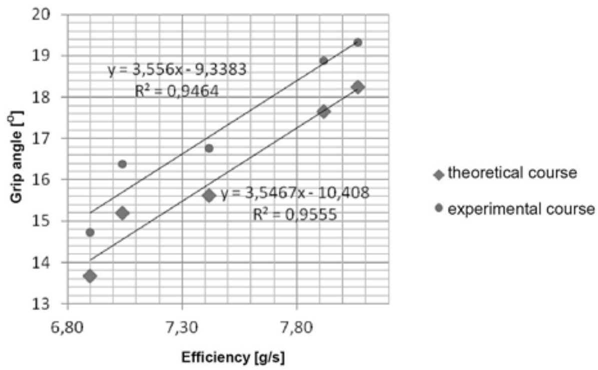

Fig.4. Dependence of the experimental and theoretical grip angle on the laboratory granulator efficiency obtained in subsequent trial tests.

In both cases, this is a linear dependence and the correlation coefficient is high. Furthermore, both straight lines have a similar gradient. The difference between the initial ordinates, calculated from regression equations, amounts to 1.0697, which, in reference to the experimental grip angle value, gives an error level of 7.0%, at its lowest value and 5.5% at the highest one. Their average calculated difference within the examined range is 6.29%. This confirms the observed regularity.

Table 2. Pressure granulation test results and grip angle value calculations

Blend number	M1		M2		M3		M4		M5	
Name	**Um**	**W [%]**	**Um**	**W [%]**	**Um**	**W [%]**	**Um**	**W [%]**	**Um**	**W [%]**
Miscanthus	0.68	13.00	0.60	13.00	0.55	13.00	0.50	13.00	0.45	13.00
Carbon	0.27	35.00	0.35	35.00	0.40	35.00	0.45	35.00	0.50	35.00
WB 45 plastifier	0.05	10.00	0.05	10.00	0.05	10.00	0.05	10.00	0.05	10.00
Blend moisture [%]	19.00		21.00		22.00		23.00		24.00	
Initial density [kg/m^3]	371		381		401		448		542	
Blend mass [g]	500.00		950.00		890.00		450.00		950.00	
Pelleting duration [s]	62.00		120.00		120.00		64.00		138.00	
Efficiency Qm [g/s]	8.06		7.91		7.41		7.04		6.90	
Remarks	Bad quality		Good quality		Good quality		Best quality		Granulate too wet	
Experimental grip angle α_{rz} [°]	**19.32**		**18.87**		**16.77**		**16.38**		**14.73**	
Measured internal friction coefficient ξ	0.98		0.95		0.92		0.88		0.8	
Measured external friction coefficient μ	0.32		0.31		0.36		0.34		0.31	
Theoretical grip angle α_{obl} [°]	**18.24**		**17.66**		**15.62**		**15.18**		**13.67**	

Markings used in the table: U_m– mass content of the component, W- moisture of the component.

Considering the presented research test results, it can be ascertained that there is conformity between theory and practice. However, explaining the reasons why the experimental grip angle value is higher in comparison to the theoretical one requires undertaking further research works.

6. Summary

Great interest in the pressure granulation of fine-grained materials, especially biomass and solid fuel blends, inspired research which aimed at developing a method of selecting the components of the granulator working arrangement. In the paper [2], the authors presented their own concept of a solution to the problem in which the determination of the grip angle in the roller - flat matrix working arrangement plays an important part. A hypothesis was formulated about the possibility of determining it on the basis of the knowledge of the external and internal friction coefficients of the feed. Continuing the research, the results of which are presented in the present article, the verification of this theory was carried out. It was found through an analysis of test and calculation results that there are no grounds to reject the hypothesis concerning the possibility of determining the grip angle on the basis of the knowledge of the external and internal friction coefficients. It is of significant importance for determining the operational efficiency of the granulator and allows for forecasting its decline caused by the reduction of the operating roller diameter due to its wear. The knowledge of the grip angle also allows one to determine the material condensation resistance torque correctly and therefore the demand for energy needed to perform the process already at the machine construction stage. It enables matching the granulator drive properly, which ensures durability of this arrangement.

The undertaken work will be continued for blends containing other components. This should enable explaining the reasons for the occurrence of the observed regularity which consists in that the experimental grip angle is bigger than the theoretical one. Research is also planned to discover phenomena which occur in the roller – flat matrix zone. In this case, it will be necessary to determine the changeability of friction coefficients and the side pressure versus regular pressure.

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