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EVALUATION OF THE FERTILIZER GRANULES STRENGTH OBTAINED FROM PLATE GRANULATION WITH DIFFERENT ANGLE OF GRANULATION BLADE

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Abstract: The goal of the paper was to assess the strength of the fertilizer granules obtained by non-pressure granulation method. The granulation process was carried out in plate granulator, according to the three-level experiment plan. A mixture of raw materials prepared in a Polish factory of agrochemicals for agriculture and horticulture was used as a study material and water was used as a wetting liquid. Granulator design parameters and process parameters were treated as entrance sizes of the experiment. Three different angles of granulation blade were used in experiments. This paper presents: the results of study of equivalent diameter size and the impact of changes in the angle of granulating blade on the strength of obtained granulate. Pfost apparatus and a set of sieves used in granulometric sieve were utilized in this study. A relation was suggested $P_\infty = f(\alpha, \chi, n, w_w, t)$. The results were presented in the form of graphs and tables. Conclusions were presented.

Key words: Non-Pressurized Granulating, Granulating Blade, Kinetic Strength of Granules, Agriculture and Horticulture Fertilizer

1. INTRODUCTION

One of the principal reasons for granulation of fine-grained materials is a need to eliminate dust. Furthermore, an additional advantage is that the material in granular form does not aggregate and can be dispensed easily. Solid horticultural and agricultural fertilizers are most frequently obtained during such process. Granulation process which involves aggregation of mostly small particles into larger assemblies is conducted in the presence of moistening liquid (Biskupski et al., 2008). So called non-pressure granulation is a process of production of solid particles with a certain size or shape from the fine material (Gluba et al., 2009a, b; Heim et al., 1991). Two mechanisms may take place during this process: the particles binds together without any other material, or the bonding forces are transmitted by the material bridges formed with a binder (Gluba et al., 2005, 2009c).

The vast majority of manufactured fertilizers are in the form of granules. In the considerable part, the position of fertilizer on the market depends on the method of its granulation and its application. In our country, we produce huge quantities of fertilizers, much more than it can be used. In this situation the manufacturing plants take steps to make their products more attractive. Therefore the share of granulated fertilizers in the total amount of manufactured fertilizers increases fertilizers properties are more adapted to the needs of customers and the properties of granulated fertilizers are improved (Borowik et al., 2012; Urbanczyk et al., 2008).

The mechanical strength of the granules is one of the basic properties of the granulation products which is decisive of its usefulness for further processing (Khan et al., 1997). Various methods of determination of granulate resistance refer to the different technological operations starting from obtaining a granulate up to its application. Two kinds of forces influence granules: the dynamic forces that accompany transport and static forces which act during storage. The kinetic and static strength (hardness) of granules are affected by many factors (Iveson et al., 1998a, b, c) including factors associated with physicochemical features of the raw materials and a method for the preparation of the pre-granulation, factors associated with the design of granulating system and technical and operational factors (Hejft et al., 2012; Zawiślak et al., 2010; Salman et al., 2004).

The knowledge of the impact of various parameters on the strength of the resulting granules allows for such a selection that product with best mechanical properties is obtained (Reynolds et al., 2005; Walker et al., 2003).

2. PAPER GOAL

The goal of the paper was to investigate the effect of changes in the angle of the granulation blade in plate granulator on the kinetic strength of the product obtained in the process of wet plate granulation.

3. APPARATUS AND METHODS OF MEASUREMENT

The study was conducted in a laboratory plate granulator. Scheme of the post is shown in Fig. 1. Scheme of the research post is presented in Fig. 2.

A granulator plate with a diameter of 0.5 m (1) was driven by an electric motor via a belt drive (3). The transfer of power from the transmission belt on a granulation plate was made via a gear mechanism (2). Frequency inverter (4) was used to determine the constant rotation speed of the plate.

The amount of drawn moistening liquid was showed by weight display (7), on which a moisturizing liquid container (5) was placed. Moisturizing liquid was delivered through rubber lines at a high pressure generated by the compressor (6).

The raw material was dosed into the bottom of the plate with the dispenser (8) and pre-wetted with a pneumatic spray nozzle (9) in the upper part. Rotational movement of the plate provided fluid delivery to the surface of bulk material. Constant intensity of liquid inflow was established with the use of rotameter (10). The granulation plate along with the instrumentation is fixed on supportive structure (11) (load-bearing structure).

Fig. 1. View of the research position of granulation harrow

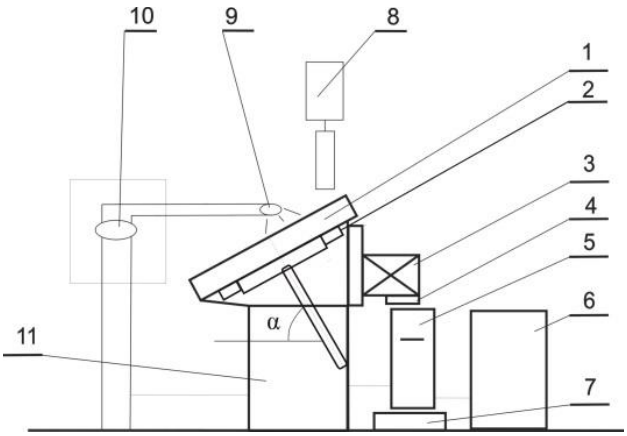

Fig. 2. Scheme of the research post for plate granulation: 1 – replaceble granulation plate, 2 – a gear mechanism, 3 – electric motor with belt drive, 4 – frequency inverter, 5 – moisturizing liquid container, 6 – compressor, 7 – scales, 8 – raw material dispenser, 9 – spray nozzle, 10 – rotameter, 11 – supporting structure

A mix of raw materials, which has been manufactured and prepared at the factory of Polish manufacturer of agrochemicals for agriculture and horticulture, was used in the study. In the technological process, the mixture which is used as a raw material, is transformed into the granulated agricultural fertilizer. Water with a density $\rho = 1000\,kg/m^3$ at constant flow rate was used as the moistening liquid.

The analysis of granulation was conducted in the periodic way, at fixed weight of the granulated batch equal 2.52 kg. Tests were performed according to the study of Hartley PS/DS-P: Ha5 (Polański, 1984) in which:

- considered amount of entrance sizes $i = 5$;
- considered number of plan arrangements $X = 27$;
- plan star shoulder $\xi = 1$;
- amount of levels of the given entrance size $n_x = 3\ (+1, 0, -1)$.

The selection of independent variables (experiment entrance sizes) was based on a literature review.

Entrance sizes:

- $x_1 = \alpha$ – the angle of the granulation plate;
- $x_2 = \chi$ – the angle of the blade in the plate granulation;
- $x_3 = n$ – the rotation speed of the granulation plate;
- $x_4 = w_w$ – mass of water added into the plate during the granulation process;
- $x_5 = t$ – material stay time in the granulator.

Before the beginning of the process – granulation plate and granulation blade were placed at the determined angle. Powdered material was placed in the bottom part of the granulation plate. The poured deposit was rinsed with proper amount of granulation liquid. Granulator drive was started and the speed of the plate was set. The process continued until the established time of material stay in granulator ended. The change of the granulation blade tilt angle was presented in the Fig. 3, 4, 5. Fig. 3 Blade position at the angle of 60°. Fig. 4 Blade position at the angle of 90°. Fig. 5 Blade position at the angle of 120°.

Geometric parameters of the granulation blade were determined on the basis on preliminary tests, which results were also included in the publication of Hejft and Leszczuk (2012).

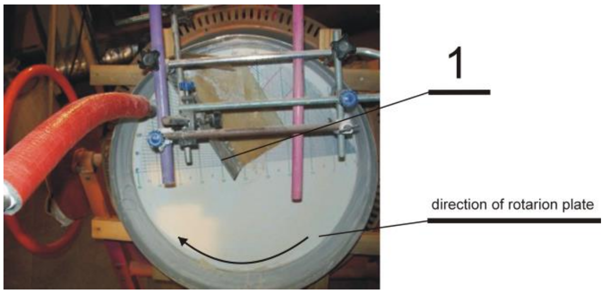

Fig. 3. The position of the granulation blade in the granulation plate at the angle of 60°, 1 – granulation blade

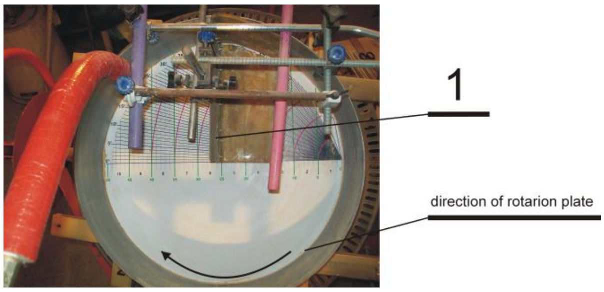

Fig. 4. The position of the granulation plate in the granulation plate at the angle of 90°, 1 – granulation blade

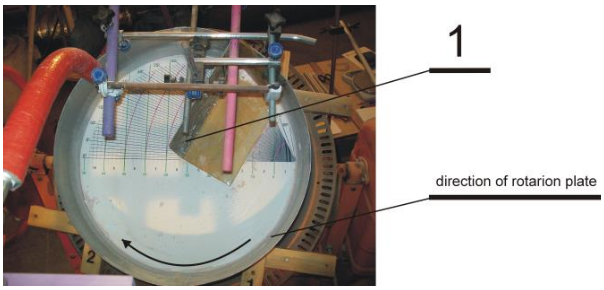

Fig. 5. The position of the granulation blade in the granulation plate at the angle of 120°, 1 – granulation blade

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Sieve analyser was used to determine the equivalent diameters of the obtained granulate. Dry sieve analysis was performed according to ISO 2591-1: 2000, using a mechanical shaker (MULTISERW Morek type LPzE-2e). The post was described on Fig. 6.

Fig. 6. Place of the determination of granules equivalent diameter

The principle of this analysis is based on a mechanical sieving of the sample through a set of sieves and weighing the individual fractions. In this method, grain material was divided into fractions containing particles with different sizes, by sieving through a set of sieves. As a result, the grain with given diameters stayed on successive sieves (with decreasing mesh sizes). Randomly selected granule samples with the weight of 0.300 kg were taken for analysis. Individual size factions were weighed at the electronic scale. After weighing of individual grain classes, the percentage share of material which stayed on every sieve against the whole material was determined. Based on received results, a substitute diameter of the set of particles dm was calculated on the basis of the formula (Urbańczyk et al., 2008) (model 1).

$$d_m = \sum_{i=1}^{n} m_i \cdot d_{śri} \quad (1)$$

In case of sieve analysis parameter: $d_{śri}$ – the arithmetic mean of the extreme dimensions of the fraction i – the average size of largest and smallest mesh for the given class of grain, m_i – mass share of individual grain classes.

Kinetic strength of the obtained granulate P_∞ was determined according to PN-R-64834: 1998. Pfosta apparatus is rectangular, metal tank with specific dimensions with the transversely placed plate. The testing machine was presented in Fig. 7.

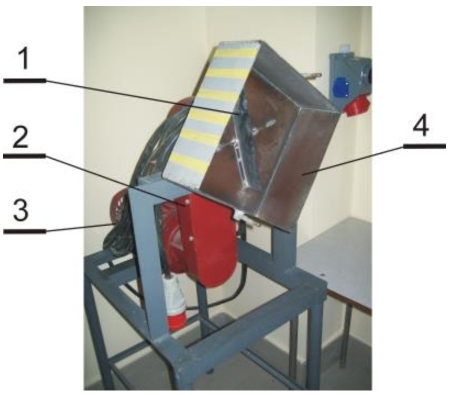

Fig. 7. Apparatus for testing the kinematic strength of granules:
1 – stationary steel plate, 2 –transmission belt, 3 – electric motor, 4 – tester box

Rotary tester has a chamber (box) (4) with dimensions of $285x285x120$ mm, in which the steel plate (1) with dimensions of $230x50x2$ mm is placed. The drive of apparatus is accomplished by an electric motor (3) and transmission belt (2).

A sample with mass of c.a. 500 g was inserted into the box of the testing machine. It rotated for 10 min at 50 rpm/min. After the test, particles which disintegrated were separated on a sieve with a mesh diameter $\phi = 1$ mm. The kinetic strength of the granules P_∞ is defined as the ratio of sample weight after the test m_2 (without the share of $0 \div 1$ mm fraction) to the weight of sample charged into the tester m_1 (Błasiński et al., 1981) (model 2):

$$P_\infty = \frac{m_2}{m_1} \cdot 100 \quad (2)$$

3. RESEARCH RESULTS

Based on the obtained research results an analysis of the influence of granulation blade tilt angle on kinetic strength of obtained granules was made tilt. To make the results more clear they were divided into three groups. Table 1 contains the results obtained for granulate at the angle tilt of 60°. Tab. 2. contains the test results of the obtained granulate at the granulation vane tilt angle of 90°. Tab. 3 contains the test results obtained for granulate at the granulation blade tilt angle of 120°.

Tab.1. Test results (angle of the blades 60°)

	independent variables						
	1	2	3	4	5	6	7
plan	$x_1 = \alpha$	$x_2 = \chi$	$x_3 = n$	$x_4 = w_w$	$x_5 = t$	P_∞	d_m
number	[º]	[º]	[rpm]	[kg]	[min]	[%]	[mm]
2.	30	60	21.6	0.324	14.0	92.9	69.01
4.	50	60	7.2	0.252	8.0	84.4	3.1
6.	50	60	7.2	0.324	14.0	51.2	4.91
8.	30	60	21.6	0.252	8.0	92.2	3.71
10.	50	60	21.6	0.324	8.0	57.8	11.71
12.	30	60	7.2	0.252	14.0	86.4	4.28
14.	50	60	21.6	0.252	14.0	86.2	4.7
16.	30	60	7.2	0.324	8.0	85.2	6.23
20.	40	60	14.4	0.288	11.0	89.8	9.46

Tab. 2. Test results (angle of the blades 90⁰)

	independent variables						
	1	2	3	4	5	6	7
plan	$x_1 = \alpha$	$x_2 = \chi$	$x_3 = n$	$x_4 = w_w$	$x_5 = t$	P_∞	d_m
number	[º]	[º]	[rpm]	[kg]	[min]	[%]	[mm]
17.	50	90	14.4	0.288	11.0	82.2	4.31
18.	30	90	14.4	0.288	11.0	92.0	8.07
21.	40	90	21.6	0.288	11.0	94.5	3.62
22.	40	90	7.2	0.288	11.0	90.6	2.33
23.	40	90	14.4	0.324	11.0	91.6	8.05
24.	40	90	14.4	0.252	11.0	91.8	3.60
25.	40	90	14.4	0.288	14.0	95.4	6.45
26.	40	90	14.4	0.288	8.0	93.6	4.45
27.	40	90	14.4	0.288	11.0	95.0	5.97

Tab. 3. Test results (angle of the blades 120⁰)

	independent variables						
	1	2	3	4	5	6	7
plan	$x_1 = \alpha$	$x_2 = \chi$	$x_3 = n$	$x_4 = w_w$	$x_5 = t$	P_∞	d_m
number	[º]	[º]	[rpm]	[kg]	[min]	[%]	[mm]
1.	50	120	21.6	0.324	14.0	36.8	8.93
3.	30	120	7.2	0.252	8.0	74.8	1.72
5.	30	120	7.2	0.324	14.0	45.2	6.98
7.	50	120	21.6	0.252	8.0	82.1	2.32
9.	30	120	21.6	0.324	8.0	85.8	9.14
11.	50	120	7.2	0.252	14.0	87.2	1.85
13.	30	120	21.6	0.252	14.0	93.4	5.20
15.	50	120	7.2	0.324	8.0	78.0	4.31
19.	40	120	14.4	0.288	11.0	87.2	6.35

Based on the obtained results (Tab. 1, 2, 3), relationship of granule kinetic strength P_∞ in a function of the input parameters of the experiment (model 3) was developed:

$$P_\infty = -631.62 + 10.27\alpha + 1.61\chi + 4.77n + 2562.41w_w - 0.08\alpha^2 + 0.01\alpha\chi - 13.61\alpha w_w - 0.04\alpha t - 7.1 \cdot 10^{-3}\chi^2 - 2.6 \cdot 10^{-3}\chi n - 1.72\chi w_w - 0.04\chi t - 0.04n^2 - 1.78n w_w + 0.13nt - 2435.97w_w^2 - 60.69w_w t + 0.09t^2 \quad (3)$$

On the basis of the test results and the regression equation (model 3) significant effects of all independent variables on the value of the average kinetic strength of granules was shown. As presented on the Fig. 7 kinetic strength is highest when the granulation plate is at the angle of about $38° \div 42°$ and the granulation blade at the angle of $90° \div 80°$.

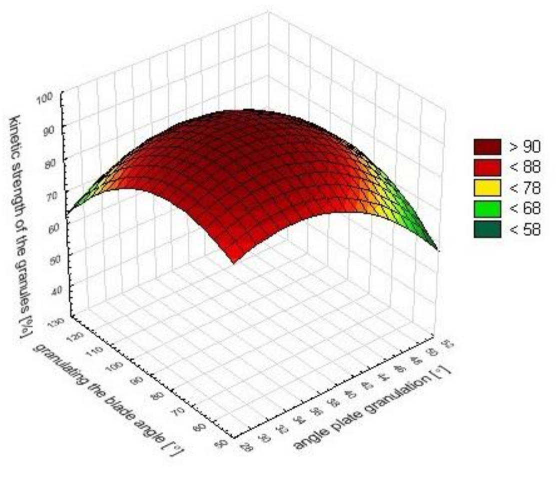

Fig. 8. The influence of the design parameters (blade and granulation plate tilt angle) on the granule kinetic strength measured by Phost apparatus

Fig. 9 depicts an exemplary association between granulation blade χ tilt angle and granules kinetic strength P_∞.

The change of granulation time from 8 min to 11 min (at the granulation plate tilt angle of $\alpha = 30°$, granulation plate rotation speed $n = 14.4$ rpm/min, amount of liquid added to the granulation plate $w_w = 0.324$ kg) results in decrease of the granule kinetic strength P_{dx} from the value of 85,9 % to 69.9 %.

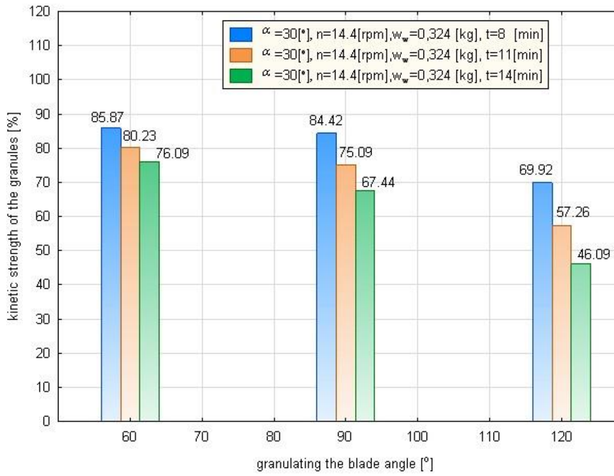

Fig. 9. Impact of the granulation blade tilt angle on the granule kinetic strength measured by Phosta apparatus

At the total time of granulation $t = 11$ min (the rest of granulation parameters: granulation plate tilt angle $\alpha = 30°$, granulation plate rotation speed $n = 14.4$ rpm/min, amount of liquid added to the granulation plate $w_w = 0.324$ kg) the granule kinetic strength P_{dx} changes from the value of 80.2 % through 75.1 % to 57.3 %.

Similar situation occurs when the granulation time is $t = 14$ min. At that time granule kinetic strength P_{dx} decreases from the value of 76.1 % to 46.1%.

The change of the granulation blade tilt angle from $60°$ to $120°$ (at the granulation plate tilt angle of $\alpha = 30°$, granulation plate rotation speed $n = 14.4$ rpm/min, amount of liquid added to the granulation plate $w_w = 0.288$ kg) during the granulation time $t = 14$ min results in the decrease of the granule kinetic strength P_{dx} for 26.3 % from the value of 87.6 % to 61.3 % (Fig. 10).

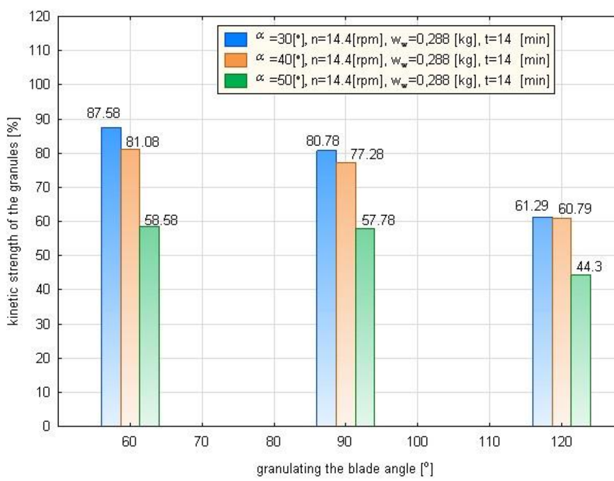

Fig. 10. Impact of the granulation blade tilt angle on the granule kinetic strength measured by Phosta apparatus

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The change of the granulation blade tilt angle from $60°$ to $120°$ (at the granulation plate tilt angle $\alpha = 40°$, granulation plate rotation speed $n = 14.4\ \mathrm{rpm/min}$, amount of liquid added to the granulation plate $w_w = 0.288\ \mathrm{kg}$ and granulation time $t = 14\ \mathrm{min}$) results in the decrease of the granule kinetic strength P_{dx} for 20.3 from the value of $81.1\ \%$ through $77.3\ \%$ to $60.8\ \%$.

The change of the granulation blade tilt angle from $60°$ to $120°$ (at the granulation plate tilt angle $\alpha = 40°$, granulation plate rotation speed $n = 14.4\ \mathrm{rpm/min}$, amount of liquid added to the granulation plate $w_w = 0.288\ \mathrm{kg}$ and the granulation time $t = 14\ \mathrm{min}$) results in the decrease of the granule kinetic strength P_{dx} by $14.3\ \%$ from the value of $58.6\ \%$ to $44.3\ \%$.

4. CONCLUSIONS

– The kinetic strength of the product obtained by wet granulation substantially depends on the design parameters of the granulator. The placement of the granulation blade in the granulator plays here a key role.
– Obtained results show that the greatest granules kinetic strength is received when the granulation blade tilt is at the angle of $60°$.
– Granulation blade tilt at the angle of $120°$ (in each point of the experiment) was associated with the accumulation of granules in the upper part of plate, right at the working surface. This resulted in the formation of granules with reduced mechanical properties.
– Analyses have also shown that the surface of the granulation blade is an obstacle for the bulk material particles located on the plate, which, by interaction with the powder material results in higher density of grains in the granules. An increasing number of contacts between the grains increases the binding strength due to greater convergence of grains. This results in the increase of resistance of granules towards the external forces, including compressive forces.
– The use of granulating blade at the angle of $60°$ and $90°$ (at different process - apparatus parameters) affects the increase in the equivalent diameter of the collection of particles (determined from the sieve analysis). It is the result of a more intense movement of the bed on a plate, affecting the frequency and strength of the interactions between the pouring deposit particles.

REFERENCES

1. **Biskupski A., Picher W.** (2008), Granulation method used in domestic fertilizer factories and properties of the obtained products, *Chemist*, 9, 398-408.
2. **Błasiński H, Gluba T.** (1981), Methods and apparatus for measuring the strength of the agglomerates, *Chemical Engineering and Equipment*, 4, 29-33.
3. **Borowik M., Malinowski P., Biskupski A., Dawidowicz M., Schab S., Rusek P., Igras J., Kęsik K.** (2012), Technology of fertilizer nitrogen-sulfur-calcium based on phosphogypsum and urea, *Chemist*, 66, 5, 535-540.
4. **Gluba T., Obraniak A.** (2009a), Evaluation of resistance to abrasion of the granular compound fertilizers Lubofoska, *Chemical Engineering and Equipment*, 4, 48-49.
5. **Gluba T., Obraniak A.** (2009b), Evaluation of the wet granulation harrow product, *Chemical Engineering and Equipment*, 4, 50-51.
6. **Gluba T., Obraniak A.** (2009c), The kinetics of agglomeration of particulate material in the granulator harrow, *Chemical Engineering and Equipment*, 4, 46-47.
7. **Gluba T., Obraniak A., Gawot-Młynarczyk E., Błaszczyk M.** (2005), Influence of the wetting parameters on the compressive strength of the granules, *VII National Granulation Symposium 2005, Puławy-Kazimierz Dolny*.
8. **Heim A., Gluba T., Kochański B.** (1991), Evaluation of mechanical properties of products from tumbling granulation, *IV National Granulation Symposium, Puławy*.
9. **Hejft R., Leszczuk T.** (2012), Effect of the scraping elements in the granulator harrow for the process, *Chemist*, 66, 5, 370-375.
10. **Iveson S. M., Litster J. D.** (1998a), Liquid – bound granule impact deformation and coefficient of restitution, *Powder Technology*, 99, 234-242.
11. **Iveson S. M., Litster J. D.** (1998b), Fundamental studies of granule consolidation – part 2. Quantifying the effect of particle and binder properties, *Powder Technology*, 99, 243-250.
12. **Iveson S. M., Litster J. D.** (1998c), Growth regime map for liquid – bound granules, *A. I. Ch. E. J.*, 44, 1510-1518.
13. **Khan M. I., Targos G. I.** (1997), Stability of wet agglomerates in granular shear flows, *J. Fluid Mechanics*, 347, 347-348.
14. **Polański Z.** (1984), *Designing experiments in the technique*, PWN, Warsaw.
15. **Reynolds G. K., Fu J. S., Cheong Y. S., Hounslow M. J., Salman A. D.** (2005), Breakage in granulation: A review, *Chemical Engineering Science*, 60, 3969-3992.
16. **Salman A. D., Reynolds G. K., Fu J. S., Cheong Y. S., Biggs Y., Adams C., Gorham M., Lukenics D., Hounslow J.** (2004), Descriptive classification of the impact failure modes of spherical particles, *Powder Technology*, 143-144, 19-30.
17. **Urbańczyk L., Wantuch W., Kotowicz J., Kowalski Z., Biskupski A., Malinowski P.** (2008), Specification of the compound fertilizer granulation using defective materials, *Chemist*, 9, 393-397.
18. **Walker G. M., Moursy H. E. M. N., Holland C. R., Ahmad M. N**. (2003), Effect of process parameters on the crush strength of granular fertilizer, *Powder Technology*, 132, 81-84.
19. **Zawiślak K., Sobczak P., Panasiewicz M., Markowska A.** (2010), Effect of selected technological parameters on the granules kinetic strength, *Acta Sci. Pol., Agraria Technica, 9 (1-2), 3-10.*