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THE INFLUENCE OF THE PROCESS OF NON-PRESSURE AGGLOMERATION ON THE HYDRAULIC DIAMETER OF PELLETS. PART I.

Summary

In processes of low-pressure (also called 'non-pressure') agglomeration, the condition to satisfy, necessary for binding the fine-grained particles into a bigger agglomerate is bringing them close enough for the action of binding forces. For the purpose of the tests, a mixture of materials was used, produced and prepared in a production plant of a Polish producer of agrochemicals for agriculture and horticulture, i.e. Intermag from Olkusz. The variable input parameters in the tests of the process of non-pressure agglomeration were: inclination angle of the pelleting plate; inclination angle of the blade in the plate pellet mill; rotational speed of the pelleting plate; mass of the water added to the plate during the process and time of the deposit of material staying in the pellet mill. Increasing the amount of pelleting liquid added to the plate results in an increase of the hydraulic diameter of pellets, whereas increasing the inclination angle of the pelleting plate results in the reduction of the hydraulic diameter of pellets. The hydraulic diameter of pellets increases along with the time of the material staying in the pellet mill. The increase of rotational speed of the pelleting plate has an impact on the increase of the hydraulic diameter of pellet particles. The use of the pelleting blade inclined in the plate at an angle of 60° and 90° has an impact on the increase of the hydraulic diameter of pellet particles.

Key words: non-pressure agglomeration, pellets diameter, pelleting plate

WPŁYW PARAMETRÓW PROCESU BEZCIŚNIENIOWEJ AGLOMERACJI NA ŚREDNICĘ ZASTĘPCZĄ GRANULATU. CZĘŚĆ I.

Streszczenie

W procesach granulacji niskociśnieniowej (zwanej również bezciśnieniową) warunkiem koniecznym do tego, aby nastąpiło połączenie się drobnych cząstek w większy aglomerat, jest ich zbliżenie do takiego stopnia, by zaczęły działać siły wiążące. Do badań użyto mieszankę surowców, która została wytworzona i przygotowana w zakładzie produkcyjnym polskiego producenta agrochemikaliów dla rolnictwa i ogrodnictwa Intermag z Olkusza. W badaniach procesu bezciśnieniowej aglomeracji zmiennymi parametrami wejściowymi były: kąt pochylenia talerza granulacyjnego, kąt pochylenia łopatki w granulatorze talerzowym, prędkość obrotowa talerza granulacyjnego, masa dodanej wody do talerza podczas procesu, czas przebywania materiału w granulatorze. Wzrost ilości dodanej do talerza cieczy granulacyjnej powoduje wzrost średnicy zastępczej granulek, natomiast zwiększenie kąta pochylenia talerza granulacyjnego wpływa na spadek średnicy zastępczej granulek. Średnica zastępcza granul rośnie wraz z czasem przebywania złoża w granulatorze. Zwiększenie prędkości obrotowej talerza wpływa na wzrost średnicy zastępczej granul. Zastosowanie łopatki granulacyjnej pochylonej w talerzu pod kątem 60° i 90° wpływa na wzrost wartości średnicy zastępczej granulatu.

Słowa kluczowe: bezciśnieniowa aglomeracja, średnica granulatu, talerz granulacyjny

1. Introduction

In processes of low-pressure (also called 'non-pressure') agglomeration, the condition to satisfy, necessary for binding the fine-grained particles into a bigger agglomerate is bringing them close enough for the action of binding forces. As a result of the action of these forces, a pellet with a certain cohesion may be created.

In the case of materials consisting of extremely fine-grained particles (with a size of 1 to 10 μm), an addition of binder is not necessary for creation of pellets. Bigger particles, from 10 to 200 μm, which have contact with each other in free space, can bind into permanent agglomerates with the use of a binding agent, e.g. water. Well-moistened materials and those retaining liquids on their surfaces are more susceptible to pelleting. Such materials are described as hydrophilic [6].

In the process of non-pressure agglomeration, intense mixing of particles of material takes place in free space, and due to the action of external forces and the forces of interaction, their binding, gradual densification, and an increased amount of produced agglomerates occur [1, 2, 3, 4].

Non-pressure agglomeration can happen according to two mechanisms, i.e. when particles of a dusty product bind with each other without another material, or when the forces that bind the particles are transmitted through material bridges (liquid bridges) created of a binding agent. The presence of an additional phase between the particles of a solid body causes even the smallest amounts of the agent to be able to cover contact surfaces of particles with a thin layer, thus filling out their unevenness [9, 10, 13].

2. The aim of the tests

The aim of the tests is to determine the most beneficial equipment and process parameters for conducting the process of agglomeration in a plate pellet mill with the use of a raking blade.

3. Research methodology

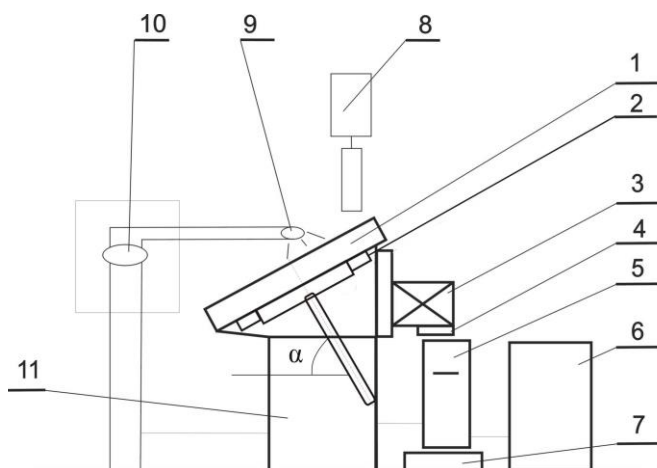The tests were carried out on a test stand, whose scheme is shown in fig. 1.

Fig. 1. Scheme of the test stand for plate pelleting [5, 8]: 1- replaceable pelleting plate, 2- gear mechanism, 3- electric motor with belt transmission, 4- frequency converter, 5- lubricating liquid container, 6- compressor, 7- scales, 8- material feeder, 9- spray nozzle, 10- rotameter, 11- supporting structure
Rys. 1. Schemat stanowiska badawczego do granulacji talerzowej[5, 8]: 1- wymienny talerz granulacyjny, 2- mechanizm zębaty, 3- silnik elektryczny z przekładnią pasową, 4- przemiennik częstotliwości, 5- zbiornik cieczy nawilżającej, 6- sprężarka, 7- waga, 8- dozownik surowca, 9- dysza rozpyłowa, 10- rotametr, 11- konstrukcja nośna

The mixture of shredded material was fed to the feeding hopper placed above feeder 8 (DSK 04 type) [15], which allows to control material supply to the appropriate place on the pelleting plate. The pelleting plate, made of stainless steel 1 (with the following dimensions: $d_t=500mm$ mm, $H=120$ mm), was driven by a three-phase electric motor (SG 80-2A type) [16] through belt transmission 3. Transmission of drive from the belt to the pelleting plate was realized by means of gear mechanism 2. The target rotational speed of the plate was set by means of frequency converter (power inverter) 4 (LG SV015IC5 type) [17]. Preparation of the granulometric liquid was performed in container 5. The amount of drawn liquid was indicated by the display on scales 7 (KPZ 2-60-S type) [18] on which lubricating liquid container 5 was placed. The level of liquid in the water container was controlled by means of an electrically-controlled sensor (W S1 S2 type) [19]. A drain valve was placed on the bottom of the container, enabling its drainage. The lubricating liquid was fed in plastic pipes at an overpressure created by compressor 6 (VIRGO 206 l/min type) [20]. The pressure of liquid was adjusted by means of a pressure reducing valve and its value was read from the manometer. Rotation of the pelleting plate was measured by means of an inductive sensor (LM12-3004PC type) [21] and read from the display of a tachometer (RC 5100 type) [22]. The material was fed in the bottom part of the plate, by means of feeder 8, and lubricated by means of Danfoss spray chute 9 (60 S 1.5 type) [23] in its top part. The rotational movement of the plate ensured that the liquid was supplied to the surface of the deposit of powdery material flowing in it. Inside the plate a pelleting blade was mounted. A constant intensity of liquid inflow was set by means of rotameter 10 (EK 3Ma type). The pelleting plate, together with instrumentation, was mounted to supporting structure 11. The sieve analysis was conducted with the use of the dry method, pursuant to PN-ISO 2591-1: 2000 [11], by means of a mechanical shaker (Multiserw Morek LPzE-2e type). The rule for determination consists in mechanical sieving of a sample through a set of sieves and weight determination of individual fractions in the shredded material [7]. In this method, separation of grainy material into fractions containing grains of various sizes was performed by sieving through a set of sieves, owing to which grains of corresponding diameters remained on subsequent sieves (of progressively smaller mesh openings). On the basis of the obtained results, the hydraulic diameter of a set of particles was calculated [14].

In the case of the sieve analysis: d_{avr} - arithmetic mean of extreme dimensions of fraction i is the average of the sizes of the bigger and the smaller openings for a given granary class.

4. Materials used for tests

For the tests, a mixture of materials created and prepared in a production plant of a Polish producer of agrochemicals for agriculture and horticulture, i.e. Intermag from Olkusz, was used. In the technological process, the mixture (plant and mineral origin) is used as a raw material for the production of pelleted agricultural fertilizer. The composition of the mixture is: Ureaform - 37% N, DAP Diammonium phosphate 18-46%, potassium sulphate - 50% K_2O, magnesium sulphate 7xH$_2$O - 16% MgO, raw magnesite - 42% MgO, and bentonite. The granary composition of the raw material was determined by means of the sieve analysis performed in a mechanical manner, presented in figure 2.

Water was the pelleting liquid used for the tests.
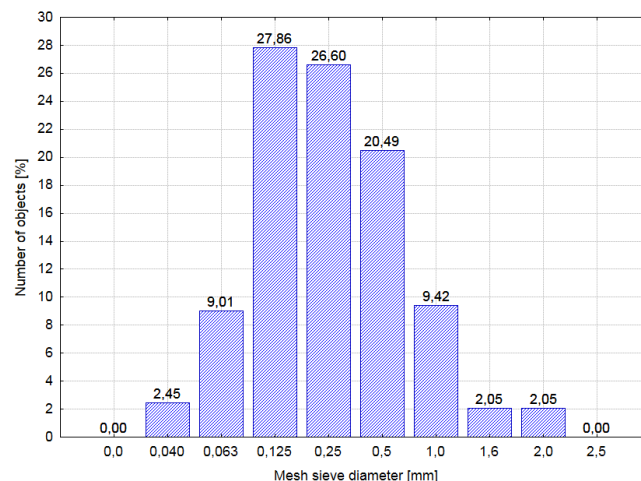
Source: own work / Źródło: opracowanie własne

Fig. 2. Granulometric distribution of raw material subjected to pelleting, obtained by means of the sieve analysis
Rys. 2. Rozkład granulometryczny surowca poddanego granulacji, uzyskany za pomocą analizy sitowej

5. Performance of tests

The tests were carried out according to Hartley's PS/DS-P:Ha5 experiment plan (a three-level plan) [12].

The input equipment variables are:
- inclination angle of the pelleting plate: $\alpha = 30°, 40°, 50°$,
- inclination angle of a blade in the plate pellet mill $\chi = 60°, 90°, 120°$,
- rotational speed of the pelleting plate: $n = 7.2; 14.4; 21.6$ rpm,
- mass of water poured into the plate during the pelleting process: $w = 0.252; 0.288; 0.324$ kg,
- time of the material staying in the pellet mill: $T = 8, 11, 14$ min.

The constant parameters are:
- diameter of the pelleting plate: $d_t = 0.5$ m,
- height of plate rim: $H = 0.165$ m,
- degree of plate filling: $k = 7\%$; which corresponds to the mass of the insert (deposit) in the pelleting plate: $m = 2.52$ kg,
- intensity of moistening: $I = 0.033$,
- distance between the hydraulic chute and the bottom of the plate: $e_d = 0.17$ m,
- place of feeding of fine-grained material: bottom part of the pelleting plate,
- place of feeding of the pelleting liquid: top part of the pelleting plate,
- pressure of supply of the pelleting liquid: $p_w = 0.5$ MPa.

6. Research results

The performed analysis of results shows that a change of parameters such as: inclination angle of the pelleting plate α, inclination angle of a blade in the plate pellet mill χ, rotational speed of the pelleting plate n, amount of the added pelleting liquid w_w, and time of the material staying in the pellet mill t, causes a change of the hydraulic diameter of pellets d_m. The test results are shown in figures 3 and 4.
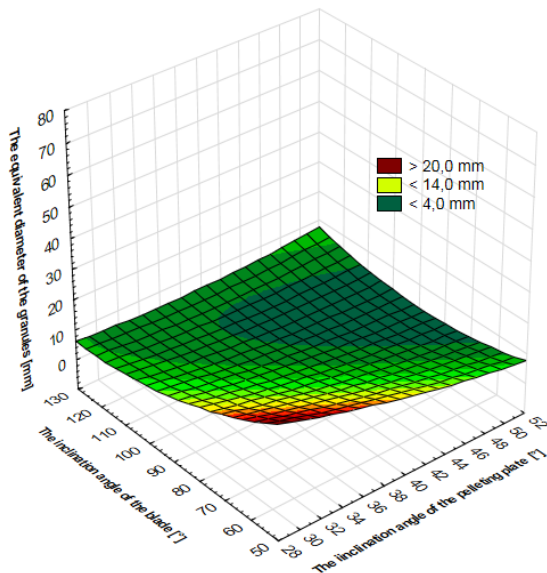
Source: own work / Źródło: opracowanie własne

Fig. 3. The influence of construction parameters (inclination angle of the pelleting plate and inclination angle of the blade) on the hydraulic diameter of pellets
Rys. 3. Wpływ parametrów konstrukcyjnych (kąta pochylenia talerza granulacyjnego i kąta pochylenia łopatki) na średnicę zastępczą granulatu
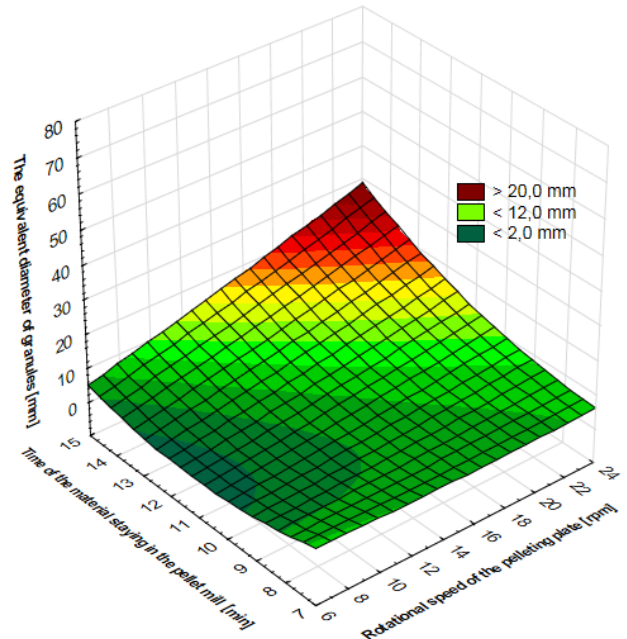
Source: own work / Źródło: opracowanie własne

Fig. 4. The influence of technological parameters (time of the material staying in the pellet mill and rotational speed of the pelleting plate) on the hydraulic diameter of pellets
Rys. 4. Wpływ parametrów technologicznych (czasu przebywania materiału w granulatorze i prędkości obrotowej talerza granulacyjnego) na średnicę zastępczą granulatu

The influence of the process and equipment parameters: inclination angle of the pelleting plate α, inclination angle of the blade in the plate pellet mill; rotational speed of the pelleting plate n, mass of the water poured into the plate during the pelleting process w_w, and the time of the material staying in the pellet mill on the hydraulic diameter of pellets, is represented by the formula (1)

$$d_m = -18.78 + 2.51\alpha + 0.39\chi - 1.89n - 278.91w_w - 1.84t + 0.02\alpha^2 + 0.01\alpha\cdot\chi - 0.05\alpha\cdot n - 10.17\alpha w_w - 0.14\alpha\, t + 3.7\cdot10^{-3}\chi^2 - 0.02\chi\, n - 3.35\chi\cdot w_w - 0.04\chi\cdot t - 0.03n^2 + 17.21n\cdot w_w + 0.18n\cdot t + 936.19\, w_w^2 + 31.92\, w_w\cdot t + 0.01t^2$$

$$(1)$$

For example:

1. An increase of the rotational speed of the pelleting plate from 7.2 rpm to 21.6 rpm (at invariable parameters: inclination angle of the pelleting plate $\alpha = 30°$, inclination angle of the pelleting blade in the pellet mill $\chi = 60°$, amount of the added pelleting liquid $w_w = 0.324$ kg, and pelleting time $t = 14$ min results in an increase of the hydraulic diameter of pellets d_m by 39.92 mm (from 27.77 mm to 67.69 mm).

At an inclination angle of the pelleting plate of $\alpha = 30°$, inclination angle of the pelleting blade in the pellet mill $\chi = 60°$, $= 40°$, the hydraulic diameter of pellets d_m increases by 32.84 mm (from 14.65 mm to 47.49 mm), while at an inclination angle of the pelleting plate $\alpha = 50°$, the hydraulic diameter also increases by 26,35 mm (from 4.67 mm to 31.02 mm). Increasing the number of rotations of the pelleting plate in the given time causes an increase of the hydraulic diameter of pellets d_m. At a higher number of rotations of the pelleting plate, pellets cover a longer distance of rolling on the plate, that is why their diameter increases. The

frequency of rotation of the pelleting plate has a large impact on the flowing movement of material that is adequate for the process. When determining its value, the aim should be to create conditions of feeding that would ensure not only the rolling of of particles on the surface of the plate, but would also prevent destruction of the already created pellets of a given size.

2. Increasing the amount of the pelleting liquid from 0.252 kg to 0.324 kg causes an increase of the hydraulic diameter of pellets d_m, at the following invariable parameters: angle of inclination of the pelleting plate α =30°, angle of inclination of the pelleting blade in the pellet mill χ =120°, rotational speed of the plate n = 21.6 rpm, time of pelleting t = 8 min, by 7.8 mm (from 0.61 mm to 8.41 mm).

The process of pelleting carried out for a time t = 11 min, at an increase of the amount of the added liquid causes an increase of the hydraulic diameter of pellets d_m by 18.95 mm (from 1.01 mm to 19.96 mm). A similar situation occurs when the time of pelleting t is changed to 14 min. Along with the increase of the pelleting liquid added to the plate, the hydraulic diameter of pellets d_m also increases by 26.87 mm (from 4.92 mm to 31.79 mm).

Creation of a pellet begins while getting the liquid into contact with the pelleted material. Sprayed particles of liquid falling onto the surface of the dusty material penetrate into its deeper layers and are, due to the flowing movement, covered. A pellet moving in the pellet mill is pressed, its inter-granary space becomes smaller, and the liquid from inside of it is pressed onto the surface. This allows a new portion of material to attach. For this reason, an increase of the amount of the pelleting liquid added to the plate w_w causes a change in the hydraulic diameter of pellets d_m.

3. An increase of the value of the inclination angle of the pelleting plate from α = 30° to 50° (at the following invariable parameters: inclination angle of the pelleting blade in the pellet mil χ = 60°, rotational speed of the pelleting plate n = 21.6 rpm, amount of the added pelleting liquid w_w = 0.324 kg, and time of pelleting t = 8 min) causes a reduction of the hydraulic diameter of pellets d_m by 19.99 mm (from 30.81 mm to 10.82 mm).

During a longer time of the material staying in the pellet mill, for t = 11 min, the hydraulic diameter of pellets d_m decreases by 28,33 mm (from 49.12 mm to 20.79 mm), while in the case of pelleting carried out for a time t = 14 min, the hydraulic diameter decreases by 36.67 mm (from 67.69 mm to 31.02 mm).

The increase of the inclination angle of the pelleting plate α (from 30° to 50°) is the result of a less intense movement of the deposit on the plate, which has an impact on the frequency and forces of interaction between the flowing particles of the deposit, which lowers the probability of their binding.

4. A change of the inclination angle of the pelleting blade from χ = 60° to 120° causes a reduction of the hydraulic diameter of pellets d_m. A change of the inclination angle of the pelleting blade from 60° to 120° (at the following invariable parameters: inclination angle of the pelleting plate α = 30°, rotational speed of the pelleting plate n = 21.6 rpm, amount of the added pelleting liquid w_w = 0.324 kg, time of pelleting t = 8 min) causes the production of pellets whose hydraulic diameter d_m decreases by 22.41 mm (from 30.81 mm to 8.4 mm).

During pelleting carried out for a time t = 11 min, at an increase of the inclination angle of the pelleting blade from

χ = 60° to 90° (at the following invariable parameters: inclination angle of the pelleting plate α = 30°, rotational speed of the pelleting plate n = 21.6 rpm, amount of the added pelleting liquid w_w = 0.324 kg) causes a change in the hydraulic diameter of the obtained pellets d_m, whose value decreases by 29.16 mm (from 49.12 mm to 19.96 mm). A similar situation occurs when the time of pelleting t is changed to 14 min, in which case the hydraulic diameter of pellets d_m decreases by 35.9 mm (from 67.69 mm to 31.79 mm).

The increase of the inclination angle of the pelleting blade in the pellet mill has an impact on the hydraulic diameter of pellets. An average size of the obtained pellets mainly depends on the time of the material staying in the plate. A change of the inclination angle of the blade χ (from 60° through 90° to 120°) causes the creation of pellets of smaller dimensions.

In this case, the kinetics of the process is mainly influenced by the different dynamics of the flowing deposit (the material accumulating near the pelleting blade), which has an impact on interactions between its particles contained in the pellet mill. The accumulation of excessive amounts of moist pellets near the blade has an impact on the change of the movement of the material on the plate, which results in diminishing the continuity of the rotational movement and the pelleted deposit entering a cataract movement. This results in the production of aggregates characterized by weak bindings and low density, which, due to mutual collisions in the pelleted deposit, undergo shredding.

On the basis of formula (1), the maximum value of the hydraulic diameter of pellets d_m, in the full range of the assumed changes of the independent parameters, is 67.69 mm, for the following values: α = 30°, χ = 60°, n = 21.6 rpm, w_w = 0.324 kg, t = 14 min, whereas the minimum value is: 0.53 mm, for the following values: α = 40°, χ = 90°, n = 21.6 rpm, w_w = 0.252 kg, t = 8 min.

7. Conclusions

1. An increase of the amount of pelleting liquid added to the plate causes an increase of the hydraulic diameter of pellets.
2. Increasing the inclination angle of the pelleting plate has an impact on its reduction.
3. The hydraulic diameter of pellets increases along with the time of the deposit staying in the pellet mill.
4. Increasing the rotational speed has an impact on the increase of the hydraulic diameter of pellets.
5. The use of the pelleting blade in the plate, inclined at angles of 60° and 90°, has an impact on the increase of the hydraulic diameter of the set of pellet particles.

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