Physicochemical Problems of Mineral Processing, 39 (2005), 219-228
Fizykochemiczne Problemy Mineralurgii, 39 (2005), 219-228

Andrzej. HEIM*, Andrzej. OBRANIAK*, Tadeusz. GLUBA*

CHANGES OF FEED BULK DENSITY DURING DRUM GRANULATION OF BENTONITE

Received March 15, 2005; reviewed; accepted May 15, 2005

Results of investigations on bentonite agglomeration in drum granulators of diameter D = 0.25-0.4 m, with drop-wise wetting are discussed. The effect of process and equipment parameters (drum diameter D, filling factor of the drum k, granulation time t, moisture content w, rotational speed of the drum) on bulk density of a bed ρ has been determined.

Keywords: drum granulation, bulk density

INTRODUCTION

The idea of transforming powders and dusts into granules is connected with the new environmental philosophy and standards concerning environmental protection and working conditions, but also with consumers' requirements related to the above mentioned materials. In general, the process of agglomeration covers processing of dust and powder materials into a granulated form. This form has no disadvantages of the dust material such as dusting, lumping, formation of overhangs in the storage tanks, at the same time preserving its basic physical properties. One of frequently used methods for production of granulated material is drum granulation and agglomeration which consists in the formation and growth of particles in a mobile bed of fine-grained (tumbling) material. Results of investigations carried out so far refer mainly to the granulation technology of specified substances, and first of all to process kinetics.

There is a few studies which present general relationships related to the production of granulated material with desired physico-mechanical properties different than granule size. One of significant parameters that describe the properties of granular materials are density and bulk density. During granulation these parameters in relation to the processed bed change because of changes in the particle size

* Technical University of Lodz, Department of Process Equipment, Stefanowskiego 12/16, 90-924 Lodz, Poland, gluba@wipos.p.lodz.pl

distribution (a change in the volume of intraparticle space) and porosity of single agglomerates. Growing moisture content of the granulated material has also a significant influence on the change of density in time.

Research on the effect of granulation process conditions on bulk density of the material was carried out by (Horwath et al. 1987, Heim et al. 2000, Gluba 2001, Gluba 2003, Gluba and Grabowski 2001).

AIM OF THE WORK

The aim of this research was to determine the effect of process and equipment parameters (drum diameter, filling of the drum with raw material, rotational speed of the granulator, granulation time and bed moisture content) on bulk density of the product obtained at the stage of wetting.

EXPERIMENTAL RIG

A schematic diagram of the experimental rig is shown in Fig. 1. Drum (1) was driven by motoreducer (3) through a belt transmission and a coupling. The rotational speed of the drum was changed smoothly using inverter (4). A granular bed placed in the drum was wetted drop-wise by means of sprayer (2), inserted axially to the drum.

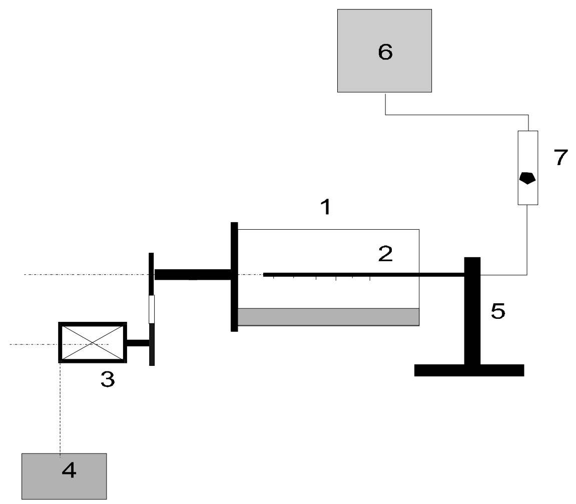

Fig. 1. Schematic diagram of the experimental rig

The wetting liquid was supplied from tank (6) placed on the level of 2.5 m from the drum axis, and its flow rate was settled by means of rotameter (7). The sprayer was mounted on a separate stand (5). For the whole time of the experiment a constant level of liquid in the tank was maintained which ensured constant pressure of liquid supplied. The wetting liquid was distilled water. The experimental rig for measuring bulk density and particle size distribution of the granulated material consists of a laboratory balance, a system of sieves with mesh size: 1, 2, 3, 4, 5, 6, 8, 10, 12 mm and of a glass measuring cylinder 250 cm^3 in volume. Bulk density of the feed was set up on the basis of the mass and volume of samples taken from the drum.

SCOPE OF INVESTIGATIONS

The following ranges of parameters were used in the experiments:

- drum diameter D = 0.25, 0.3, 0.35, 0.4 m,
- filling factor of the drum k = 5, 7.5, 10, 12.5, 15, 20%,
- relative rotational speed $n_w = \frac{n}{n_{kr}} = 0.15 - 0.375$.

All drums had the same length L = 0.24 m. The granular bed was wetted drop-wise during drum rotation at a constant rate of liquid outflow Q = 60 ml/min, until overwetting of the material which led to sticking of the bed on the inner walls of the granulator.

MEASURING METHODS

In preliminary investigations the values characterising raw material were determined. Particle size distribution and mean size was determined during measurements with a laser particle size analyser FRITSCH. The size of bentonite particles used in further investigations ranged from 0 to 0.16 mm, and the mean volumetric size was $d_m = 0.056$ mm.

Bulk density of the raw material was measured for two states of packing of its particles: for the loosely packed and compact material, and the result was arithmetic mean from these measurements.

While analysing on-line the properties of granulated products, at constant time intervals equal to 60 or 120 seconds, samples were taken after stopping the drum in order to measure the following:

- bulk density,
- particle size distribution.

To be sure that the sample was representative for the whole bed, it was always taken using a special device of length equal to the drum length, which eliminated the effect of segregation caused by axial circulation of the granulated bed. After making appropriate measurements, the sample was returned to further granulation.

Bulk density was determined by weighing the representative samples on an analytical balance. The samples were placed in a measuring cylinder which enabled determination of its bulk density. The bulk density was calculated from the formula:

$$\rho = \frac{m_b - m_t}{V_c} \tag{1}$$

Particle size analysis of the product was carried out using a system of sieves with mesh d_o= 1, 2, 3, 4, 5, 6, 8, 10, 12 mm. A sample of granulated material taken in a given moment was sieved on screens without shaking to prevent destruction of the granules. Each fraction obtained in this way was weighed on an analytical balance. Next, the whole sample was returned to further granulation. On this basis mass fractions were determined and then total mass distribution and mean diameter were calculated.

RESULTS OF INVESTIGATIONS

The effect of equipment and process parameters (D, k, n_w) on changes in bulk density of wetted fine-grained bed during granulation is described in the study. Figures 2 and 3 show examples of the relations ρ = f(t) and ρ = f(w) for different values of drum filling factor k.

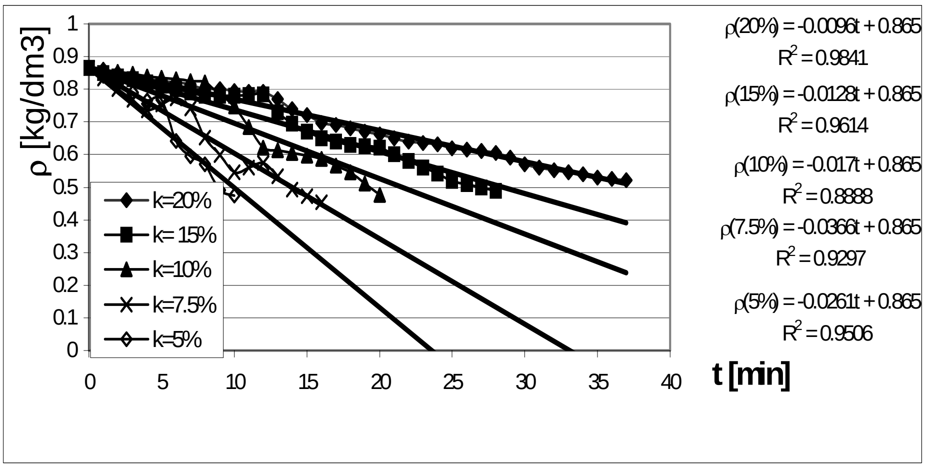

Fig. 2. Change of the bed bulk density during granulation at different values of the drum filling factor, at D = 400, n_w = 0.2

A nearly linear dependence of bulk density on time and the increase of feed moisture content follows from the graphs presented above. The bulk density of the processed bed decreases with the wetting time. A decrease of bulk density of the bed in time can be explained by the increase of agglomerate size, which results in an increase of void spaces between the formed granules at a simultaneous lack of condensation of their inner structure.

To visualise differences in the rate of changes of bulk density of the agglomerated material that occur in one experiment, the results obtained were approximated with a linear function which determined a mean rate of the discussed changes. That enabled an evaluation of local deviations which were observed for each experimental run. Although linear equations approximate with big accuracy the character of bulk density function vs. time, in the entire granulation cycle, in all tested cases one can observe in the graph a short-term period, or even a point (about w = 0.2), which separates two main ranges of bulk density changes in time. This frequently occurring deviation from a strictly linear character of the relationship requires a more extensive discussion.

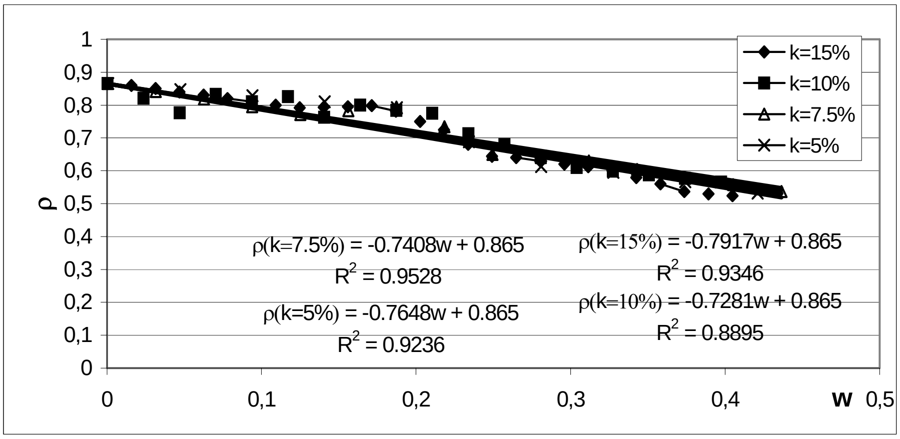

Fig. 3. Dependence of bulk density of the bed on moisture content for different values of the drum filling factor at D = 400, $n_w = 0.15$

In the first observed period, the bulk density decreases much slower than when the bed is characterised by a high level of granulation. In the first period, agglomerates with dry surfaces are formed around granulation centres (nuclei) and the raw material that has not been processed yet fills up the intragranular spaces, and at the very onset of the process may even be a specific medium in which a few granules already formed can move. The later phenomenon of a more abrupt decrease of bulk density in the second stage of granulation occurs in the moment when nearly the whole loose material has been granulated and the further process consists only in an increase of the dimension of agglomerates being formed. This is caused by the lack of unprocessed raw material which would fill up void intragranular spaces at this stage of the process. After the first period, the rate of bulk density decrease is usually close to the rate described by the slope of the proposed straight line.

The dependence of bulk density on mean size of the granulated material is confirmed by a comparison of changes in these two values in the wetting time shown in Fig. 4. It can be observed that characteristic points in both graphs that separate time intervals in which significant differences occur in the rates of changes of tested parameters, appear for the same moments of time and also that particular ranges of changes in these properties are the same.

The period between the 13th and 17th minute of the process is particularly important in the case of the graphs shown as examples of granulation at the parameters given in Fig. 4, where the effect of changes in the process kinetics on the rate of decrease of the bulk density of the granulated bed is very distinct.

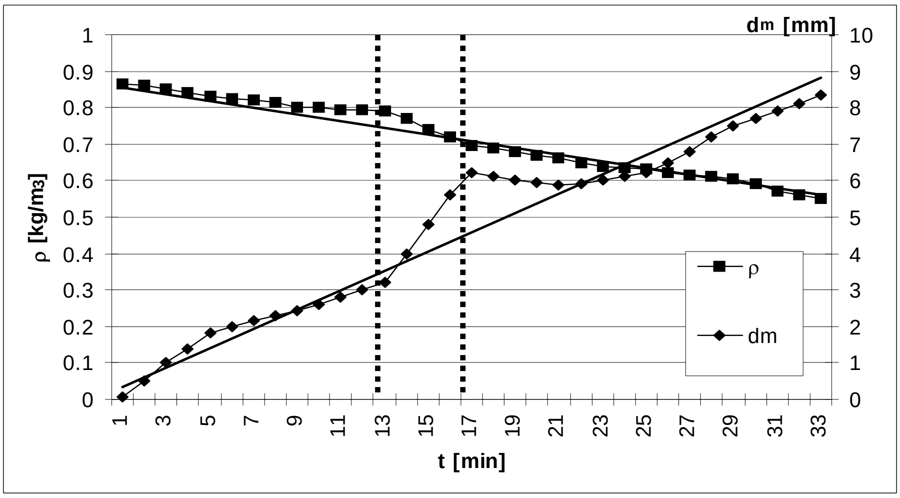

Fig. 4. Comparison of changes in the bulk density and mean size of the agglomerate in the granulation time, example for the experiment at parameters: D = 400 mm, k = 15%, n_w = 0.2

For each experimental run carried out at different operating parameters, there was a characteristic period caused, naturally, by a different mass of the feed in different time intervals. The effect of drum filling factor was estimated at the set up values of wetting time and feed moisture content. Naturally, because the wetting parameters are constant, for experiments carried out at high filling factor of the drum (bigger feed mass) for the same wetting time higher densities are obtained (a slower decrease of this parameter) than in the runs with low factor k.

The effect of filling factor k on changes in the bulk density as a function of moisture content of the granulated bed was negligible. The change of the drum filling factor k (Fig. 3) had no effect on the differentiation of bulk density of the granulated product of the same moisture content.

Analogous relations of bulk density changes were prepared for two other operating parameters of the rotating drum (granulator diameter D and relative rotational speed n_w).

An example of the relationship illustrating changes in the bulk density as a function of wetting time and bed moisture content for different drum diameters of the granulator is shown in Fig. 5a,b.

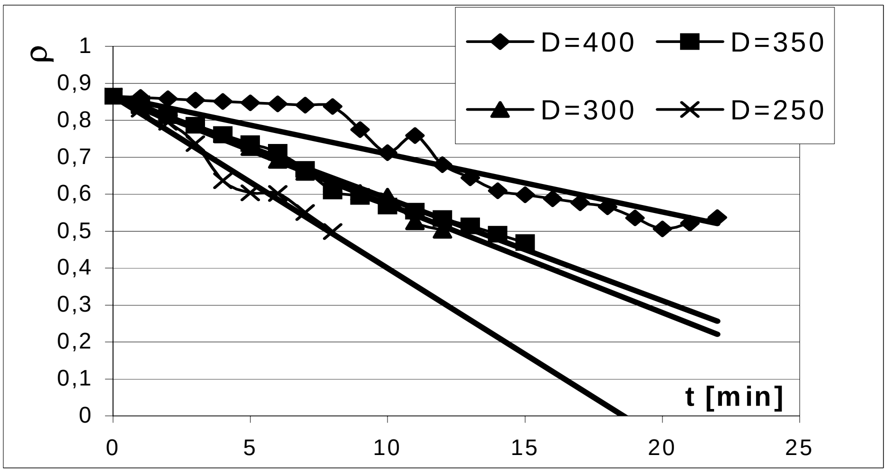

Fig. 5a. The effect of wetting time on bulk density for different drum diameters at k = 10%, $n_w = 0.15$

Analysis of the slopes of linear approximations shown in Fig. 5a allows us to state that there is a significant effect of the drum size on changes in bulk density of the granulated material with the wetting time.

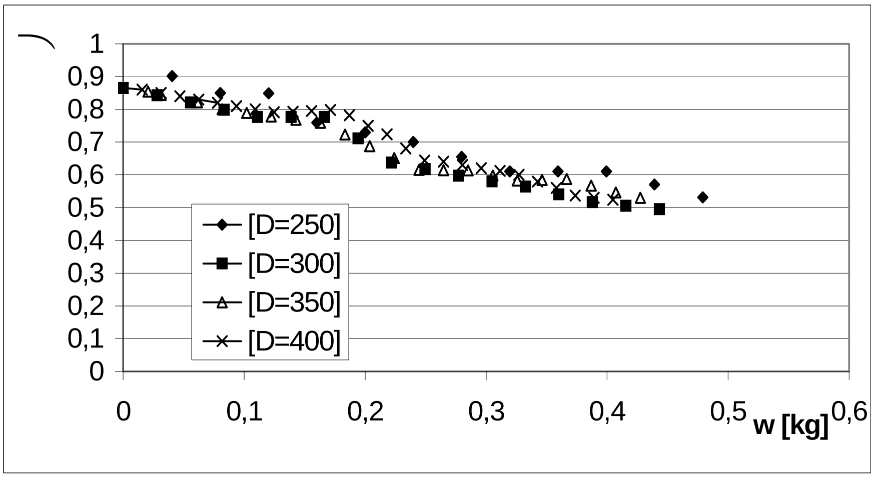

Fig. 5b. The effect of moisture content on bulk density for different drum diameters, at k = 15%, $n_w = 0.15$

The rate of bulk density changes was slower for drums with bigger diameter than for the small ones. This was related to the feed mass which depended in a natural way on the drum size. At constant wetting parameters it affected the granulation rate (prolonged the process time) and changed the bed properties.

When comparing the effect of drum diameter on bulk density as a function of bed moisture content, the role of this parameter decreased just for the same reasons as the role of the granulator filling factor k did. This tendency is illustrated in Fig. 5b. Changes of the bulk density in wetting time for experiments carried out in the same granulator and for constant values of filling factor k, at different rotational speed of the drum are identical to those related to the bed moisture content because of the lack of changes in the feed mass. An example of the relation illustrating the effect of relative rotational speed on bulk density is shown in Fig. 6. The effect of relative rotational speed appeared to be very small and could be considered negligible.

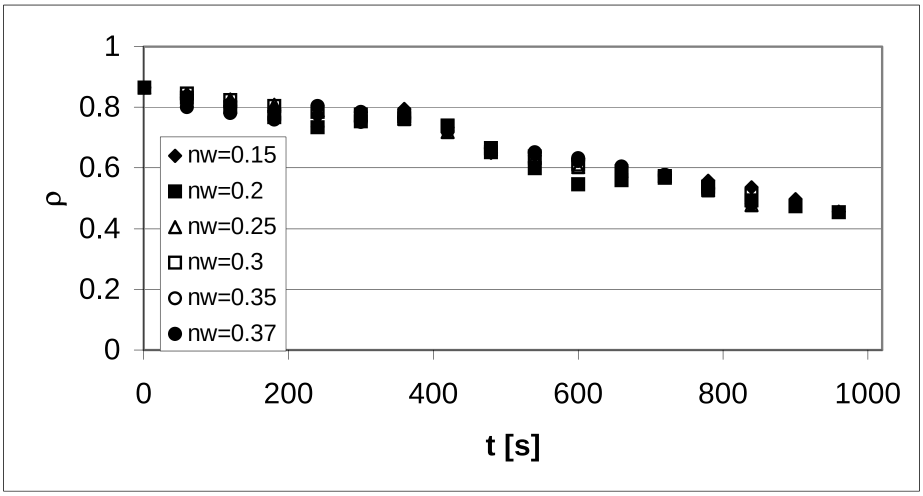

Fig. 6. The effect of time on bulk density for different relative value of rotational speed n_w, at k = 7.5%, D = 400 mm

Due to high accuracy of the linear approximations obtained for most experimental runs and a simple form of these relations, the change of bulk density of the granulated product in time can be described by equation (2)

$$\rho = -A \cdot t + \rho_p \tag{2}$$

where: ρ_p= 0.865 kg/dm^3 is the bulk density of the raw material.

The slope of straight line A, which determines the rate of changes of the bulk density in time, was related to varying equipment and process parameters. As a result, the dimensionless equation (3) was obtained with correlation coefficient R = 0.985.

$$A = \frac{\partial \rho}{\partial t} = 10^{-3.5} \cdot (D/L)^{-1.9} \cdot n_w^{\ 0.06} \cdot k^{-1} \tag{3}$$

While analysing the obtained relations it is interesting to observe the inversely proportional effect of drum filling factor and drum diameter in the power close to -2. The negative power determinant at the drum diameter corresponds approximately to the inversely proportional effect of the drum cross section on bulk density changes. The inversely proportional effect of these two values on the bulk density decrease can be explained by the fact that both factor k and diameter D are the parameters which describe the mass of granulated packing, with increase of which at a constant wetting rate, the feed is granulated slower. The relationship confirms also a negligible effect of changes of rotational speed.

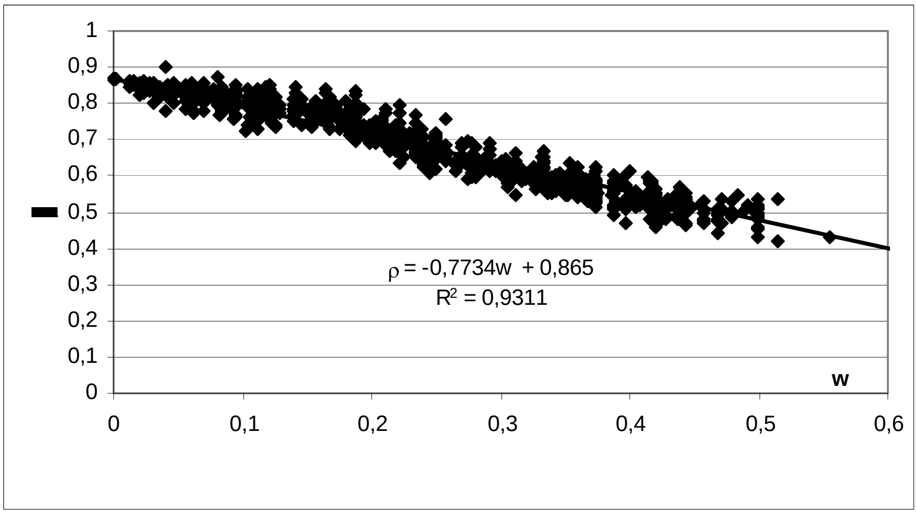

Fig. 7. Decrease of batch density of bentonite with a change in moisture content of granulated bed in all tests

The above considerations have been confirmed by relations presenting the effect of moisture content of the granulated bed on its bulk density. In view of the moisture content definition, such a comparison eliminates the effect of a processed bed mass and wetting intensity resulting from different drum sizes and filling levels. Analysis of the results of all tests (972 measuring points), whose correlation is illustrated in Fig. 7, allowed us to propose equations in the form:

$$\rho = \rho_p - 0{,}77 \cdot w \tag{4}$$

Relation (4) and results presented in Fig. 7 confirm also validity of the assumed approximation of linear changes in batch density with advances of the granulation process. It was proved that the slope of straight line ρ=f(w) did not depend on equipment and process parameters (D, k, n_w). It can be presumed that during such granulation it can be affected, beside moisture content, only by wetting parameters and raw material properties.

NOMENCLATURE

k – filling factor of the drum,
n_w – relative rotational speed of the drum,
t – time of wetting (granulation), s,
m_b – gross sample mass,
n – rotational speed of the drum, 1/s,
m_t – measuring vessel mass,
ρ_n – bulk density of the product, kg/m^3,
A – slopes of the straight lines,
D – drum diameter, m.

ACKNOWLEDGEMENT

The study was carried out within the research project no. 4 T09C 023 22 sponsored by KBN in 2002-2005.

REFERENCES

GLUBA T., *The effect of wetting liquid droplet size on the growth of agglomerates during wet drum granulation*, 7th Symposium on Agglomeration 2001, (Albi France), vol. 2, 877-886.

GLUBA T., GRABOWSKI R. (2001), *The effect of wetting conditions on granule porosity*, Prace Naukowe Instytutu Górnictwa Politechniki Wrocławskiej 95, Konferencje 31, 15-24

GLUBA T. (2003), *The effect of wetting droplet size on the growth of agglomerates during wet drum granulation*, Powder Technology 130, 219-224

HEIM A., GLUBA T., OBRANIAK A., (2000), *The effect of process and equipment parameters on material properties during drum granulation*, Proceedings of the 3rd Israeli Conference for conveying and handling of particle solids vol. 1, pp. 2.14-2.19.

HORWATH E., PATAKI K. (1987), *Study of the rolling-bed granulation III,* Hungarian J. of Indust. Chem. Veszprem. 15. 133-140.

Heim A., Obraniak A., Gluba T., *Zmiany gęstości nasypowej wsadu podczas granulacji bębnowej bentonitu,* Physicochemical Problems of Mineral Processing, 39 (2005) 219-228 (w jęz. ang)**.**

Przedstawiono wyniki badań aglomeracji bentonitu w granulatorach bębnowych o średnicy D=0.25-0.4m, przy nawilżaniu kroplowym. Określono wpływ parametrów procesowo-aparaturowych (średnicy bębna D, stopnia wypełnienia bębna k, czasu granulacji t, wilgotności w, prędkości obrotowej aparatu) na gęstość nasypową złoża ρ.