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THE EFFECT OF EQUIPMENT AND PROCESS PARAMETERS ON TORQUE DURING DISK GRANULATION OF BENTONITE

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Changes of torque during foundry bentonite granulation in disk granulators were studied. Variable parameters were the diameter and inclination angle of the granulator disk and filling of the disk with granular material. The bed of loose material was wetted drop-wise during tumbling, at a constant volumetric liquid flow, by a sprinkler that ensured uniform supply of the wetting liquid. In every trial the instantaneous values of net torque were measured. The effect of the disk diameter, its angle of inclination, filling with raw material and moisture content of the granulated bed on torque changes was assessed. A correlation equations was proposed to describe the effect of the above parameters on the reduced torque change.

Key words: disk granulation, torque

INTRODUCTION

For majority of operations that take place in rotary granulators the type of bed motion characterises and determines the process [Kapur 1992]. Granular bed dynamics in tumbling granulators, i.e. the motion of granules and particles and forces with which the bed and disk interact, determines the angle of bed inclination [Heim et al. 1995] and net torque [Heim et al. 2000], and consequently, the power of a driving motor [Gluba et al. 1995]. The inertial and friction forces in the discussed system are determined by such equipment and process parameters as the diameter and inclination angle of the apparatus [Chadwick and Bridgwater 1997], its filling with raw material [Kantorowicz 1959] and rotational speed [Heim et al. 1995]. The effect of these parameters on the dynamics of a model granular bed during mixing in a horizontal rotary drum [Koroticz 1961, Heim et al. 1995], during grinding in ball mills [Harris et

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al. 1985, Tarjan 1981] and during granulation in a horizontal drum granulator [Obraniak 2002] has already been studied. However, there are no studies on bed dynamics during disk granulation in a broad range.

AIM OF THE STUDY

The aim of this study was to determine the effect of selected process and equipment parameters, namely bed moisture content, disk filling and diameter and angle of disk inclination on torque.

RANGE OF STUDIES

The variable parameters were:
- disk diameter D = 0.5, 0.75, 1.0 m,
- filling of the granulator with granular bed k = 3% - 7%,
- angle of disk inclination α = 45° - 53.

The torque was measured on line during wet disk granulation.

MEASURING EQUIPMENT and METHODS

The experimental set up is shown in the photograph in Figure 1. The disk was driven by a motoreducer by means of a belt transmission and flexible coupling. A smooth change of disk rotational speed was obtained using an inverter, and the speed was controlled by a speedometer. Instantaneous values of torque were measured by a torquemeter, converted by a reader and recorded by a computer. The granular bed placed in the disk was wetted dropwise by a sprinkler which ensured a uniform liquid supply. The sprinkler was mounted on a stand independent of the granulator. The wetting liquid (distilled water) was supplied from a tank located on the level 2.5 m above the disk surface, and its constant flow rate ($Q=0.7 \cdot 10^{-6}$ m^3/s) was controlled by a rotameter. For the whole time of testing a constant liquid level was kept in the tank which ensured constant pressure of the supplied liquid. The granular bed was wetted until final moisture content was equal to $w_k=0.29$. Every 60 s or 120 s a sample was taken and bulk density and the angle of natural repose were measured. After that it was returned to the disk. The process of granulation was carried out batch-wise for each of the three disk dimensions at steady-state process and equipment parameters, i.e. filling of the disk and inclination angle of the granulator axis.

Results of measurements of instantaneous values (at time intervals 1s) of net torque M were converted to the reduced torque M* according to equation (1).

$$M^*(t) = \frac{M(t) - Mj}{m_s + Q \cdot \rho_w \cdot t} \tag{1}$$

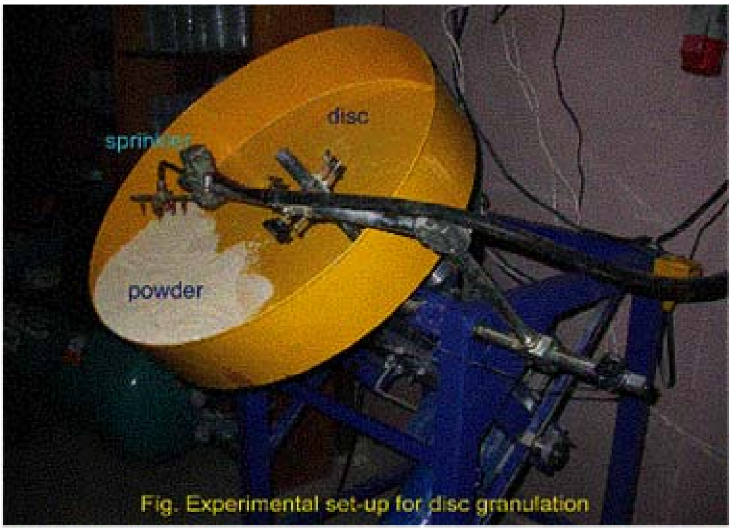

Fig. 1. Experimental set-up

Next, mean values of torque were calculated for 10-second periods (from 10 consecutive values). Variability of the reduced torque in time, when the wetting liquid is supplied continuously at a constant flow rate, is identical to the change of torque as a function of feed moisture content. This moisture content in a given moment "t" is calculated from the equation:

$$w = \frac{m_w}{m_s} = \frac{Q \cdot t \cdot \rho_w}{m_s} \tag{2}$$

RESULTS

An example of the dependence of reduced torque M* averaged for 10-second periods on moisture contents is illustrated in Fig. 2. When analysing the diagrams three ranges can be distinguished each time for which different functions were obtained. In the first range, dependence of the torque on time is in the form of an increasing function, in the second range a decrease of the torque is observed, while in the third one it is stabilised.

Particularly interesting is the initial growth of the torque and its further steady state. This character of torque changes can be explained by changes in the parameters that characterise the granulated bed during the process. Then, the particle size distribution changes and due to water supply, the mass and moisture content of the entire bed and individual granules as well as the bulk density and inner friction angle at certain stages of the process also change.

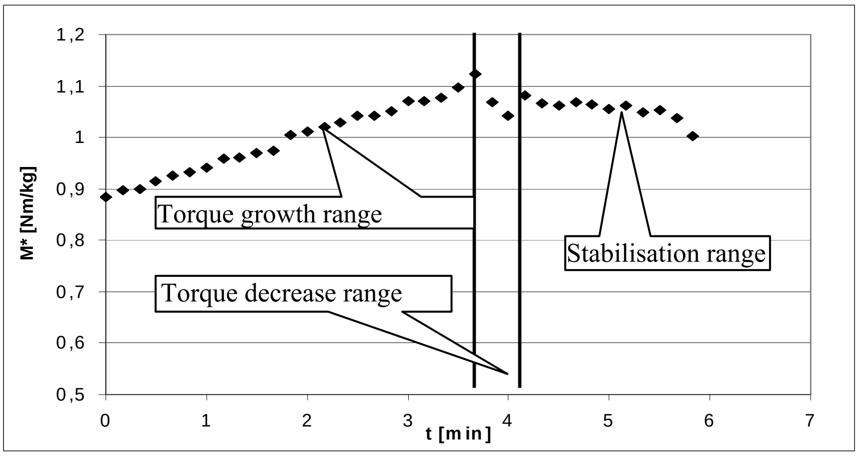

Fig. 2. Example of the dependence of reduced torque on wetting time, (D=0.5, k=5%; α=45°)

It follows from Fig. 2 that after reaching some boundary value of bed wetting, the further liquid supply causes a decrease of the torque, and next the torque is on a stable level which is a result of steady state of the parameters that characterise the processed material (bulk density, angle of natural repose).

Analysis of results obtained in the studies indicates that the torque during bed wetting (granulation) in the rotating disk depends also on the equipment and process parameters, i.e. the degree of filling of the granulator k, disk diameter D and its angle of inclination α.

Figure 3 shows an example of comparison of reduced torque changes during bed wetting for different levels of disk filling k. On the basis of the results obtained it can be concluded that the reduced torque decreases with an increase of disk filling. This tendency is observed in the whole wetting range; from the starting point, through the stage of growth, until torque stabilisation. This is most probably related to a decreasing (with an increase of filling) distance of the point of application of the resultant force of friction (between the bed and disk surface) from the axis of the disk rotation. Owing to the arm of the force this has an effect on the torque coming from the resultant force of friction. Analysis of the relationships obtained allows us to conclude that different values of coefficient k, (due to changes in raw material mass) affect the wetting time and agglomeration rate, which in Fig. 3 is revealed by both total process duration and different time points in which characteristic stages of granulation occur.

To confirm the observed tendencies and to explain the effect of filling degree k, changes of torques in Fig. 3 are shown in Fig. 4 as functions of averaged bed moisture content changing during the process. Relations obtained show that for tests made at all degrees of filling k, the maximum unit torque is obtained for similar bed moisture contents. The torque is also stabilised for similar moisture contents.

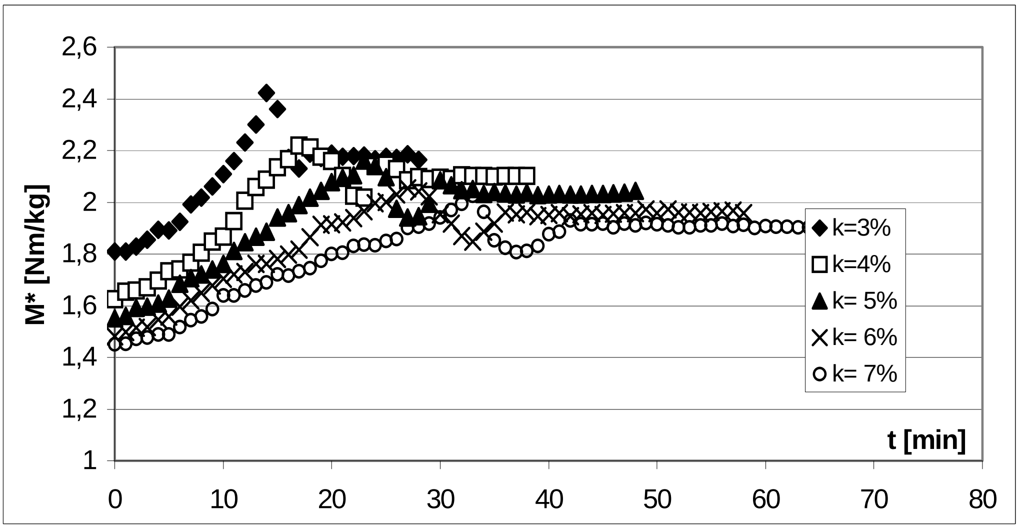

Fig. 3. Example of changes in reduced torque as a function of time for different values of disk filling k (D=1 m; α=47)

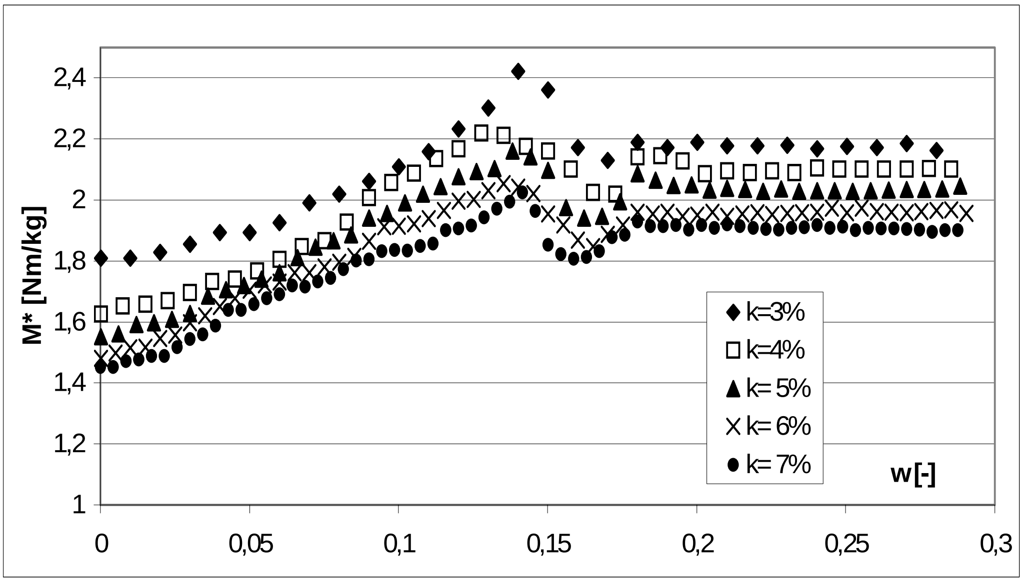

Fig. 4. Example of changes in reduced torque as a function of bed moisture content for different values of disk filling k (D=1 m; α=47)

This provides an evidence of the effect of changes in disk filling only on the system dynamics. There is no such influence on changes of the granulated bed properties, i.e. process kinetics. Similar conclusions can be drawn from the analysis of changes in reduced torques during granulation in three disks with different diameters.

The effect of the next parameter – the disk diameter on reduced torque as a function of moisture content is shown in Fig. 5.

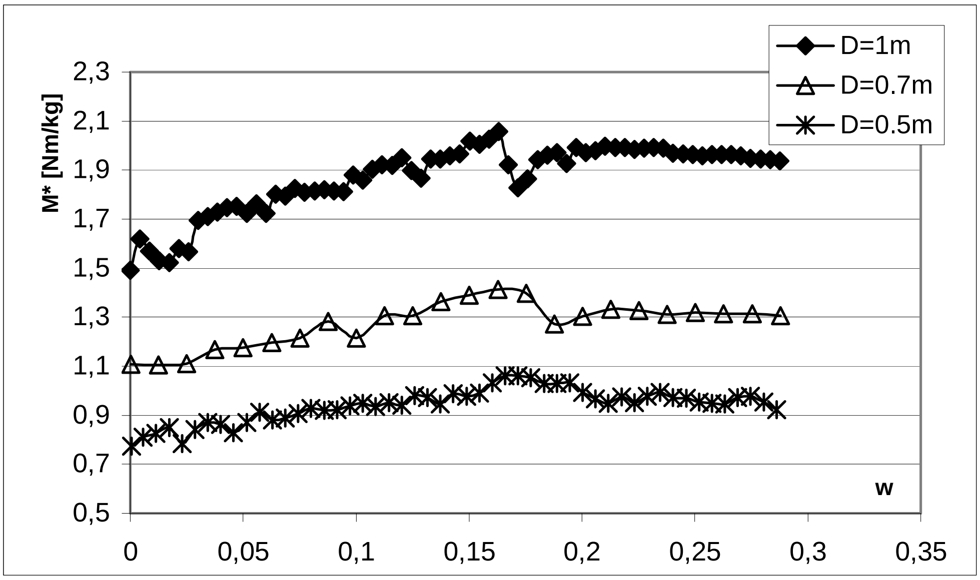

Fig. 5. Example of changes in reduced torque with bed moisture content for three disk diameters (k=7%, α=45°)

It follows that for a disk with bigger diameter, the values of M* are higher. An increase of the reduced torque is probably caused by a growing distance of the point of application of the resultant force of friction between the bed and disk surface, and hence by increasing the arm of this force which gives resistance to the torque.

An example of a diagram representing the reduced torque as a function of wetting time for five angles of disk axis inclination is shown in Fig. 6. When analysing the relations it was found that in the whole range of granulation, the values of reduced torque M* are the higher the lower are the values of α. The influence of the disk inclination angle on the torque is connected with the components of forces of bed pressure on the disk bottom and edge. This has an effect on the resultant force of friction. Moreover, it can be observed that the disk inclination affects the duration of subsequent periods of granulation, and consequently on the agglomerate formation rate (process kinetics). This is revealed by differences in the duration of particular granulation periods at a changing inclination angle.

Owing to the presence of three ranges that differ in the character of reduced torque changes, it is difficult to correlate its values and the granulator operation parameters (disk diameter, filling of the granulator, angle of axis inclination) with one general equation. Hence, separate relations were proposed to describe the reduced torque as a function of equipment and process parameters for two ranges, in the first one the torque was growing and in the last one it assumed constant values. For the range of a small decrease after reaching a maximum, due to short duration no such relations were proposed.

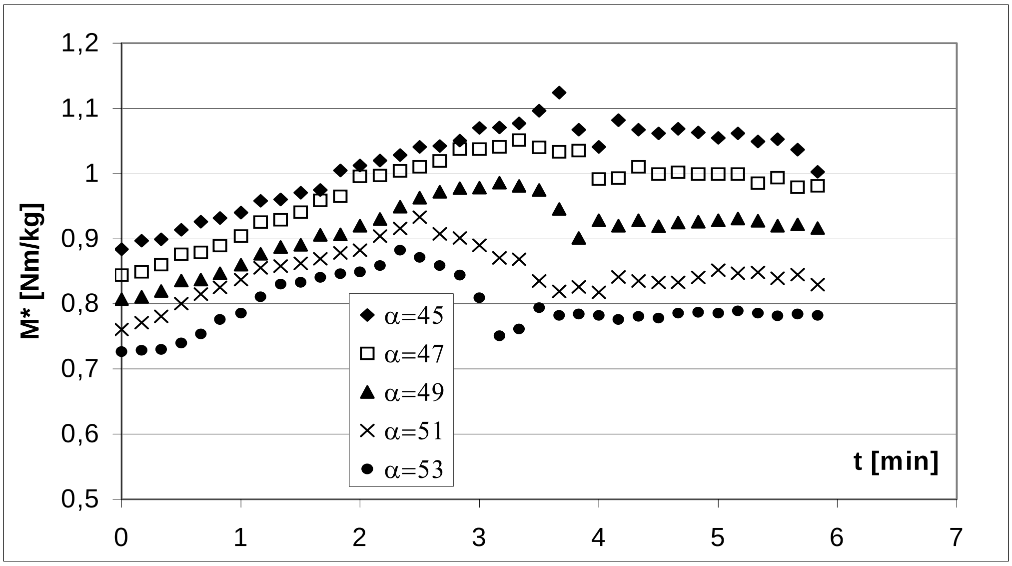

Fig. 6. Comparison of changes in the reduced torque as a function of moisture content for five angles of disk inclination (D = 0.5, k = 5%)

For the range in which the reduced torque was kept on a constant level, the following equation was obtained:

$$M^*_{st} = 10^{0.62} \cdot D^{1.08} \cdot k^{-0.15} \cdot \cos\alpha^{1.28} \tag{3}$$

This relation was obtained for the value of the correlation coefficient R^2=0.99.

It follows from this relation that the angle of granulator axis inclination and disk diameter has the biggest influence on the torque, while the degree of filling affects the torque to a lesser extent.

A graphic comparison of the values obtained from measurements and the proposed correlation is illustrated in Fig. 7.

In the range of torque growth, beside the effect of equipment and process parameters a dependence of the reduced torque on bulk density, i.e. a parameter characterising changes in the processed bed properties, was observed. Additionally, a negligibly small effect of the angle of natural repose was found. The following relation was obtained:

$$M_w^* = 10^{0.71} \cdot D^{0.93} \cdot k^{-0.12} \cdot \cos\alpha^{0.47} \cdot \rho_n^{-0.23} \qquad (4)$$

A graphic comparison of values obtained from measurements and correlation (4) is shown in Fig. 8.

The above relation was obtained at the correlation coefficient R^2=0.95.

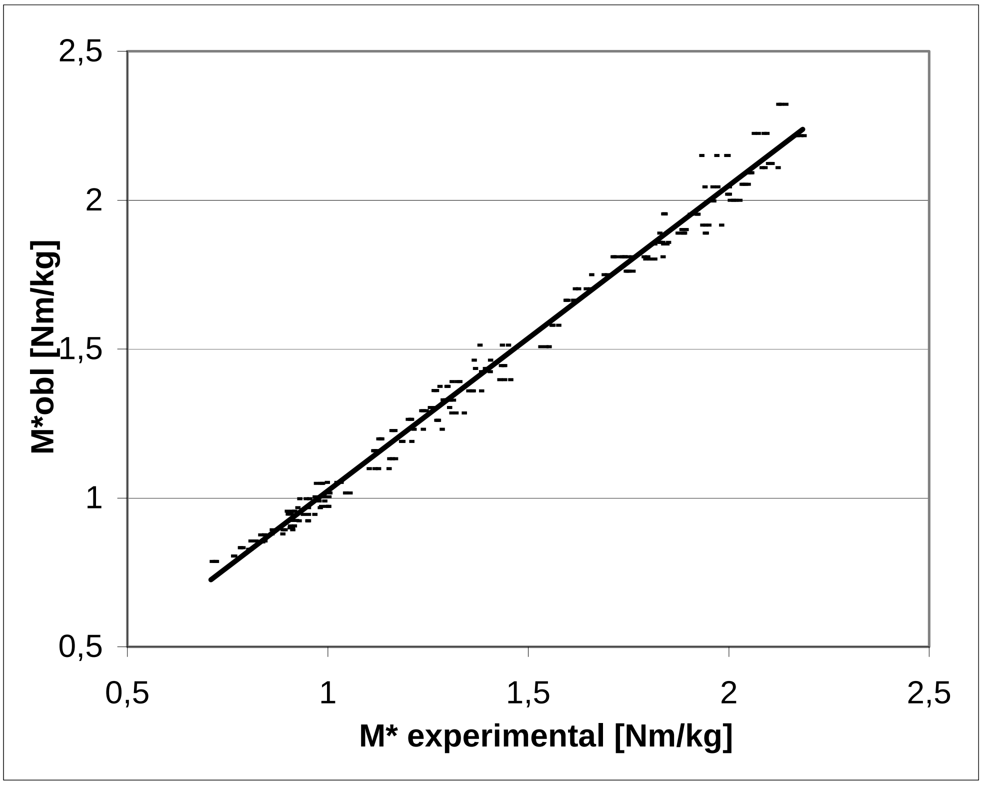

Fig.7. Comparison of values obtained from measurements and resulting from equation (3)

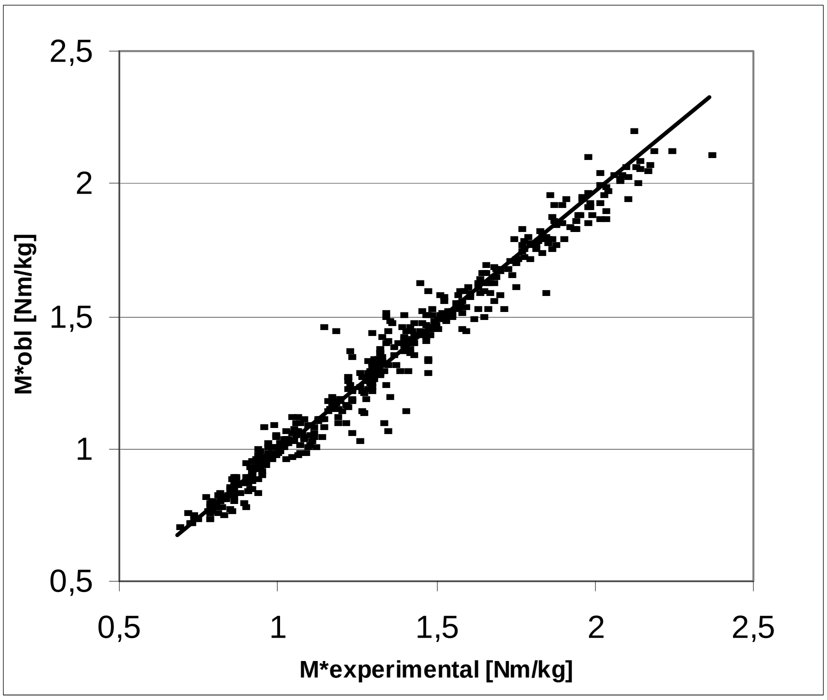

Fig. 8. Comparison of values obtained from measurements and resulting from relation (4)

CONCLUSIONS

1. Reduced torque M* increases with an increase of bed moisture content only in the initial period of disk granulation to settle down after a certain decrease.
2. The reduced torques are higher for disks with bigger diameters.
3. The value of reduced torque decreases with an increase of disk filling with granular material.
4. A significant effect of the angle of disk inclination on the reduced torque was observed.
5. Changes in the values of torque during granulation can be described by correlation equations.

ACKNOWLEDGEMENT

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LIST OF SYMBOLS

m_s – mass of loose material on the disk [kg]
$m_w = Qt\rho_w$ – mass of wetting liquid added [kg]

M – net torque [Nm]
Mj – torque of idle run for empty disk [Nm]
M* – reduced torque [Nm/kg]
M* obl – calculated reduced torque [Nm/kg]
w – moisture content of the bed [kg/kg]
D – disk diameter [m]
k – level of filling the disk with granular material [%]
α – angle of inclination of the disk axis [deg]
ρ_n – bulk density of the bed [kg/m^3]
t – wetting time [s]
Q – volumetric flow rate of wetting liquid [m^3/s]
ρ_w – water density [kg/m^3]
n – rotational speed [1/s]

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Przeprowadzono badania zmian momentu obrotowego podczas procesu granulacji bentonitu odlewniczego w granulatorach talerzowych. W badaniach zmieniano: średnicę i kąt pochylenia talerza granulatora oraz stopień wypełnienia talerza materiałem ziarnistym. Złoże materiału sypkiego nawilżano kroplowo w czasie jego ruchu przesypowego, przy stałym objętościowym natężeniu dopływu cieczy, za pomocą zraszacza zapewniającego równomierne podawanie cieczy zwilżającej. Podczas każdej próby mierzono chwilowe wartości momentu obrotowego na wale granulatora. Przeprowadzono ocenę wpływu średnicy aparatu, jego kąta pochylenia, stopnia wypełnienia talerza oraz wilgotności granulowanego złoża ziarnistego na zmianę momentu obrotowego. Zaproponowano dwa równania korelacyjne opisujące wpływ w/w parametrów na zmianę zredukowanego momentu obrotowego.