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MODEL OF ENERGY CONSUMPTION IN THE RANGE OF NUCLEATION AND GRANULE GROWTH IN DRUM GRANULATION OF BENTONITE

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Abstract. The energy consumption during granulation process in horizontal drum granulators at variable process and equipment parameters: drum diameter, angular velocity and the degree of drum filling with raw material was investigated. The feed was wetted drop-wise during tumbling at a constant liquid flow rate. During the whole process the instantaneous values of the driving torque on the shaft were measured. The effect of the drum diameter, its angular velocity, drum filling degree and moisture content of the feed on energy consumption was evaluated. A model of the dependence of energy needed for nucleation and granules growth during wet granulation for different process and equipment parameters was proposed in the paper.

keywords: agglomeration, granulation energy, drum granulation, bentonite

1. Introduction

The dynamics of a granular bed in drum granulators, i.e. the motion of the bed and individual particles, as well as forces of their interactions, determine the value of torque measured on the granulator shaft, and as a result, the power of a driving motor and energy used to carry out the process.

The analysis of static and dynamic equilibrium of the granulated bed, and also results obtained by Heim et al. (2001, 2004) prove that inertia and friction forces in the tumbling feed depend significantly on such equipment and process parameters as bed moisture content, drum diameter, its filling degree and rotational velocity of the granulator.

The changes of reduced torque as a function of feed moisture content were investigated by Heim et al. (1999). The obtained results are shown in Fig. 1.

In the graphs representing the relations of the reduced torque, three ranges can be distinguished, for which different characters of the relation were obtained. In the first range the dependence of torque on moisture content has approximately the form of square function. In the second range a decrease of the value is observed, and in the third range the value is constant. At the end of the third range there is an abrupt drop of the torque. Particularly interesting is the initial torque increase and its further fixing. Such a character of the torque can be explained by changes in the parameters characterising the granulated bed during the process such as granulation degree, granule diameter, bulk density of the feed and due to liquid supply the total mass of the bed. The influence of some of these parameters on the bed dynamics was investigated both in model mixing of the granular bed in a horizontal tumbling mill (Forssberg and Zeng, 1991; Rajamani et al., 2000) and in drum and disk granulators: (Heim, 2004; Mellmann, 2001), and during grinding in ball mills (Hogg and Fuerstenau, 1972; Kapur et al., 1992). However, there are a few studies devoted to energy consumption required to circulate the processed bed, and hence discussing the costs of drum granulation process.

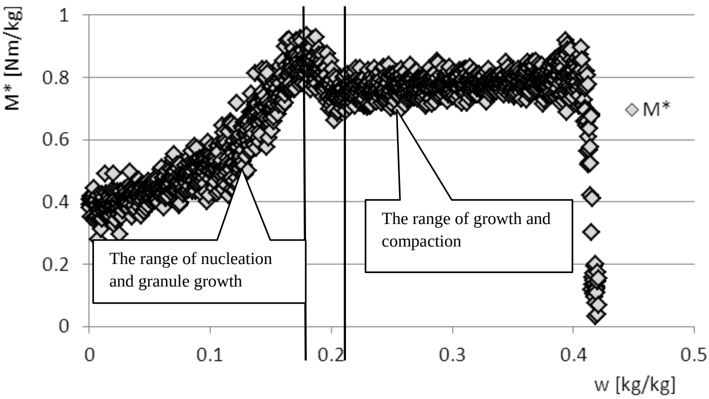

Fig. 1. The effect of feed moisture content on the reduced torque (D=0.4 m; φ=20%; ω=1.4 rad/s) (Heim et al., 1999)

2. Aim of the study and range of investigations

Aim of the study was to determine the effect of drum diameter, rotational velocity of the granulator and degree of its filling with raw material on the energy required for the transformation of powder material into granulated product.

The following ranges of changes in the parameters were used in the studies: diameter of granulator drum D = 0.25; 0,3; 0,35 and 0.40 m, drums length L=0.4 m, filling of the drum with granular material φ = 5% to 20%, angular velocity of the drum ω = 1.05 to 3.35 rad/s. The investigations were performed in four drums that had the same length L and different diameters. The range's change of drum angular velocity was select in such way to provide cascading - the typical feed movement for drum tumbling granulators.

The degree of drum filling with raw material φ was changed gradually by 2.5% or 5% in the range 5÷20% of the inner drum volume, depending on drum diameter. Such a filling range ensures correctness of granulation process. The proposed ranges of changes of process and equipment parameters (*D, ω, φ*) overlap the ranges used in drum granulation processes.

The tested material was foundry bentonite and the wetting liquid was distilled water.

3. Equipment and measuring methods

A schematic diagram of the experimental set up is shown in Fig. 2. Drum (1) was driven by motoreducer (6) by means of a belt transmission and a clutch. A fluent change of rotational velocity of the drum was obtained by means of inverter (7), and controlled by a revolution counter. Instantaneous torque values were measured by torque meter (3) and reading device (4). Next, they were processed and recorded by computer (5). The granular bed placed in the drum was wetted drop-wise by means of sprinkler (2), which was introduced axially to the device that ensured a uniform liquid supply. The sprinkler was mounted on tripod (8), which was independent of the granulator. The wetting liquid (distilled water) was supplied from tank (10), placed at the height of 2.5 m from the drum axis and its constant flow rate (Q = 10^{-6} m^3/s) was fixed by means of rotameter (9). During the trial, a constant liquid level was kept in the tank, which guaranteed a constant pressure of supplied liquid. The granular bed was wetted until the material got overwetted which caused that the bed stuck to the inner wall of the granulator.

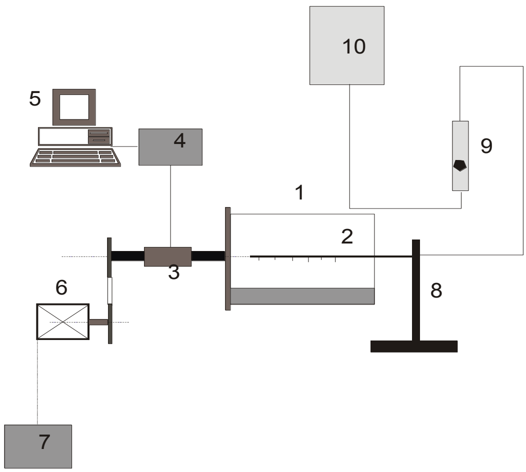

Fig. 2. Schematic diagram of the equipment. 1- drum granulator; 2- sprinkler; 3- torque meter; 4- reading device; 5- computer, 6- motoreducer; 7- inverter; 8- tripod; 9- rotameter; 10- tank

Every 120 s a sample was taken, subjected to sieve analysis and returned to the drum. The process of granulation was carried out batch-wise, each time at determined process and equipment parameters: drum filling with material, rotational velocity of the granulator and drum diameter.

4. Results

Results of the measurement of instantaneous torque values *M(t)* read in 1s time intervals on the granulator shaft during granulation (wetting stage) of the granular bed tumbling in the drum were converted to the values of reduced torque *M*(t)*.

The instantaneous values of reduced torque *M*(t)* were calculated on the basis of instantaneous torque *M(t)*, as well as on the basis of the torque of idle run (at empty granulator) M_j and the total feed mass in the drum (raw material m_s and wetting liquid $m_w(t)$) from Eq. (1):

$$M^*(t) = \frac{M(t) - M_j}{m_s + m_w(t)}. \tag{1}$$

Due to the fact that the wetting liquid was supplied all the time during granulation process with constant volume flow rate, the changes of reduced torque vs. wetting time were the same as the torque changes vs. bed moisture content *w*. Moisture content of the feed at the time *t* was calculated from Eq. (2).

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

In the case when the wetting liquid is supplied continuously at a constant flow rate to the system, the reduced moment in time is analogous to the torque in the function of feed moisture content.

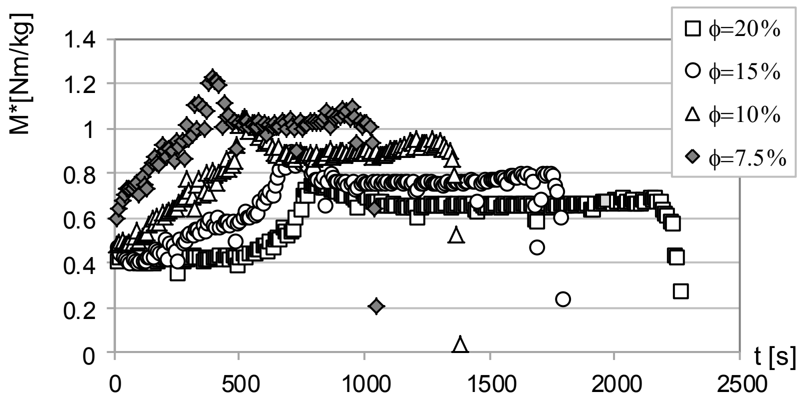

Fig. 3. Comparison of changes in reduced torque vs. time for different values of drum filling φ (D = 0.4 m; ω = 1.4 rad/s)

From analysis of the obtained results it follows that the value of torque during granulation in a tumbling drum with wetted bed depends also on such equipment and process parameters as drum diameter, filling of the drum φ and its rotational velocity. This is confirmed by a comparison of changes in the reduced torque during bed wetting for various degrees of drum filling φ shown in Fig. 3. Diagrams in this figure were prepared for mean values of the torque from 10 subsequent measuring points, (every 10 s). It was found that the reduced torque was decreasing with an increase of drum filling, which is related most probably to the bed – drum wall contact surface, which with volume increase grows slower than the feed mass.

Similar relations were obtained for different diameters and angular velocities of the drum. It follows from them that the reduced moment increases with an increasing drum diameter and its angular velocity. This is probably caused by an increasing distance between the bed mass centre and drum axis and an increase of the friction forces due to the increase of centrifugal force.

To specify how much changes of the torque, and consequently power, can provide information on the granulation process, a comparison was made between changes in the reduced torque and changes in the mass fraction of the smallest particles which was considered as not granulated material. This relation is illustrated in Fig. 4. The comparison of changes in the torque and total fraction of not granulated mass U_s made it also possible to determine the time interval in which the whole raw material was processed into granulated product. It can be observed that the mass of not granulated material reduced rapidly for moisture content (and also time), at which the reduced torque reached a maximum. The fraction of not granulated material corresponding to this maximum value is about 10% and decreases to ca. 5% after setting up the torque M^*.

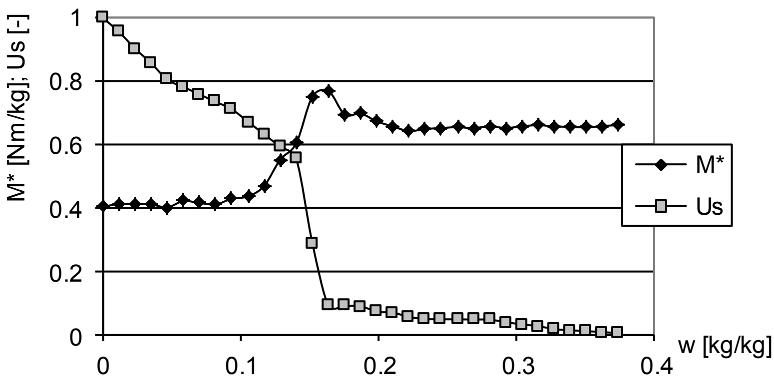

Fig. 4. Comparison of changes in reduced torque and mass fraction of not granulated material vs. moisture content (D = 0.4 m; φ = 15%; ω = 1.05 rad/s)

Values of the torque shown in Fig. 5 were calculated as an average from 10 subsequent measuring points after every minute of the measurement.

On the basis of the values of reduced torque the values of unit power demand were calculated from equation (3):

$$N^*(t) = M^*(t) \cdot \omega \,. \tag{3}$$

Due to the fact that practically all fine-grained material is processed into granulated product at the first stage of the process (later only growth and concentration of the previously formed agglomerates is observed) the energy required to form granulated product, was determined on the basis of power changes at the first stage of the process. Experimental points of power change at the first stage were approximated by quadratic polynomial.

At the second stage of the process a stabilized value of the unit power can be observed. It is a result of stable movement of previously formed granules and subsequent lack of changes in dynamics of tumbling feed. An example of power changes in both stages is shown in Fig. 5.

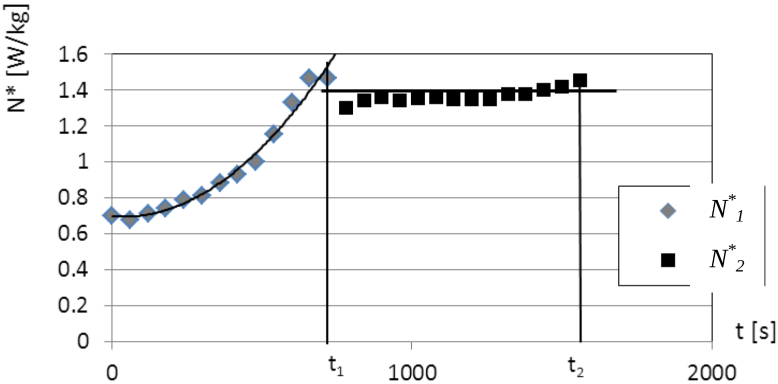

Fig. 5. Approximation of the results by mathematical functions

The energy required for the transformation of powder feed into granules was determined from the equation (4):

$$E_1^* = \int_0^{t_1} N_1^*(t)dt \,. \tag{4}$$

and the energy consumption for the subsequent growth and concentration of previously formed granules from equation (5):

$$E_2^* = \int_{t_1}^{t_2} N_2^*(t)dt \,. \tag{5}$$

The values of energy obtained as a result of integration of the functions approximating all experimental power changes (75) was related to equipment and process parameters used in the experiments.

For the stage of nucleation and granule formation a power function at correlation coefficient $R^2 = 0.945$ was derived:

$$E_1^* = 10^{2.64} \cdot D^{2.92} \cdot \varphi^{0.72} \cdot \omega^{0.87} \,. \tag{6}$$

The second stage of process in which granules grow as a result of layering and coalescence is described by power equation (7):

$$E_2^* = 31600 \cdot D^{3.12} \cdot \varphi^{0.82} \cdot \omega^{1.15} . \tag{7}$$

The correlation coefficient for this equation was $R^2 = 0.965$. Figure 6 presents the example of comparison between the energy values obtained as the result of integration of quadratic equations and those calculated from Eq. 6.

Based on analysis of the results it was found that energy required for raw material granulation in a drum granulator depended on equipment and process parameters, at which the process was carried out.

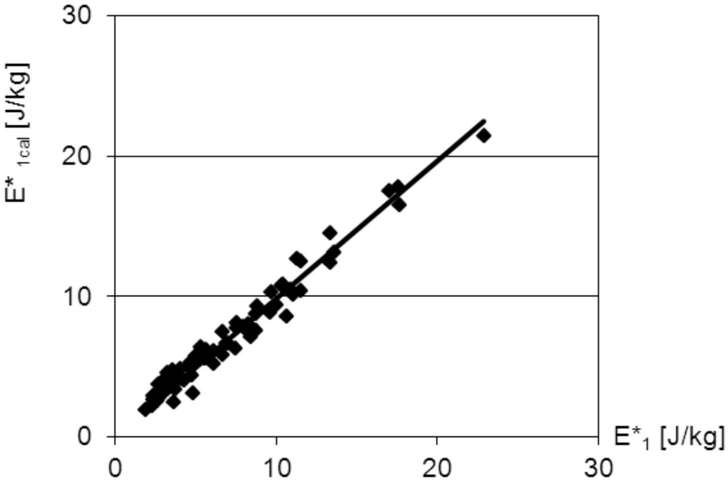

Fig. 6. Comparison of energy obtained from integration of square functions and calculated from Eq. 6

5. CONCLUSIONS

The analysis of results demonstrated that the energy required during nucleation (the initiation of agglomerates formation) as well as their growth and concentration for the granulation of powder material in drum granulator depends on process and equipment parameters. The analysis of the obtained power equations indicates that the energy requirement in both stages of granulation is proportional to the volume of transformed raw material (exponent by drum diameter is close to 3). More significant influence of the rest of analyzed parameters on energy requirement during the stage of growth and concentration of formed granules were also observed.

The result of energetic parameters measurements during granulation may be the indicator of process realisation. It can be observed that the mass of not granulated material reduced rapidly for moisture content (and also time), at which the reduced torque reached a maximum value.

Nomenclature

E^* - unit energy, J/kg
M - torque on drum shaft, Nm
M_j - torque of idle run, Nm
M^* - reduced torque, Nm/kg
N - power supplied, W
N^* - reduced power, W/kg
Q - volume flow rate of liquid, m^3/s
m_s - mass of raw material, kg
m_w - mass of wetting liquid, kg
t - wetting (granulation) time, s
w - bed moisture content, kg/kg
ρ_w - water density, kg/m^3
ω - angular velocity, rad/s.

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