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# INVESTIGATION OF THE DRUM GRANULATION CONDITIONS FOR MINERAL RAW MATERIAL OF DIFFERENT GRAIN SIZE COMPOSITIONS

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Results of investigation on drum granulation of fine-grained materials of different particle size distributions at changing conditions and variable parameters of bed wetting are discussed in the paper. In the experiments fine-grained dolomite flour with different grain size composition and grains < 0.315 mm was used. Changing conditions of bed wetting determined by wetting intensity were applied. The effect of particle size distribution of raw material and wetting of the granulated bed on particle size composition of the obtained product was determined.

*Key words: agglomeration, granulation, size distributions, wetting conditions*

## INTRODUCTION

One of the often applied agglomeration methods is pressure-free granulation carried out in rotary drums with rolling motion of the feed. For most materials a defined amount of wetting or binding liquid is required to be added to the granulated material (Kapur and Fuerstenau 1966, Sastry and Fuerstenau 1973, Newitt and C-Jones 1958). During the rolling motion of a wetted fine-grained bed the solid particles interact with liquid droplets and air. The size and type of forces acting on single material particles and their agglomerates strictly depend on properties of particular media, their relationships and in particular on the particle size distribution of the raw material, the shape of particles and extent of spraying of the wetting liquid.

Research carried out by many authors (Gluba et al. 1990, Pataki et al. 1987, Horvath et al. 1989) proved that properties of the products of wet granulation depend strictly on bed wetting. It was found that in the range of moisture content at which granulation of raw material took place in a proper way, an increase in moisture content of the feed resulted in the formation of a product with larger grain size and

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more resistant mechanically. It was shown also (Adetayo et al. 1993, Linkson et al. 1973) that properties of the granulated material depend on the grain size and composition of the raw material being granulated.

The conditions of wetting liquid supply to the bed are also very important for the granulation process. During wetting, granulation nuclei are formed and then they grow due to joining subsequent grains of the raw material and also due to combining other nuclei. Thus, the conditions of wetting liquid supply can affect significantly the nucleation process in the bed, and as a result determine properties of the granulated product. Both the time of the wetting liquid supply and the degree of liquid jet split (droplet size) are important. Studies concerning the effect of particle size distribution of the material and wetting conditions on granulated product properties described in the literature do not provide clear explanation because of complexity of the problem. Further studies in this area are required.

Results of the investigation of drum granulation of dolomite flour of different initial grain size compositions at varying conditions of bed wetting in the drum are presented in the paper. The investigation was divided into two parts. In part I an attempt was made to determine the impact of wetting conditions for particular raw materials on the properties of granulated product obtained immediately after supplying of a wetting liquid. Part II included the description of the effect of the amount of liquid supplied to the bed on the properties of granulated product obtained from particular raw materials after a determined granulation period.

## EXPERIMENTAL

### MATERIAL

The investigated material was dolomite flour with particle diameter < 0.315 mm. On the basis of four initial size groups of this material seven mixtures of different particle size distributions further on denoted by the symbols D1 to D7, were prepared. Each mixture was a starting material for the granulation process. The particle size distribution of the raw materials was determined by a laser size analyzer Analysette 22 (FRITSCH GmbH). A comparison of curves of the total (volumetric) particle size distribution for all raw materials used in the tests is shown in Fig. 1. Basic physical properties of the raw materials used in the tests are summarised in Table 1.

### EXPERIMENTAL SET-UP AND METHODS

Granulation was carried out batch-wise in a laboratory drum granulator 0.4 m in diameter and 0.24 m long, at a constant rotational speed of 0.40 $s^{-1}$ and constant mass of raw material in the drum equal 2 kg. The wetting liquid (water) was supplied to the moving bed by a pneumatic nozzle at changing operating parameters which determined liquid jet splitting and wetting duration.

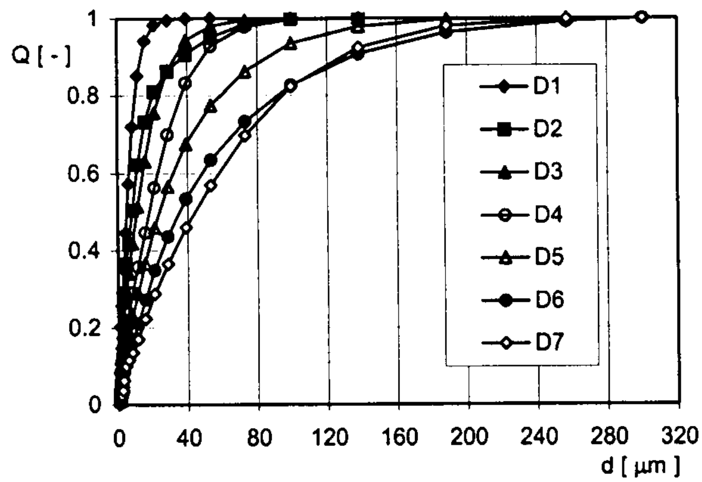


Fig. 1. Comparison of particle size distributions of fine-grained raw materials

Table 1. Physical properties of raw materials

| Mater. | $\rho_b$ [kg/m$^3$] | $\rho$ [kg/m$^3$] | $\varepsilon_m$ [-] | $m_{1m}$ | $M_{2m}$ | $K_{1m}$ | $K_{2m}$ |
|---|---|---|---|---|---|---|---|
| D1 | 916 | | 0,666 | 6,14 | 26,4 | 2,01 | 1,28 |
| D2 | 994 | | 0,637 | 13,7 | 274,7 | 5,10 | 2,20 |
| D3 | 1153 | 2741 | 0,579 | 14,47 | 188,8 | 3,43 | 1,60 |
| D4 | 1181 | | 0,569 | 22,06 | 366,8 | 1,80 | 1,26 |
| D5 | 1207 | | 0,560 | 34,37 | 1186,2 | 2,90 | 1,60 |
| D6 | 1243 | | 0,547 | 53,08 | 2906,2 | 2,47 | 1,59 |
| D7 | 1287 | | 0,530 | 57,49 | 2437,0 | 1,21 | 1,17 |

The other process parameters applied in the investigation concerned

1. the impact of bed wetting conditions
   - mean moisture content of the bed: 0.14 kg water/kg powder
   - parameters of the pneumatic nozzle:
   - water flow rate $Q_w$ = 3, 4, 5, 6, 7 dm$^3$/h,
   - air flow rate $Q_a$ = 3.5 m$^3$/h.
2. the impact of the amount of liquid supplied to the bed
   - time of feeding the wetting liquid 132 to 276 s
   - total time of granulation t = 6 min
   - parameters of the pneumatic nozzle:
   - water flow rate $Q_w$ = 6 dm$^3$/h,
   - air flow rate $Q_a$ = 3.5 m$^3$/h.

In the first part of the investigations, the effect of wetting liquid feed rate to a fine-grained bed on the properties of granulated product obtained from particular raw materials immediately after dosing the wetting liquid was determined. The product obtained after the wetting had been completed, was distributed into size fractions and dried. The grain size composition was determined on the basis of the mass of each size fraction. In the second part, the effect of the amount of liquid supplied to the granulated feed at constant operating parameters of the wetting nozzle on the grain size composition of the product obtained after a defined granulation period was specified. The amount of wetting liquid was changed by altering the time of its feeding. In the whole experimental cycle a constant total time of granulation t = 6 min was applied. The time was counted from the onset of wetting. When the granulation was completed, the product was divided into size fractions, dried and the particle size distribution was determined.

## RESULTS AND DISCUSSION

### INVESTIGATION OF THE IMPACT OF BED WETTING CONDITIONS

The process of granulation investigated at the stage of wetting was carried out for seven fine-grained raw materials (dolomite) taking into account five bed wetting parameters. Variable bed wetting conditions were determined by means of wetting intensity calculated from the formula:

$$I_w = \frac{m_w}{m_m \cdot N_w} \tag{1}$$

where: $m_w$ – mass of water fed into the granular bed, kg
$m_m$ – mass of fine-grained material in the drum, kg
$N_w$ – number of drum rotations during wetting,

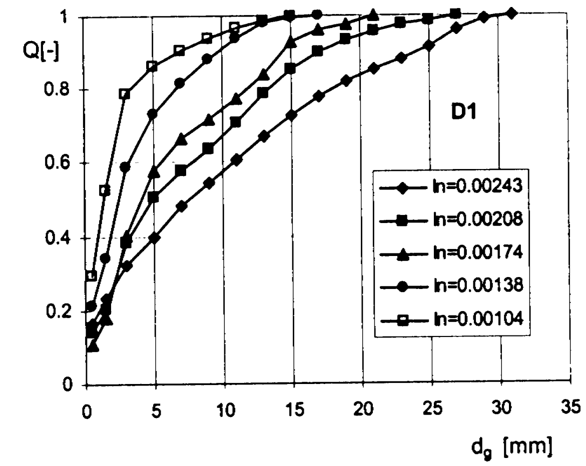


Fig. 2. A comparison of particle size composition of the granulated product obtained from raw material D1 at different values of wetting intensity

Figure 2 shows a comparison of curves for the total grain size composition of the granulated product obtained from raw material D1 at different values of wetting intensity. A similar character and system of grain size composition curves were obtained for other raw materials used in the experiments. It was found on the basis of the curve analysis that an increase of wetting intensity resulted in formation of bigger granules. This relationship is illustrated in Fig. 3 which shows the effect of the bed wetting intensity on the maximum diameter of granules produced from particular raw materials. In the description of particle size distribution of both raw materials and granulated product the theory of moments was applied. Ordinary and central moments of the k-th order were determined on the basis of the distribution function of real particle size distribution:

$$m_k = \sum_{i=1}^{n} d_i^k x_i \tag{2}$$

$$M_k = \sum_{i=1}^{n} (d_i - m_1)^k x_i \tag{3}$$

On the basis of central moments the concentration and asymmetry coefficients of the distribution, $K_1$ and $K_2$, respectively, were determined from the relationships:

$$K_1 = \frac{M_4}{M_2^2} - 3 \tag{4}$$

$$K_2 = \frac{M_3}{(M_2)^{3/2}} \tag{5}$$

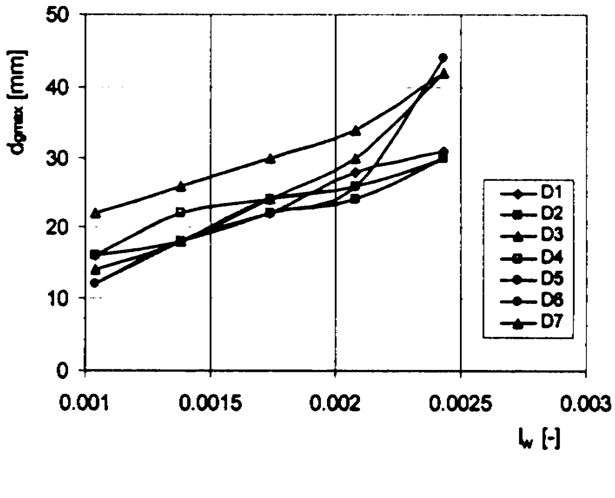


Fig. 3. The effect of wetting intensity on the maximum diameter of granules

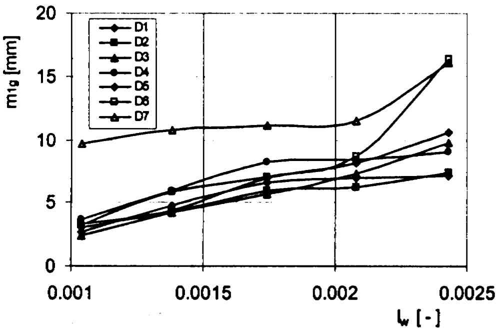


Fig. 4. The effect of wetting intensity during granulation on the value of $m_{1g}$

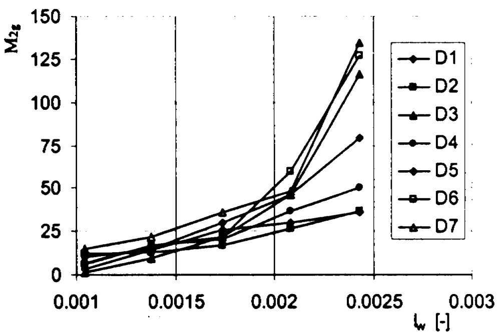


Fig. 5. The effect of wetting intensity during granulation on the value of $M_{2g}$

The effect of wetting intensity during granulation on the properties of granulated product obtained from particular raw materials, as determined by parameters $m_{1g}$ and $M_{2g}$ is shown in Figs. 4 and 5. It follows from the above graphs that the increase of wetting intensity has an influence on both the mean diameter of granules being formed ($m_{1g}$) and the increase of $M_{2g}$ value, i.e. on the increase of the range of grain size composition of the final product. These relationships occur in the case of all raw materials tested, however their character is different. This confirms the effect of a parameter which differentiates the raw material, i.e. the grain size composition.

The effect of grain size composition of the raw material described by parameters $m_{1m}$ and $M_{2m}$, and of wetting intensity on the grain size and composition of granulated product obtained during wetting is defined by the power equations:

$$m_{1g} = A \cdot m_{1m}^{\ 1.4} \cdot M_{2m}^{\ -0.6} \cdot I_w^{\ 1.2} \tag{6}$$

$$M_{2g} = B \cdot m_{1m}^{\ 1.3} \cdot M_{2m}^{\ -0.6} \cdot I_w^{\ 2.8} \tag{7}$$

The correlation coefficients for both equations exceeded 0.9.

The above equations prove that the grain size composition of the granulated product obtained during wetting of a fine-grained bed strictly depends on the wetting conditions and grain size composition of the raw material being granulated.

In the range of graining used in the experiments, the grain size of the product after the bed wetting has been completed, is directly proportional to the mean grain diameter of the raw material ($m_{1m}$) and inversely proportional to the range of grain size composition ($M_{2m}$). These two parameters of grain size composition of the raw material had a similar influence on the range of grain size composition of the granulated product described by parameter $M_{2g}$. Hence, it follows that at the stage of wetting, the granulated product with bigger grains and wider range of grain size composition can be obtained from a raw material with bigger grain but narrower range of grain size composition. Most probably, this conclusion cannot be extended onto arbitrary grain size compositions of granulated materials, and in particular on monodisperse systems. These relationships can hold for distributions which are often encountered in practice and which are close to a normal distribution.

The other parameter which has a significant effect on the nucleation process, and, consequently, on grain size composition of the granulated product obtained during bed wetting, is the rate of wetting liquid supply. An increase of wetting intensity means that the wetting liquid is supplied to the bed in a shorter time. In the case when liquid is supplied by a pneumatic spray nozzle, an increase of liquid flow rate through the nozzle $Q_w$ at constant air flow rate $Q_a$ causes lesser splitting of the jet supplied by the nozzle, which can be characterized by the $Q_a/Q_w$ quotient. The increase of wetting intensity denotes both shortening of the time of wetting liquid supply to the bed and wetting it with less dispersed jet, i.e. with bigger droplets.

As follows from the experiments, the wetting liquid supplied in the form of bigger droplets (higher wetting intensity) provides more advantageous conditions for binding particular grains into nuclei and then attaching subsequent grains to these nuclei. As a result, bigger agglomerates are formed in a shorter time.

## INVESTIGATION OF THE IMPACT OF BED WETTING DEGREE

The granulation tests were carried out for 7 fine-grained raw material and for 5 wetting times for each material type. The range of moisture content of the material at which the granulation process was correct, appeared to be different for each raw material. The widest range of changes in the moisture content taken as a mass of water added to 1 kg of dry material was possible for raw materials with the finest particles and decreased with an increase in the size of raw material particles.

Figure 6 shows a comparison of the curves representing total particle size distribution of granulated product obtained from the raw material with the smallest particles (D1) at different wetting of the feed determined by saturation degree S which denotes the filling of intraparticle space in the granulated raw material with the wetting liquid. The system of curves in Fig. 6 proves that with an increase in the saturation degree a product is obtained with bigger particles and a smaller percentage of fraction < 1 mm, which contains also not granulated residue. When a larger amount of the wetting liquid is added, more liquid bridges are formed, next material particles adhere to the already existing granules, and subsequent nuclei of granulation are started.

In the description of particle size distribution of both raw materials and granulated product the theory of moments was applied. The effect of saturation degree of the material on particle size distribution of the granulated product expressed by the moments calculated from eqs. (2) to (5) is shown in Fig. 7.

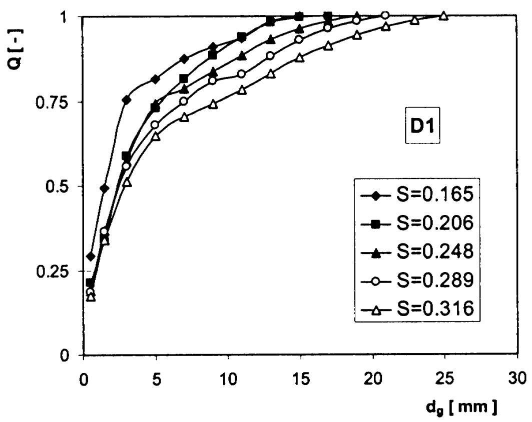


Fig. 6. Comparison of particle size distribution curves

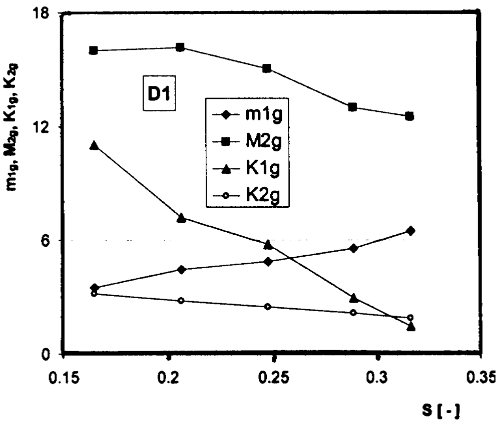


Fig. 7. Dependence of particle size distribution of the product on saturation degree of the raw material (D1)

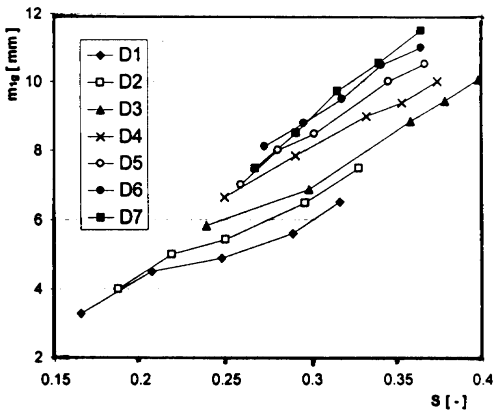


Fig. 8. Dependence of moment $m_l$ of the granulated product ($m_{lg}$) on saturation degree of the raw material

Basic properties which characterise the granular material, i.e. $m_l$, $M_2$, $K_l$ and $K_2$ were used to describe the particle size distribution.

It follows from Fig. 7 that an increase in the saturation degree affects changes in parameters of the particle size distribution curves. On the basis of analysis of these values also for other raw materials used in the granulation process, it was found that a similar character of changes could be observed only in the case of moment $m_l$. Figure 8 shows the dependence of mean particle diameter of the granulated product ($m_{lgr}$) on the saturation degree for all raw materials tested.

It follows from Fig. 8 that an increase in the saturation degree in each case leads to formation of granulated product with bigger particles. This dependence has approximately linear character for all materials, but the rate of increase of mean diameter is different for subsequent raw materials. This is related to varying properties of materials, and in particular to different particle size distributions. The effect of particle size distribution of the raw material and its saturation degree on particle size of the granulated product expressed by the moment $m_l$ is described by eq. (8):

$$m_{1g} = C \cdot m_{1m}^{0,87} K_{2m}^{0,3} M_{2m}^{-0,37} S^{0,7} \tag{8}$$

where $m_{1g}$ and $m_{1m}$ are the ordinary moments of the first order for granulated product and raw material, respectively, $K_{2m}$ is the asymmetry coefficient of particle size distribution curve, and $M_{2m}$ is the central moment of the second order of particle size distribution curve. The correlation coefficient for eq. (5) was R = 0.96.

It follows from eq. (8) that the particle size distribution and the moisture content of the raw material have a significant effect on the particle size of the granulated product. This effect is revealed by both mean particle size of raw material ($m_{1m}$) and other parameters which characterise particle size distribution curves ($K_{2m}$ and $M_{2m}$). For raw material used in the experiments, the mean particle diameter of granulated product increases with the growth of $m_{1m}$ and $K_{2m}$, and is inversely proportional to $M_{2m}$. Granulated products with bigger particles are obtained from raw material with bigger particles, smaller range of particle size distribution and positive asymmetry of size distribution curves.

## CONCLUSIONS

On the basis of the results of our investigations it can be stated that the process of wet granulation, and as a result the grain size composition of a product obtained, is strongly dependent on both the grain size composition of raw material and the method of processing, in particular the amount of wetting liquid supplied and wetting conditions of the bed. The grain size of granulated product can be modified to some extent already during the bed wetting. This can be done by changing the intensity of wetting liquid supply as well as altering the amount of liquid added to the granulated raw material. An increase of wetting intensity usually results in the formation of bigger "green" granules which during further granulation can give a final product with coarser grains. This depends, however, on the mechanisms which occur further during granulation (coalescence, grinding, crushing, etc.) determined by the bridge bonding power of particular grains which is connected with the amount of wetting liquid added to the bed (saturation degree). An increase of the bed wetting in a determined range leads to an increase of the mean diameter of granulated product and a growth of granulation degree of the feed. The grain size composition of the granulated product strictly depends on the grain size composition of the raw material subjected to granulation. In the studied range of grain size distribution, the size of grains of the granulated product appeared to be directly proportional to the grain size of the raw material. Results of the investigations show that by an appropriate selection of the grain size composition of the raw material and its wetting conditions, it is possible to control to some extent the process of granulation in order to obtain a final product of desired properties.

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## NOMENCLATURE

A, B, C coefficients
d - particle size, mm
$d_g$ - granule diameter, mm
$d_i$ - i-th class diameter, mm
$I_w$ - wetting intensity, -
$K_1$ - concentration coefficient, -
$K_2$ - asymmetry coefficient, -
$m_k$ - ordinary moment of the k-th order,
$M_k$ - central moment of the k-th order,
$Q_a$ - air flow rate, $m^3/h$
$Q_w$ - water flow rate, $m^3/h$
S - saturation degree, -,
$x_i$ - percent of mass fraction, -
$\varepsilon_m$ - porosity of raw material, -
$\rho$ - density of the raw material, $kg/m^3$
$\rho_b$ - bulk density of the raw material, $kg/m^3$

**Gluba T., Heim A., Obraniak A**., *Badania warunków granulacji surowca mineralnego o różnych składach ziarnowych*, Fizykochemiczne Problemy Mineralurgii, 35, 2001, 103-112, (w jęz. ang.)

Przedstawiono wyniki badań mokrej granulacji bębnowej mączki dolomitowej o różnych składach ziarnowych przy zmiennych warunkach nawilżania złoża. Ciecz zwilżającą (wodę destylowaną) podawano na przesypujące się w bębnie złoże drobnoziarniste za pomocą dyszy pneumatycznej W czasie nawilżania zmieniano natężenie przepływu wody przez dyszę przy stałej wartości natężenia przepływu powietrza, oraz czas dozowania cieczy przy ustalonych parametrach pracy dyszy. Dawało to zmienną szybkość nawilżania złoża, którą określano za pomocą intensywności nawilżania a także zmienną wilgotność wsadu określaną za pomocą stopnia saturacji cieczy. Określono wpływ parametrów składu granulometrycznego surowca i warunków nawilżania złoża (intensywności nawilżania i stopnia saturacji) na skład ziarnowy granulatu uzyskanego tuż po zakończeniu nawilżania a także po określonym czasie granulacji po nawilżaniu.