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STUDIES ON GRANULATION IN A FLUIDIZED BED II.
THE EFFECTS OF THE AMOUNT OF THE BINDER ON THE PHYSICAL PROPERTIES OF GRANULES FORMED IN A FLUIDIZED BED

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As the physical properties of granules formed in a fluidized bed with spraying of a binder are considerably affected by the amount of the binder, it is important to know this effect from both theoretical and practical points of view. The most important conclusions on the effects of changes in the amount of the binder, found in literature are summarized. The experimental set up, the methodology and the test methods for the determination of the physical properties of the granules are outlined. The results of the experiments relating to the effects of the amount, concentration and feed rate of the liquid on the physical properties of the granules are shown in the Figures. The experimental results are evaluated and an equation is given for the calculation of the average particle size of the granules.

Granulation is one of the most important processes in many production lines. On the one hand, the granules formed can be used as raw materials for further processes, e.g. for pressing in the pharmaceutical and plastic industries, and for melting in the glass industry, etc., and on the other hand granules can be the final product of a process line, for instance in the cases of fertilizers, plastics, detergents, insecticides, pharmaceuticals in capsules, and products of the food industry, etc.

Granulation is differently defined by various authors [1, 2]. The term "granulation" is used here to mean the grain forming processes in which from a heap of material consisting of small particles, a heap of material that contains greater particles (granules) is formed without a change in the state of most of the solid phase. The particle size distribution of the granules formed by these processes is within relatively narrow limits, but the dimensions of the granules are never so homogeneous as those of tablets, dragees or briquets.

In the last decade, granulation in a fluidized bed became more and more widespread. Granulation in a fluidized bed can be realized in many ways, but that of spraying a binder into the bed is of considerable importance primarily in the pharmaceutical industries, although in recent years it was adopted in other branches of industry (e.g. the granulation of detergents, fertilizers, and foodstuffs etc.). Granulation in a fluidized bed with the spraying of a binder into the bed and the apparatus suitable for its realization were reported in several papers [3, 4, 5, 6, 7, 8, etc.].

The point of granulation in a fluidized bed with spraying is that a liquid material (e.g. solvent) or a solution, melt or suspension of a binder is atomized into the fluidized bed of the particles to be granulated. During this process the mixing, wetting, agglomeration of the particles and the elimination of the solvent content of the granules (drying) or the solidification of the liquid phase in the granules (for instance by setting or by a chemical reaction) take place. The physical properties of granules formed in a fluidized bed with the spraying a binder into the bed are determined by the following independent variables:

a) operational parameters

- the quality, the mean particle size, the particle size distribution and the specific surface area of the substance to be granulated;
- the quality of the binder;
- the physical properties, the concentration and the relative quantity of the granulating liquid;

b) process parameters

- the feed rate of the wetting liquid;
- the expansion of the fluidized bed;
- the ratio of the minimum bed height and the diameter of the bed;
- the extent of the break-up of the granulating liquid;
- the temperature of the fluidizing air at the inlet;

c) the parameters of the apparatus

- the quality of the air distributor plate that supports the bed;
- the shape of the body of the granulator;
- the distance between the atomizer and the distributor plate.

The flow rate of the air ensures the fluidized state is not included since the mean particle size of the granules steadily increases in a batch process, hence to maintain a given bed expansion and an approximately uniform motion of particles it is necessary to continuously increase the flow rate of the air. That means that the gas flow rate is a dependent variable if bed expansion is constrained.

With regard to the operational and process parameters of granulation in a fluidized bed with spraying, here the effects of the amount, feed rate and concentration of the granulating liquid on the physical properties of the granules will be dealt with.

When solving a particular granulation in a fluidized bed with the spraying of a binder, after the selection of the appropriate binder several questions have to be answered. What should be the concentration of the binder in the granulating liquid, what amount of this liquid is needed to attain the required particle size and what feed rate should be applied for the injection into the bed? To determine the optimum values of the parameters just mentioned experiments are needed in almost every case. However, the number of these experiments can be reduced if one knows the effects of the various parameters on the physical characteristics of the granules. These questions were already dealt with by several authors [4, 7, 9, 10, 11] and their relevant conclusions are summarized.

An increase in the amount of the granulating liquid - that means in the case of a constant feed rate an increase in the duration of spraying - at first causes an increase in the mean size of the granules, but later on the growth rate diminishes and an equilibrium emerges [4, 9]. This is caused by the fact that two opposite processes take place simultaneously: a build-up and a break-up and after a certain point agglomeration is offset by attrition effects. MÖBUS [9] studied the change of the particle size distribution of the granules formed as an addition to the mean particle size, and found that by increasing the amount of the granulating liquid the particle size distribution diminishes and later this distribution parameter acquires a constant value in a similar manner to the mean size.

The results on the effect of the feed rate of the granulating liquid on the physical properties of the granules are evaluated in literature by two different methods. RANKELL and co-workers [4] studied the effect of the feed rate of the granulating liquid by increasing the feed rate while keeping the duration of the spraying at a constant value. Hence an increased feed rate also means a greater amount of granulating liquid. They found that the mean particle size of the granules increases linearly with the increase of the feed rate. This conclusion is supported by the investigation of MÖBUS [9] who in addition found that the increase of the feed rate of the granulating liquid also increases the deviation of the particle size distribution. DAVIES and GLOOR [10] studied the effect of the feed rate by varying the feed rate of the granulating liquid while the amount of the latter was kept at a constant value. They found that the increase in the feed rate of the liquid somewhat increased the mean particle size and the wear resistance, bulk density and rollingness of the granules improved. However, it must be stated that these changes are not important except in the case of the mechanical strength.

Several authors referred to the effect of the change of the concentration of the granulating liquid on the physical properties of the granules formed [4, 7, 9, 11].

Emphasis should be placed on the results of DAVIES and GLOOR [11] who studied the effect of the concentration of the granulating liquid on the physical properties of the granules in the cases of four different binders, while keeping the amount of the granulating liquid at a constant value. They found that with the increase of the concentration of the granulating liquid, the mean size and the wear resistance of the granules increase. The trend of the changes is nearly the same, but there are major differences in the numerical values in the cases of the different binders.

THE EXPERIMENTAL APPARATUS AND THE METHOD OF THE EXPERIMENTS

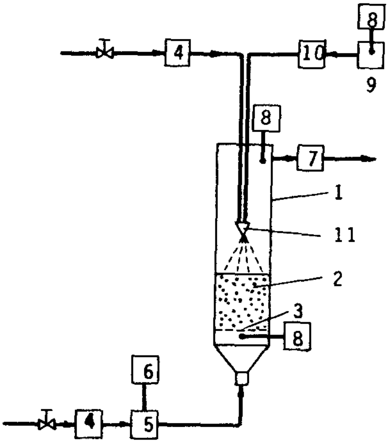

Fig. 1

1 - fluidization apparatus
2 - fluidized bed
3 - underplate
4 - flow meter
5 - preheater
6 - toroidal transformer
7 - cyclone
8 - thermometers
9 - thermostated tank
10 - pump
11 - nozzle

A schematic drawing of the set up used in the experiments on the granulation in a fluidized bed is shown in Fig. 1. The main part of the apparatus is the 0.3 m long granulator of 0.11 metre I.D. The fluidized bed is upheld and air is evenly distributed by the porous glass distributor plate (3). The main air stream enters the conical-cylindrical bottom under the plate via the flow meter (4) and the electric preheater (5). The temperature of the air at the inlet is controlled by the variable transformer (6) and is checked by the thermometer (8). The air leaves the granulator via the cyclone (7) and its temperature is measured by the thermometer (8). The granulating liquid is fed into the nozzle (11) from the thermostated tank (9) by the pump (10).

The amount of the air fed into the nozzle can be measured by the flow meter (4).

In the experiments, the raw material to be granulated was preheated by a hot air stream, and the quantity and temperature of the air were adjusted according to the fluidization properties of the raw material. After the temperature of the air at the outlet attained a given constant value,the atomization of the granulating liquid was started with a given feed rate. Owing to the wetting the particles agglomerate, hence their particle size steadily increases. The minimum fluidization velocity also increases. Therefore, to maintain the same bed expansion and motion of particles, the gas velocity must continuously become greater. Accordingly, the amount of air that ensures the fluid state was increased in accordance with the progress of the agglomeration. Having fed the planned amount of granulating liquid, the product was dried by maintaining the fluid state for a while and after that the physical properties of the product were determined.

As raw material the 0.1 - 0.2 millimetre fraction of quartz sand of a real density of ρ = 2630 kilograms per cubic metre, rollingness coefficient [12] of φ = 0.59 and a minimum fluidization velocity of u_m'' = 0.027 metre per second were used. The granulating liquids were aqueous gelatine solutions of different concentrations. In the experiments dealt with here not only the dimensions of the apparatus,the raw material and the binder, but the relative expansion of the bed, the mass of the raw material, the temperature of the air at the inlet and the distance of the nozzle from the underplate were constant.

TEST METHODS FOR THE DETERMINATION OF THE PHYSICAL PROPERTIES OF THE GRANULES

In the following the test and calculating methods used for the determination of the physical properties of the granules formed in the experiments are summarized. The test methods were detailed in the first paper of this series [12].

a) The Determination of the Particle Size Distribution and of the Average Particle Size

The particle size distribution was determined by sieve analysis. The granules were separated into the following fractions by a ten-minute sieving with a vibration sieve (VEB Kombinat Medizin und Labortechnik, Typ: Thvr 1, Made in Leipzig GDR):

$(0.1 - 0.2)\times10^{-3}$ m; $(0.2 - 0.4)\times10^{-3}$ m; $(0.4 - 0.6)\times10^{-3}$ m;
$(0.6 - 1.0)\times10^{-3}$ m; $(1.0 - 2.0)\times10^{-3}$ m; $(2.0 - 4.0)\times10^{-3}$ m;
and above 4.0×10^{-3} metre.

The results of the sieve analysis obtained in weight per cent were also converted into vol. per cent - within the size limits of $(0.1 - 2.0)\times10^{-3}$ metre - by the help of the particle density of each fraction. The mean particle size was calculated on the basis of the vol. per cent composition [12].

b) The Determination of the Porosity

The minimum bed height (Y_m) of known amounts of average samples of the fractions separated by the sieve analysis was determined in the manner described in the first paper of this series [12]. Then the minimum void fraction was calculated as follows:

$$\varepsilon'_{m2} = \frac{Y_m - \frac{G_b}{\rho F}}{Y_m} \qquad (1)$$

The porosity of each fraction can be obtained with these void fractions according to the following equation [12]:

$$\varepsilon_p = 2.2(\varepsilon'_{m2} - 0.55) \qquad (2)$$

For the determination of the volumetric percentage particle distribution, the average granule density of the fractions has to be known which can be simply calculated with the porosities of the fractions:

$$\rho_{sz} = (1 - \varepsilon_p)\,\rho \tag{3}$$

In this way the porosity and the particle density were determined for each fraction and with the vol. per cent composition of the fractions the average porosity and the average particle density were calculated.

c) The Determination of Wear Resistance

The wear resistance of the granules was determined by abrasion in a fluidized bed under standard circumstances [12]. A given amount of the $(0.4\text{-}0.6)\times10^{-3}$ metre fraction of the bulk to be investigated ($Y_m/D \approx 1$) was charged in a 0.04 metre diameter glass fluidization apparatus having a fritted glass distributor plate, after which the apparatus was closed at the top by a sieve. The particles were kept in fluidized state for ten minutes at a bed expansion of 3 times. After wearing the samples were sieved on a 0.4×10^{-3} metre sieve. The wear resistance was calculated as follows [12]:

$$K_s = \frac{G_m}{G_b} \cdot 100 \tag{4}$$

EXPERIMENTAL RESULTS

The physical properties of granules formed by granulation in a fluidized bed with spraying are affected by many parameters. If a given experiment is repeated even with the utmost care the physical properties of the granules generally are not identical, since it is extremely difficult to maintain the numerous operational and process parameters at steady values. Therefore, it is indispensable to investigate the repeatability of the experimental results.

a) The Repeatability of the Experimental Results

The repeatability of the experimental results was determined on the basis of ten parallel experiments. Relying upon the preliminary experiments, the mean parameter values were chosen for the experimental circumstances. These and the average values, and the deviation of the most important physical properties of the granules formed are given in Table 1.

Table 1

V'/V = 20 vol. per cent
w' = 5.9×10^{-5} kg/sec
c' = 60 kg/m^3
c_g = 0.45 w.%

The characteristics of the granules		Average values	Deviation $\pm$ (%)
Particle composition vol. per cent	$d \cdot 10^3$ (m)		
	0.1-0.2	6.6	17.2
	0.2-0.4	26.8	11.3
	0.4-0.6	25.8	7.7
	0.6-1.0	26.3	15.5
	1.0-2.0	14.5	23.4
$\bar{d} \cdot 10^3$ (m)		0.64	6.5
ε_p (-)		0.38	3.0
ρ_1 (kg/m^3)		811	4.2
ρ_2 (kg/m^3)		840	5.1
ρ_3 (kg/m^3)		1059	3.4
φ (-)		0.52	5.0

The loosened, apparent and compacted bulk densities and the rollingness coefficients were determined as described in the first paper of this series [7]. The deviation was calculated as

$$\sigma = \pm \sqrt{\frac{\Sigma(\bar{x} - x_i)^2}{n - 1}}$$

where x_i is some property of the granules, n is the number of the determinations and $\bar{x}$ is the arithmetic mean of the results of parallel measurements. Table 1 shows that with respect to the particle composition the deviation of the experiments is significant, therefore in all cases three parallel experiments were carried out and the Figures given show the effects of various parameters, every dot corresponds to the average value of three parallel experiments.

b) The Effect of the Amount and the Feed Rate of the Granulating Liquid on the Physical Properties of the Granules

In a considerable part of our investigations - in about 90 experiments - the effects of the relative quantity and feed rate of the granulating liquid on the physical properties of the granules were investigated. To know the effects of these two variables is important from both the theoretical and practical points of view. The granulating liquid in these experiments was an aqueous gelatine solution of a concentration of c' = 60 kilograms per cubic metre. The relative amount of the granulating liquid was varied within the 0 - 30 vol. per cent range at five different feed rates. The relative quantity of the granulating liquid was related to the overall volume of the particles to be granulated (the particle volume of the sand to be granulated was 300×10^{-6} cubic metre). At a constant feed rate the charge of a greater amount of the granulating liquid requires a longer period of time, thus as the relative quantity of the granulating liquid increases the duration of the granulation (t') and the average binder content of the particles ($\bar{c}_g$) also increases.

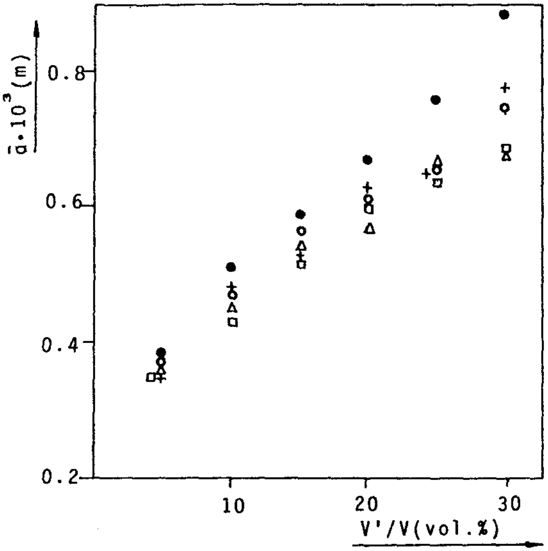

Fig. 2. ● - $w'=2.5\times10^{-5}$ kg/sec
○ - $w'=4.2\times10^{-5}$ kg/sec; + - $w'=5.9\times10^{-5}$ kg/sec
△ - $w'=7.6\times10^{-5}$ kg/sec; □ - $w'=9.2\times10^{-5}$ kg/sec

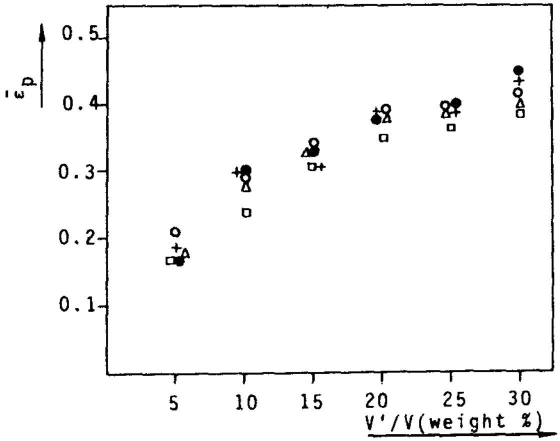

Fig. 3. ● - $w'=2.5\times10^{-5}$ kg/sec
○ - $w'=4.2\times10^{-5}$ kg/sec; + - $w'=5.9\times10^{-5}$ kg/sec
△ - $w'=7.6\times10^{-5}$ kg/sec; □ - $w'=9.2\times10^{-5}$ kg/sec

In Fig. 2 the average particle size ($\bar{d}$) is given as a function of the relative quantity of the granulating liquid. When the relative amount of the liquid was increased from 5 vol. per cent, the average particle size increases by about two times. Since a build-up granulation takes place, the increase of the average particle size also causes an increase in the average porosity of the particles ($\bar{\varepsilon}_p$), as shown in Fig. 3.

In many respects the amount of the particles that were not granulated is an important indicator. In Fig. 4 the relative amount of the initial particle fraction (in weight per cent) is plotted against the relative amount on the sprayed binder solution.

The effect of the relative quantity of the granulating liquid upon the particle size distribution of the formed granules is shown in Fig.5. The cummulative sieve residue values are plotted in a log-normal diagram. It was found that the particle size distribution of the granules formed in a fluidized bed with spraying can be approximated well by a logarithmic normal distribution function.

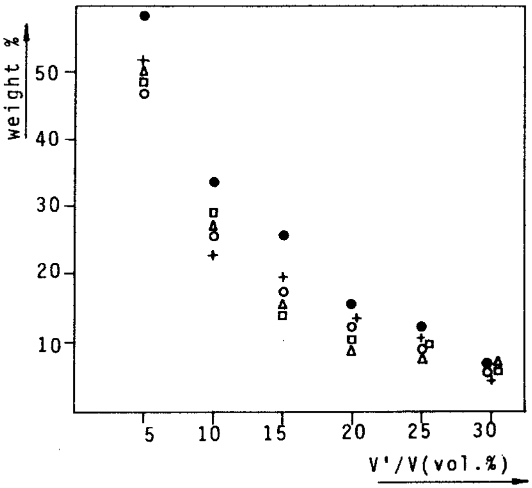

Fig. 4. d = (0.1-0.2)×10^{-3} m
● - w'=2.5×10^{-5} kg/sec; o - w'=4.2×10^{-5} kg/sec
+ - w'=5.9×10^{-5} kg/sec; Δ - w'=7.6×10^{-5} kg/sec
□ - w'=9.2×10^{-5} kg/sec

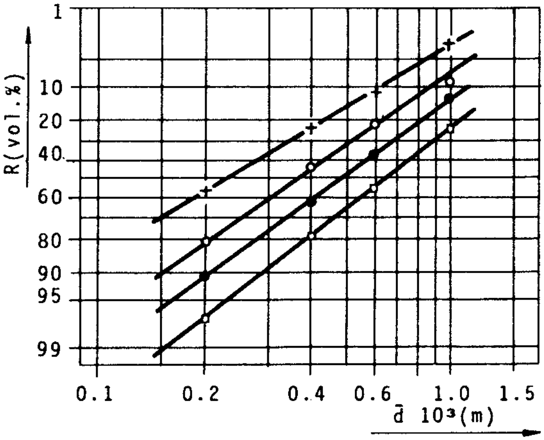

Fig. 5. + - V'/V = 5 v.%; o - V'/V = 10 v.%
● - V'/V = 20 v.%; □ - V'/V = 30 v.%
w' = 5.9×10^{-5} kg/sec

At three different values of the relative amount of the granulating liquid, the change of the binder concentration was investigated as a function of the size of the granules. In Fig. 6 the binder content of the different fractions is plotted against the overall weight of the dry material. At first the binder content of the granules increases with the growth of the particle size, but above an average particle size of 0.5×10^{-3} metre it aproaches an almost constant level. This agrees well with the statement described in our previous paper [12] that the wear resistance of the granules is approximately the same above the $(0.4-0.6)\times10^{-3}$ metre particle size.There is an approximately linear relation between the greater average binder content that prevails with the greater quantity of the liquid and the wear resistance as shown in Fig. 7.

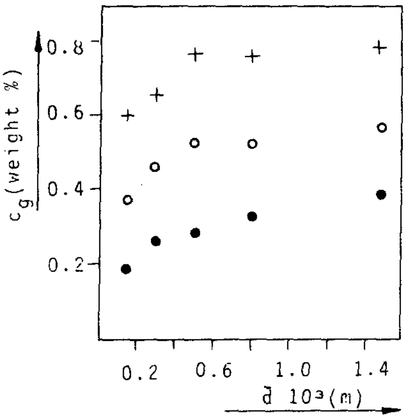

Fig. 6. V'/V = 30 vol.%
$\bar{c}_g$ = 0.68 w.%
V'/V = 20 vol.%
$\bar{c}_g$ = 0.45 w.%
V'/V = 10 vol.%
$\bar{c}_g$ = 0.23 w.%
w' = 5.9×10^{-5} kg/sec

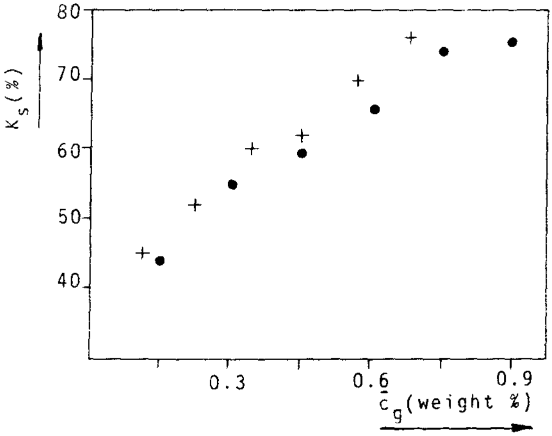

Fig. 7. w' = 5.9×10^{-5} kg/sec
+ - V'/V changes (c' = 60 kg/m^3)
• - c' changes (V'/V = 20 vol.%)

It was found that the increase of the feed rate - within the studied interval - had only a slight effect on the average size,average porosity, and the particle size distribution of the formed granules,provided the overall amount of the liquid sprayed in did not change. However, even in this case, some tendencies can be found,for instance in Figs. 2 and 3 it is shown that the increase of the feed rate generally somewhat decreases the average particle size and the average porosity, but these tendencies are not so clean-cut and firm as those found in the case of the relative amount of the granulating liquid. This is also supported in Fig. 8 where the particle size distribution of the granules formed with the least, average and greatest feed are plotted in a lognormal diagram. The points fall fairly well along a straight line that indicates that the particle size distribution is nearly identical.

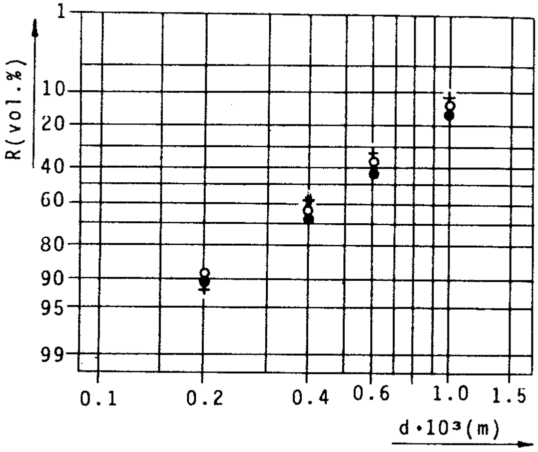

Fig. 8. $V'/V=20$ vol.%; •-$w'=2.5\times10^{-5}$ kg/sec o-$w'=5.9\times10^{-5}$ kg/sec; +-$w'=9.2\times10^{-5}$ kg/sec

c) The Effect of the Concentration of the Granulating Liquid and of the Amount of the Binder on the Physical Properties of the Granules

In the next series of experiments the main variable was the concentration of the granulating liquid. The difference between the series of experiments was that in the first one the relative amount of the binder related to the bed weight was kept at a constant value despite the change in the concentration of the granulating liquid, whereas in the second one the amount of the binder also changed with the variation of the concentration. The concentration was varied in the 20 - 120 kilograms per cubic metre range.

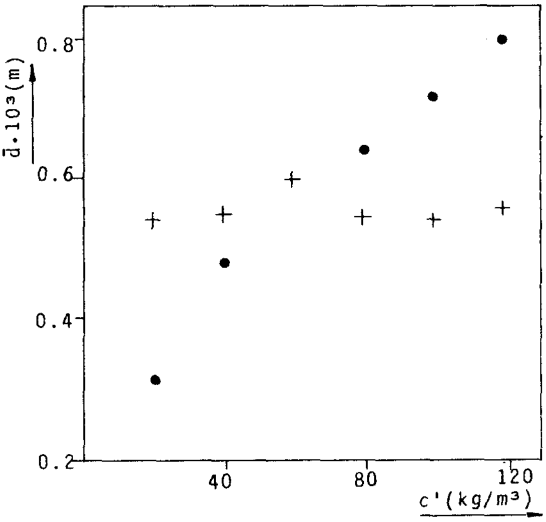

Fig. 9. $w' = 5.9\times10^{-5}$ kg/sec
+-$\bar{c}_g$ = 0.45 w.%; •-$\bar{c}_g$ = variable

The change of the concentration of the granulating liquid when the amount of the binder is kept at a constant level does not strongly affect the average size and porosity of the granules formed - at least within the studied concentration range. In Fig. 9 the average size is plotted against the concentration. However, the constant value of the average size does not unequivocally mean that the particle content of the bulk is unchanged. In Fig.10 the amount of the particles that were not granulated is shown as a function of the liquid concentration. It was found that the relative amount of the particles not granulated increases above the concentration of 60 kilograms per cubic metre.

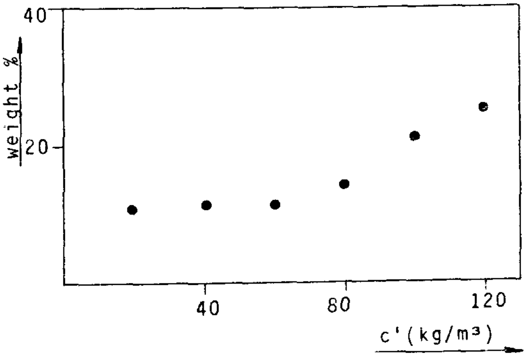

Fig. 10. $d = (0.1\text{-}0.2)\times10^{-3}$ m
$\bar{c}_g$ = 0.45 w.%; $w' = 5.9\times10^{-5}$ kg/sec

When the granulation is carried out with the same amount of granulating liquid of different concentrations, the average particle size and the average porosity increases with an increase in the concentration since in this case the overall quantity of the binder is proportional to the concentration. The effect of the concentration of the liquid on the average particle size is also shown for this case in Fig. 9.

When the concentration of the granulating liquid - that is the amount of the binder - is increased, the amount of the starting particle fraction approaches a lower limit as shown in Fig. 11. If the amount of the binder is increased by raising the binder concentration - while injecting the same amount of granulating liquid - the wear resistance of the granules increases almost linearly, although at great concentrations it approaches an upper limit (see Fig. 7).

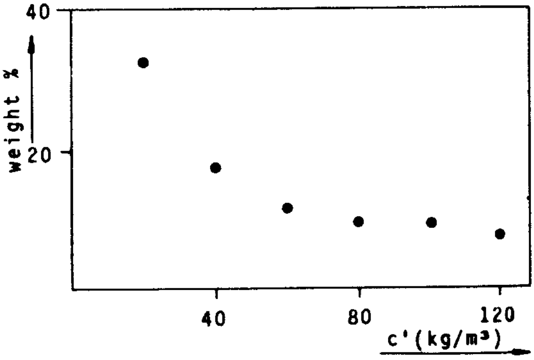

Fig. 11. $d = (0.1\text{-}0.2)\times10^{-3}$ m
$V'/V = 20$ vol.%; $w' = 5.9\times10^{-5}$ kg/sec

DISCUSSION

In the following section conclusions are drawn from the experimental results and wherever it is possible, comparisons are made with the results of other researchers.

The average size of the granules can effectively be enlarged by an increase in the relative quantity of the granulating liquid (Fig. 2). This increase is nearly linear at smaller feed rates, while at the two greatest feed rates it was found that after a certain point the growth of the particles is offset by wear effects and the growth rate diminishes. Several authors reported that after a certain time this latter effect totally compensates for the build-up, and a further addition of the liquid does not have any effect on the average size [9].

The wear resistance of the granules formed determines the value at which this equilibrium state is attained. If quartz sand is granulated with gelatine solutions, granules of high wear resistance are formed, therefore the equilibrium was not reached in the experiments dealt with here.

In build-up granulation the growth of the particle size also causes an increase in the average porosity of the particles. The porosity values show that granules mainly grow by a gradual build-up, since in the case of the linking up of granules the porosities should have been greater than the measured values of about 50 vol. per cent.

In most cases the primary function of granulation is to form a fraction of a given size range in the greatest quantity possible or that the amount of the powder not granulated should be the least possible in the final product. In Fig. 4 it is shown that above the 20 vol. per cent relative liquid quantity the decrease of the amount of the particles not granulated slows down and a further addition of the granulating liquid is unnecessary or it is reasonable only if the wear resistance of the granules is to be increased. From Fig. 7 it is obvious that the wear resistance of the granules - within the studied interval - steadily increases with the relative quantity of the granulating liquid.

If the feed rate of the granulating liquid is increased, the average particle size and the average porosity slightly diminish within the studied range of feed rate. This is inconsistent with the findings of DAVIES and GLOOR [10] that the size of the granules increases with the feed rate of the granulating liquid. The significance of this contradiction is considerably reduced by the fact that the changes found are slight in either case. The feed rate of the granulating liquid mainly affects the strength of the granules and the distribution of the binder in the particle fractions. These changes and the calculating method of the equilibrium and maximum feed rates of the granulating liquid will be dealt with in the next paper of this series in detail.

The experiments carried out to study the effect of the concentration of the granulating liquid showed that the optimum concentration of the gelatine solution was between 60-80 kilograms per cubic metre. Above this value the amount of the raw material that was not granulated grew if the amount of the binder was kept at a constant value (Fig. 10). The same optimum concentration is found in Fig. 11, where it is shown that the amount of the particles not granulated decreases up to a concentration of 60-80 kilograms per cubic metre, but later it does not change considerably despite the greater amount of the binder. This can be caused by the fact that together with the concentration, the viscosity of the solution also increases and after a certain limit deteriorates the atomization of the liquid. The average size of the granules is not considerably influenced by the concentration of the granulating liquid, provided the overall quantity of the binder is kept at a constant value (Fig. 9). When the liquid concentration is increased while keeping the relative amount of the granulating liquid at a constant level, the average particle size grows almost linearly, since in this case the greater concentration also means a greater amount of binder (Fig. 9). This conclusion is in agreement with the results of the experiments of DAVIES and GLOOR [11] carried out with gelatine as a binder.

Our conclusions can be summarized on the basis of Fig. 2 and 9 where it is obvious that the mean size of the granules is mainly determined by the overall amount of the binder, independently of the relative amount, feed rate and concentration of the granulating liquid, at least in the studied interval. Relying upon the experimental results the following equation was derived

$$\bar{d} = a_1 \frac{c'w't'}{V\rho\rho'} + a_2 \qquad (5)$$

The values of the constants for the studied model system were determined by a least square fitting method, and it was found that $a_1 = 6.2\times10^{-2}$ metre, $a_2 = 3\times10^{-4}$ metre. The differences between the average particle sizes calculated by Eq. 5 using the above values of the constants and the measured ones are plotted against

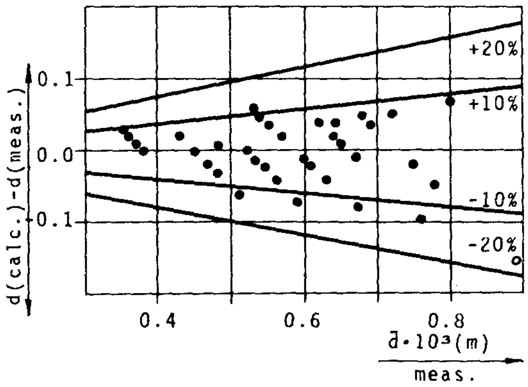

Fig. 12

the measured average particle sizes in Fig. 12. The relative differences between the measured and calculated values were less than ± 10 per cent in most cases.

The dependence of the constants a_1 and a_2 in Eq. 5 on the physical properties of the binder and the granulating liquid was studied in further experiments that will be dealt with in a subsequent paper.

SYMBOLS USED

a_1	constant (metre)
a_2	constant (metre)
c'	the concentration of the granulating liquid (kilograms per cubic metre)
c_g	the binder content of the granulating liquid (weight per cent)
$\bar{c}_g$	the average binder content of the granules (weight per cent)
D	the diameter of the apparatus (metre)
d	particle size (metre)
$\bar{d}$	average particle size (metre)
F	the cross section of the apparatus (sq. metre)
G_b	the mass of the fraction charged in (kilogram)

G_m	the mass of the sieve residue (kilogram)
K_s	wear resistance (per cent)
R	sieve residue (vol. per cent)
T''_b	air temperature at the inlet (degree centigrade)
t'	the duration of the spraying (second)
u''_m	minimum fluidization velocity (metres per second)
V	overall volume of the particles to be granulated (cubic metre)
V'	the volume of the granulating liquid (cubic metre)
V'/V	the relative amount of the granulating liquid (vol. per cent)
w'	the feed rate of the granulating liquid (kilograms per second)
Y	bed height (metre)
Y_m	minimum bed height (metre)
Y/Y_m	bed expansion coefficient (dimensionless)
Y_p	the distance between the atomizer and the underplate (metre)
ε_{m2}	minimum void fraction (dimensionless)
ε_p	the porosity of granules (dimensionless)
$\bar{\varepsilon}_p$	average porosity (dimensionless)
ρ	real density (kilograms per cubic metre)
ρ_1	loosened bulk density (kilograms per cubic metre)
ρ_2	apparent bulk density (kilograms per cubic metre)
ρ_3	compacted bulk density (kilograms per cubic metre)
ρ_{sz}	granule density (kilograms per cubic metre)
$\bar{\rho}_{sz}$	average granule density (kilograms per cubic metre)
ρ'	the density of the granulating liquid (kilograms per cubic metre)

σ deviation

φ rollingness coefficient (dimensionless)

REFERENCES

1. RUMPF, H., Chemie Ing. Techn. 30, 144 (1958)
2. NEWITT, D.M., CONWAY-JONES, J.M., Trans Instn. Chem. Engrs. 36, 422 (1958)
3. WURSTER, D.E., J. Pharm. Sci. 49, 82 (1960)
4. RANKELL, A.S., SCOTT, M.W., LIEBERMAN, H.A., CHOW, F.S., BATTISTA, J.V., J. Pharm. Sci. 53, 320 (1964)
5. CONTINI, S., ATASOY, K., Pharm. Ind. 28, 144 (1966)
6. WOLF, G., Pharm. Ind. 30, 552 (1968)
7. LISKE, T., MÖBUS, W., Pharm. Ind. 30, 557 (1968)
8. PILPEL, N., Chem. and Proc. Eng. 50, 67 (1969)
9. MÖBUS, W., Ceskoslov. farm. 18, 109 (1969)
10. DAVIES, W.L., GLOOR, Jr.W.T., J. Pharm. Sci. 60, 1860 (1971)
11. DAVIES, W.L., GLOOR, Jr.W.T., J. Pharm. Sci. 61, 618 (1972)
12. ORMÓS, Z., Hung. Ind. Chem. 1, 207 (1973)

РЕЗЮМЕ

При грануляции в распылительно-псевдоожиженном слое количество связующего вещества имеет значительное влияние на физические свойства образующихся гранул, поэтому знание этого влияния важно с практической и научной точки зрения. Авторы коротко рассматривают важнейшие условия связанные с влиянием изменения количества связущего вещества, найденные в литературе. Описываются экспериментальный аппарат и методы определения физических свойств гранул. Экспериментальные данные, выражающие влияние количества и концентрации, а также скорости подачи гранулирующей жидкости на физические свойства гранул, представляются в таблицах и на рисунках. Экспериментальные данные оцениваются авторами и даются соотношения для вычисления среднего диаметра гранул.