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DRYING OF WET SOLID SPHERES THROUGH CONTACT WITH DRY FINE SOLID PARTICLES DURING MIXING

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Abstract—Wet silica-gel spheres (size: 3–4 mm and 5–6 mm) were mixed with dry fraction of fine silica gel (size 0·3–0·43 mm). It has been proved experimentally that the main resistance to the moisture transfer lies in the spheres. On the basis of this fact a mathematical model of the process has been worked out. The whole problem was reduced to the diffusion of liquid or vapour in a sphere surrounded by a limited volume of well-stirred fine particles. Fine gel particles and the air between them were treated as one pseudophase. The concept of effective diffusivity, comprising the internal structure of the sphere as well as the mechanism of the mass transfer, was introduced.

The values of the effective diffusivity were found experimentally by the use of two methods. The first method was based on the mathematical model of the process discussed here, the other one consisted in the determination of the effective diffusivity by investigating single spheres dried in a stream of dry air (turbulent flow, $Re = 5510$). Similar results were obtained by these two methods.

NOMENCLATURE

a,	slope of equilibrium line;
c,	concentration of diffusing substance in sphere [g/cm^3];
c_i, c_0,	initial concentration of diffusing substance in sphere [g/cm^3];
c_f,	final concentration of diffusing substance in sphere [g/cm^3];
$\bar{c}$,	average concentration of diffusing substance in sphere at time τ [g/cm^3];
c_∞,	equilibrium concentration of diffusing substance in sphere [g/cm^3];
C,	concentration of diffusing substance in pseudophase [g/cm^3];
C_∞,	equilibrium concentration of diffusing substance in pseudophase [g/cm^3];
$C_{r\infty}$,	equilibrium concentration of diffusing substance in small particles [g/cm^3];
D_e,	effective diffusivity [cm^2/min];
K,	equilibrium constant;
M_0,	initial amount of diffusing substance in a sphere [g];
M_τ,	amount of diffusing substance leaving the sphere up to time τ [g];
M_∞,	amount of diffusing substance leaving the sphere after an infinite time [g];
n_k,	number of spheres in a volume V_k;
q_n,	non-zero positive roots of $\tan q_n = \dfrac{3q_n}{3 + \lambda \, . \, q_n^2}$;
r,	distance from centre of sphere in the direction of diffusion [cm];
r_0,	radius of sphere [cm];
v,	part of pseudophase volume which falls to one sphere [cm^3];
V_f,	volume of total pseudophase in a mixer [cm^3];
V_k,	volume of sphere load which was introduced to mixer [cm^3];
V_r,	sum of all small particles volumes in mixer [cm^3];
X,	equilibrium moisture content in small silica-gel particles [kg moisture/kg dry solid];
Y,	equilibrium moisture content in silica-gel spheres [kg moisture/kg dry solid].

Greek symbols

ε_k,	external void fraction of silica-gel spheres;

ε_r,	external void fraction of small silica-gel particles;
λ,	effective ratio of volumes of medium (pseudophase) and sphere;
ρ_k,	apparent density of silica-gel spheres [g/cm^3];
ρ_r,	apparent density of small silica-gel particles [g/cm^3];
τ,	time [min].

INTRODUCTION

MASS transfer from one kind of solid particles to another during mixing is a problem which may be applied in such domains as catalysis and drying of solids. In this paper, investigations of moisture transfer are described. They are directly connected with the problems of drying.

Enormous development of the surface separating two materials of different moisture content, renewals of the surface during mixing and the possibility of running the process at low temperatures, those are the advantages of this operation.

The real mechanism of moisture transfer between solid particles is very complex because of the three phases taking part in the process and the difficulty of determining changes of the moisture content in them. In this paper a simplified mathematical model of the process is introduced. The mass-transfer kinetics may be investigated by means of this model. A system composed of wet solid spheres and dry fraction of fine solid particles is considered.

EQUIPMENT

The apparatus employed is shown diagrammatically in Fig. 1. A horizontal rotating steel cylinder with perspex lids, 146 mm in diameter and 200 mm in length was the main device. The cylinder was rotated by a power transmission system giving a variation of rotation speed in the range of 4–31 rev/min. To eliminate the influence of the degree of mixing on the process of moisture transfer this device was adapted to radial mixing of these particles; the completely mixed state is reached after several turns of the mixer. To secure a dominating role of the radial direction of mixing, both kinds of material were located uniformly along the length of the mixer.

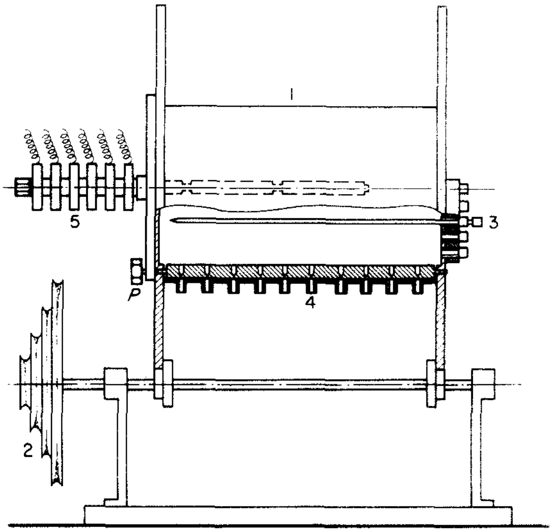

FIG. 1. Apparatus for mixing solid particles. (1) mixer, (2) sheave, (3) sampling thief (first used by Maitra and Coulson), (4) sampling thief connected with mixer, (5) temperature measurement system, (P) handwheel.

The method of sampling was yet another problem. Two kinds of sampling device were used. The first one was similar to a special sampling tube first used by Maitra and Coulson [1], Fig. 1. It consisted of a tube with a rod closely fitted inside it. The tube had a slot cut out along its length. The sampling tube was inserted into the mixture over the whole length of the mixer, slot upwards. When the rod was removed, material filled the sampling tube. This device was used to take samples from three or even five horizontal levels of the mixture. The other kind of device is also shown in Fig. 1. This device was connected with the mixer. The drum had a strip cut out along its length. The brass barrel was touching this strip. The barrel rotated inside an outer steel sleeve. There were ten cavities of 10-mm dia. drilled at equal intervals along the length of the barrel to the depth of 23 mm. The cavities were adjusted to the strip of the mixer by means of a handwheel *P*

(Fig. 1) and when this strip was in its lowest position the material filled the cavities of the barrel. The device had drains leading to the vessels for weighing on the outside of the mixer. The samples taken by means of these two kinds of devices were subjected to gravimetric analysis.

It is necessary to describe the system of measuring the temperatures inside the mixture. The main device of this system was a plexi "probe" with three thermocouples (constantan–copper). Thermojunctions were located at equal intervals along the length of the probe at distances of 20, 100 and 180 mm from the internal surface of the lateral wall of the mixer.

MATERIALS

The mixed materials were silica-gel spheres (diameters 3–4 mm and 5–6 mm) and fine particle fractions of silica-gel (0·25–0·30 mm, 0·30–0·43 mm, 0·43–0·60 mm, 0·60–0·75 mm and 0·75–0·80 mm). The properties of silica-gel are shown in Table 1.

Wetting of the material presented a special problem. The silica-gel load for wetting was first dried under special conditions, e.g. for 3 h at a temperature of 100°C and then was placed on a net above the water surface in a hermetically closed vessel. The vessel was inserted for a suitable period of time in a thermostatic chamber (temperature 40°C or 50°C).

The dry materials was obtained by drying at a temperature of 150°C.

PRELIMINARY EXPERIMENTS

An important problem in the research on drying wet spheres through contact with a dry load of fine particles was the investigation of the uniformity of wetting the load over its whole volume. Many experiments in which wet silica-gel spheres (5–6 mm) were mixed with a dry fraction of fine silica-gel (0·3–0·43 mm) showed the same moisture content in small particles at three different levels of the mixture in spite of a pronounced radial segregation of particles; in fact a core of small particles forming along the circulation axis of the load, was noticed. In these experiments the volume ratio of the mixture to the mixer was about a third. Visual observations of the mixture gave us some indications of the mechanism of mixing. An accumulation of spheres (without any fine particles) was observed underneath the mixing surface. The spheres were covered with fine particles on entering again the static zone of the mixer. As a result continuous renovation of the mass-transfer surfaces and an increase of the intensity of mixing of fine particles was taking place. Any differences of moisture content in mixing material were also removed by radial mixing inside the fine particles fraction.

Another important problem was the determination of the distribution of the resistance to mass transfer in the investigated system. Several experiments were made on the kinetics of the wetting of the originally dry, fine particle

Table 1. *Properties of silica-gel*

Material	Fraction (mm)	Bulk density (g/cm^3)	External void fraction	Apparent density (g/cm^3)
Wide-pore silica-gel	0·25–0·30	0·379	—	—
Wide-pore silica-gel	0·30–0·43	0·370	0·51	0·755
Wide-pore silica-gel	0·43–0·60	0·373	—	—
Wide-pore silica-gel	0·60–0·75	0·387	—	—
Wide-pore silica-gel	0·75–0·80	0·376	—	—
Silica-gel spheres	3–4	0·470	0·39	0·770
Silica-gel spheres	5–6	0·480	0·37	0·761

fraction through contact with a load of wet spheres. The following parameters influencing the operation were investigated: the diameter size of the spheres (3–4 and 5–6 mm), the size of fine particles (size range 0·25–0·80 mm) and speed of the drum rotation (4 and 31 rev/min). The samples for analysis were taken only from the fraction of fine particles by only partially opening the slots of the sampling device). The results of wetting the fine particles are plotted against mixing time in Fig. 2. It should be noticed that in these experiments conducted for different speeds of rotation and for different sizes of small particles all the points representing the wetting of silica-gel lie very nearly on one curve. Wetting speed increased when smaller spheres (3–4 mm) were used in these experiments. The results show us that the main resistance to moisture transfer lies on the side of spheres in the investigated system.

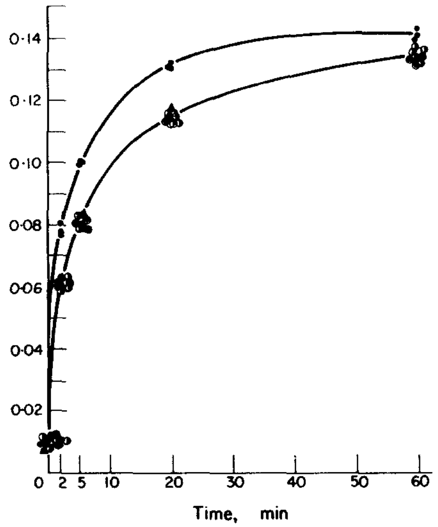

FIG. 2. Investigation of the kinetics of wetting fine particles, moisture content (kg moisture/kg dry solid) vs. time (min).
◑—rotational speed = 4 rev/min, spheres 5–6 mm, fraction 0·43–0·60
⊙—rotational speed = 31 rev/min, spheres 5·6 mm, fraction 0·43–0·60
▲—rotational speed = 31 rev/min, spheres 5·6 mm, fraction 0·75–0·80
○—rotational speed = 31 rev/min, spheres 5·6 mm, fraction 0·25–0·30
●—rotational speed = 31 rev/min, spheres 3·4 mm, fraction 0·43–0·60

A number of experiments were carried out to determine the temperature changes in the mixture during moisture transfer between particles. In these experiments the mixer was filled to two-thirds of its volume which made it possible to plunge the probe with thermocouples into the mixture. A temperature increase was noticed at the beginning of each experiment (2–6 degC) and later the temperature of the mixture returned to the ambient temperature (15–16°C). This maximum temperature was caused by the adsorption heat emitted in large quantities at the beginning of the process when the molecules of water vapour were adsorbed by the most active spaces of the fine silica-gel particles.

MATHEMATICAL MODEL OF THE PROCESS

Using the fact that the main resistance to moisture transfer lies on the side of the spheres a mathematical model of the process was introduced. It required an additional assumption that the process is isothermal. This assumption was only proved approximatively because of the prevalence of the maximum temperature at the beginning of each experiment.

Let us consider a model in which the internal diffusion of moisture in the spheres controls the rate of the process. The spheres are surrounded by small gel particles. The load of fine particles together with the air between the particles can be considered as one pseudophase. The volume of the mixture is limited and, if well stirred, the moisture content in the pseudophase depends only on time, and is determined essentially by the condition that the total amount of moisture in the pseudophase and in the spheres remains constant as the process of diffusion proceeds. Assuming that all the spheres have equal diameters and excluding moisture transfer among spheres it can be taken that all the spheres are in the same condition and the complex mixture can be replaced by a collection of single spheres, each of which is surrounded by an identical part of the pseudophase. The general problem can be stated mathematically in terms of water in a single sphere diffusing to the part of the pseudophase apportioned to that sphere. The concentration of moisture in the sphere is initially c_0 and the pseudophase is free from moisture ($C = 0$). The concept is introduced of effective diffusivity, which depends on the internal structure of the sphere and the mass transfer.

We require a solution of the diffusion equation

$$\frac{\partial c}{\partial \tau} = D_e \left(\frac{\partial c^2}{\partial r^2} + \frac{2}{r} \frac{\partial c}{\partial r} \right) \tag{1}$$

with the initial conditions

$$c = C_0, \qquad 0 < r < r_0, \qquad \tau = 0$$

$$C = 0 \qquad\qquad \tau = 0$$

and with the boundary conditions

$$\frac{\partial c}{\partial r} = 0, \qquad r = 0 \qquad \text{at all the times}$$

$$c = KC, \qquad r = r_0, \qquad \tau > 0$$

$$v \frac{\partial C}{\partial \tau} = 4\pi r_0^2 D_e \frac{\partial c}{\partial r}, \qquad r = r_0, \qquad \tau > 0.$$

A convenient form of solution was obtained by Carslaw and Jaeger [2] through the use of the Laplace transform. The solution which is quoted by Carman and Haul [3], Berthier [4] and Crank [5] is presented below.

$$\frac{M_\tau}{M_\infty} = 1 - \sum_{n=1}^{\infty} \frac{6\lambda(\lambda + 1)}{9(1 + \lambda) + \lambda^2 q_n^2} \times \exp\left(-\frac{q_n^2 D_e \tau}{r_0^2} \right). \tag{2}$$

Here q_n are the non-zero positive roots of

$$\tan q_n = \frac{3q_n}{3 + \lambda q_n^2}. \tag{3}$$

The roots of (3) are given by Crank [5].

λ is the effective ratio of volumes of pseudophase and sphere

$$\lambda = \frac{v}{\frac{4}{3}\pi r_0^3 K}. \tag{4}$$

Series (2) is convergent. In Fig. 3 M_τ/M_∞ is plotted against $(D_e \tau/r_0^2)^{\frac{1}{2}}$ for four "final falls of moisture content" in the sphere, viz. 90, 70, 50 and 30 per cent. The definition of "the final fall of moisture content" can be derived from the material balance of the process.

$$\tfrac{4}{3}\pi r_0^3 c_0 = vC_\infty + v/\lambda C_\infty \tag{5}$$

hence

$$\tfrac{4}{3}\pi r_0^3 c_0 = M_\infty + M_\infty/\lambda = M_\infty(1 + 1/\lambda). \tag{6}$$

"The final fall of moisture content":

$$M_\infty/\tfrac{4}{3}\pi r_0^3 c_0 = \frac{1}{1 + 1/\lambda}. \tag{7}$$

The above presented solution for one sphere can, in our case, be related to the whole load of spheres by modifying the definition of λ.

The calculation of λ for the whole load of spheres is presented below.

The volume of one sphere is:

$$\tfrac{4}{3}\pi r_0^3 = \frac{V_k(1 - \varepsilon_k)}{n_k}.$$

The volume of the part of the pseudophase apportioned to one sphere $v = V_f/n_k$

Hence

$$\lambda = \frac{v}{\frac{4}{3}\pi r_0^3 K} = \frac{V_f n_k}{n_k V_k(1 - \varepsilon_k)K} = \frac{V_f}{K V_k(1 - \varepsilon_k)}. \tag{8}$$

In order to plan experiments on the basis of solution (2) it is necessary to know the equilibrium constant K. The way of its determination is presented below.

After a long mixing of wet spheres with dry fine particles the state of equilibrium is reached —the moisture contents of both kinds of the material do not change. Repeating the experiments for different mass ratios of loads of spheres and fine particle fractions the following relation can be obtained $Y = fX$, where Y is the moisture content in the spheres (kg moisture/kg dry solid), which is in equilibrium with the moisture content in fine particles, and where X is the moisture content in fine particles (kg

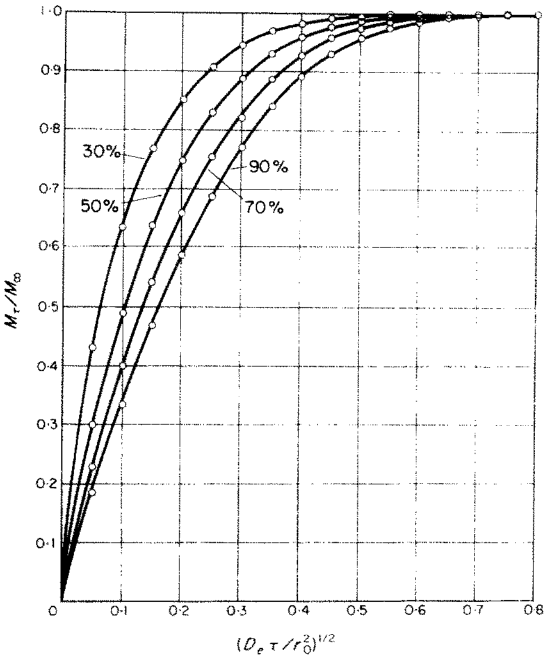

FIG. 3. Mathematical model of process, M_τ/M_∞ vs. $(D_e\tau/r_0^2)^{\frac{1}{2}}$.

moisture/kg dry solid) in the equilibrium state with the moisture content in spheres. Values X and Y may be plotted as $\rho_k Y$ vs. $\rho_r X$, where ρ_k and ρ_r are apparent densities of spheres and fine particles respectively. When a straight line plot is obtained this relation may be written

$$\rho_k Y = a\rho_r X\,. \tag{9}$$

This equation may be written in another form

$$c_\infty = aC_{r\infty}. \tag{10}$$

A volume of fine particles in a pseudophase may be found from the relation

$$V_r = (1 - \varepsilon_r)V_f. \tag{11}$$

The relation between moisture contents in fine particles and in the pseudophase may be presented in the following equation

$$C_{r\infty} = \frac{1}{1 - \varepsilon_r}C_\infty. \tag{12}$$

Substituting equation (12) in equation (10) we receive

$$c_\infty = \frac{a}{1 - \varepsilon_r}C_\infty \tag{13}$$

where $a/1 - \varepsilon_r$ is the sought constant K.

The mathematical model just presented makes it possible to anticipate the time of the drying of spheres to a required moisture content when the effective diffusivity is known. The problem may be inverted and the effective diffusivity may be calculated on the basis of the model when the drying time is found experimentally. The last method will be used to verify the mathematical model of the process.

MATHEMATICAL MODEL OF THE PROCESS—EXPERIMENTAL INVESTIGATIONS

The first part of the experimental work was carried out in order to determine the equilibrium $Y = f(X)$. The equilibrium state between the moisture contents in silica-gel spheres and in the fine particles of silica-gel (size: 0·3–0·43 mm) was investigated for two systems. Spheres of 5–6-mm dia., were used in the first system and 3–4-mm dia. spheres were used in the second.

As preliminary experiments indicated, a straight line relation between Y and X could be assumed: $\rho_k Y = a\rho_r X$. The apparent densities of silica-gel spheres from the fraction 5–6 and 3–4 mm were 0·761 and 0·770 g/cm^3 respectively. The apparent density of fine particles of silica-gel (0·3–0·43 mm) was 0·755 g/cm^3. As apparent densities of the investigated materials were nearly identical, they were cancelled in the calculations and the equilibrium state was presented by the equation $Y = aX$.

As it was found experimentally the moisture equilibrium was reached after mixing silica-gel spheres with fine silica-gel particles for 3 h. The samples consisting of fine particles only, were taken after this time and subjected to gravimetric analysis. When the moisture content of the fine particles fraction after mixing was already known the moisture content of spheres from the mass balance could be calculated because the mass capacity of the air was very small and was not considered in the calculation; the mass quantities and the initial moisture contents of both the materials were known. Eighty-four experiments were made in which different mass ratios of spheres and fine particles were used. The results are shown in Fig. 4. The slope of the equilibrium line equaling 45° was assumed in planning all the experiments for the range of the moisture contents in materials from 0 to 0·3 kg/kg dry solid. According to this assumption the constant $a = 1$ hence the constant

$$K = \frac{1}{1 - \varepsilon_r}. \qquad (14)$$

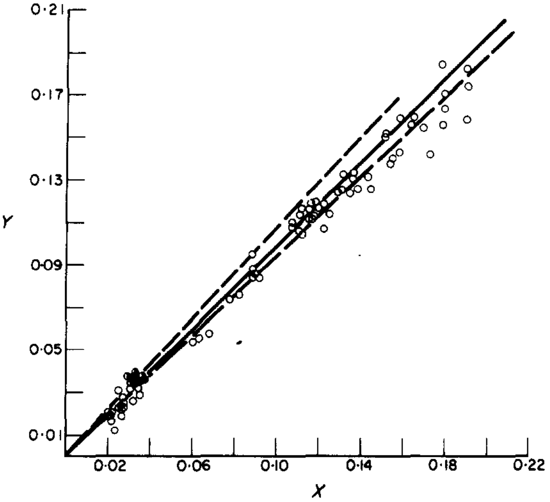

FIG. 4. Diagram of equilibrium between the moisture content of spheres and the moisture content of fine particle fraction.
○—spheres 5–6 mm, fraction 0·3–0·43 mm
◐—spheres 3–4 mm, fraction 0·3–0·43 mm

The next part of the experimental work was carried out to determine the effective diffusivity on the basis of the mathematical model of the process. Five series of experiments were carried out. In four of them wet spheres of silica-gel (diameter size: 5–6 mm, moisture content about 0·3 kg/kg dry solid) were mixed with a dry fraction of silica-gel 0·3–0·43 mm (moisture content about 0 kg/kg dry solid). Spheres of diameter 3–4 mm were used in the fifth series. For each series of these experiments a different "final fall of moisture content" in the spheres was planned (for the first, 30 per cent; for the second, 50 per cent; for the third, 70 per cent; for the fourth, 90 per cent; and for the fifth, 90 per cent). The quantities of both mixed materials for the definite "final fall of moisture content" in the spheres were calculated on the basis of equations (7), (8) and (14).

Values ε_r and ε_k were found experimentally by means of mercury. The mixer was closed hermetically during each experiment. The speed of the drum rotation was 31 rev/min in all the experiments. The ambient temperature was constant (15–16°C). The mixer was stopped for sampling; the samples consisted of fine particles only. The quantities M_τ, M_∞, M_0, τ and the average radius of a spheres were found experimentally. Hence the effective diffusivities were calculated on the basis of the curves shown in Fig. 3. The results of calculation are presented in Fig. 5 and 6 (effective diffusivity, D_e vs. mixing time, τ).

In order to verify the mathematical model of the process, the values, of the effective diffusivity for single spheres dried in the stream of dry air (the turbulent flow, $Re = 5510$, temperature 15–16°C) were determined. A scheme of the equipment is shown in Fig. 7. The air flowed through the drying tower (filled with dry silica-gel) to a glass tube with a contraction area where the investigated silica-gel sphere was

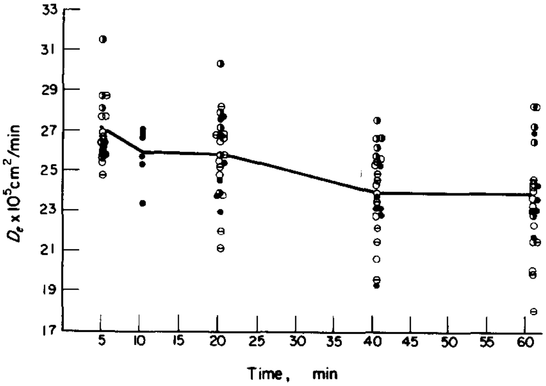

FIG. 5. Values of effective diffusivity (spheres 5–6 mm) $D_e \cdot 10^5$ cm²/min vs. time (min).
◐—"final fall of moisture content" 90 per cent
○—"final fall of moisture content" 70 per cent
⊖—"final fall of moisture content" 50 per cent
●—"final fall of moisture content" 30 per cent

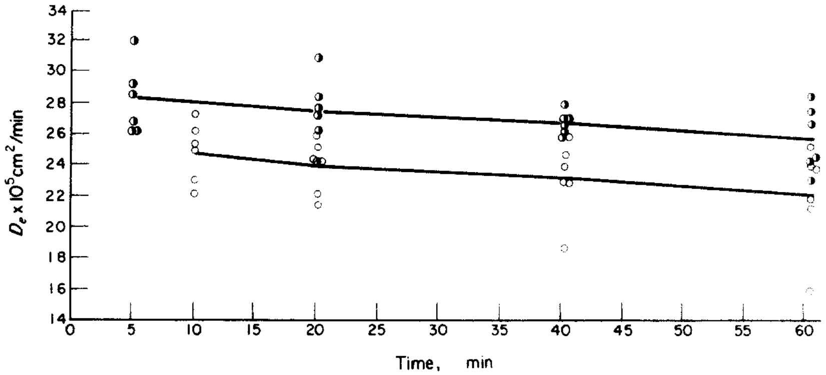

FIG. 6. Comparison of the values of effective diffusivity obtained by the use of spheres 5–6 mm and 3·4 mm, $D_e . 10^5$ cm^2/min vs. time (min).
◑—spheres 5–6 mm, fraction 0·3–0·43 mm
⊙—spheres 3–4 mm, fraction 0·3–0·43 mm

placed. A net plug which was put at the top of the tube did not allow the sphere to get out of the tube. From time to time the air humidity was controlled by means of a psychrometer.

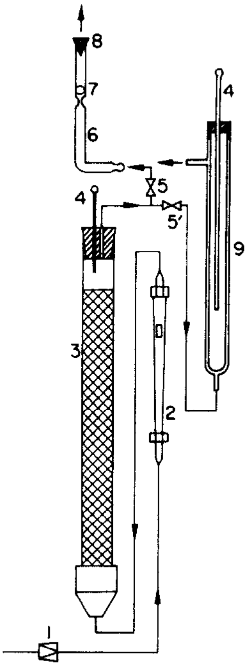

FIG. 7. Apparatus for the determination of effective diffusivity by drying single silica-gel spheres. (1) pressure reducing valve, (2) rotameter, (3) drying tower, (4) thermometers, (5,5′) valves, (6) glass tube with contraction area, (7) investigated silica-gel sphere, (8) net plug, (9) psychrometer.

When mist was observed on the surface of the mirror at the temperature 70°C, the filling of the tower was changed. Spheres used in the investigation were chosen from the fraction 5–6 mm. The moisture contents in the sphere before and after the experiment were determined through the gravimetric analysis. In order to find the effective diffusivities the known model was used of diffusion within a sphere towards the medium of constant concentration of a diffusing substance. The equation is given below [6]

$$E = \frac{\bar{c} - c_f}{c_i - c_f} = \frac{6}{\pi^2} \sum_{v=1}^{\infty} \frac{1}{v^2} \exp\left[- v^2 \pi^2 D_e \tau / r_0^2\right].$$

The results of experiments are shown in Fig. 8 (effective diffusivity, D_e vs. drying time, τ). The results of experiments carried out for one sphere at two different air temperatures are presented in Fig. 9.

DISCUSSIONS OF RESULTS

It can be seen in Fig. 5 that the values of the effective diffusivity determined on the basis of the mathematical model of the process were greater at the beginning of each experiment than those determined after some time of mixing. This phenomenon may be explained by the increase of the mixture temperature at the

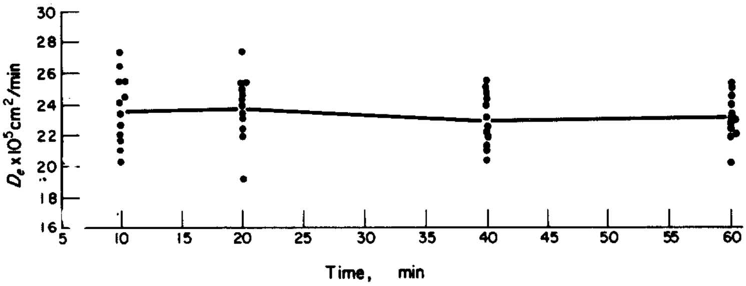

FIG. 8. Values of effective diffusivity which were determined by drying single silica-gel spheres; $D_e \cdot 10^5$ cm^2/min vs. time (min).

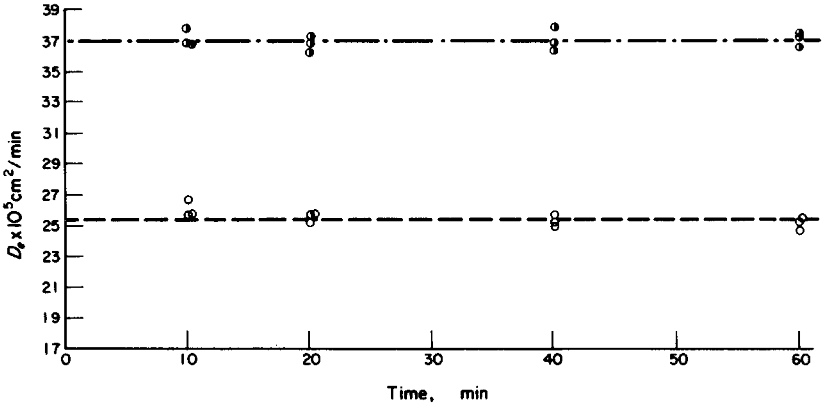

FIG. 9. Effect of temperature of drying air on the value of effective diffusivity; $D_e \cdot 10^5$ cm^2/min vs. time (min).
◑—temperature 27–28°C
○—temperature 15–16°C

beginning of the process, which was caused by the adsorption heat. The results of experiments for single spheres presented in Fig. 9 confirm the supposition that the effective diffusivity, D_e increases with the increase of temperature.

We can also notice in Fig. 5 that effective diffusivity decreases with the decrease of the quantity of the fine particle fraction in the whole mixture. This phenomenon may be explained by the increase of the share of fine particles in the mass-transfer resistance.

We find from Fig. 6 that values of the effective diffusivity for spheres of 3–4 mm, are smaller than those for spheres of 5–6 mm. This may also be the result of the increase of the share of fine particles in the resistance to mass transfer, which is caused by a decrease of sphere diameters.

The values of the effective diffusivity obtained on the basis of the mathematical model of the process were compared with those determined by drying single spheres (Fig. 10). We can notice the divergence of the results mostly at the beginning of the process, when values of the effective diffusivity obtained on the basis of the mathematical model are too high. As it has been mentioned above, this phenomenon is connected with the increase of mixture temperature at the beginning of mixing. The scatter of the results of both methods (15–30 per cent) was

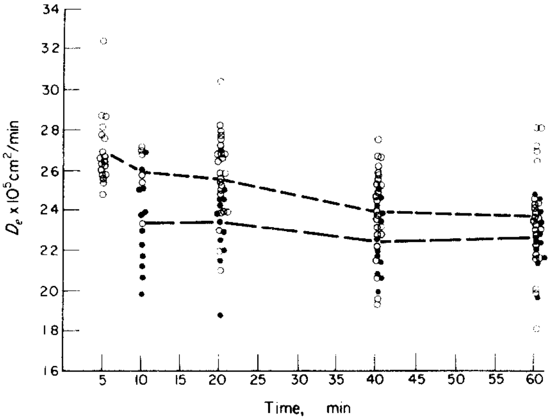

FIG. 10. List of values of effective diffusivity obtained by the use of the mathematical model of the process (○) and of those determined by drying single silica-gel spheres (●); $D_e \cdot 10^5$ cm^2/min vs. time (min).

caused by the particle size dispersion within one fraction of spheres and non-spherical shape of some particles of this fraction.

The presented mathematical model of the process enables us to anticipate approximately the time of mass transfer between solid particles during mixing; when the particles differ greatly in the size of their equivalent diameter. The effective diffusivity may be found experimentally. It should be remembered that the effective diffusivity is a function of temperature.

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Résumé—Des sphères de silicagel humide dont les diamètres variaient de 3 à 4 mm et de 5 à 6 mm ont été mélangées avec und fraction sèche de silicagel fin dont le diamètre variait de 0,3 à 0,4 mm. Il a été démontré expérimentalement que la résistance principale au transport d'humidité se trouvait de côté des sphères. Sur cette base, un modèle mathématique du processus a été élaboré. Le problème a été ramené tout entier à la diffusion du liquide ou de la vapeur dans une sphère entourée par un volume limité de particules fines bien agitées. Les particules fines de gel et l'air entre elles ont été traités comme une pseudophase. On a introduit le concept de diffusivité effective, en tenant compte aussi bien de la structure interne de la sphère que du mécanisme du transport de masse.

Les valeurs de la diffusité effective ont été trouvées expérimentalement à l'aide de deux méthodes. La première méthode était basée sur le modèle mathématique du processus discuté ici, l'autre consistait dans la détermination de la diffusivité effective en étudiant séparément des sphères séchées dans un écoulement turbulent d'air sec avec $Re = 5510$. On a trouvé des résultats semblables par ces deux méthodes.

Zusammenfassung—Feuchte Silikagel-Kugeln (Grösse: 3–4 mm und 5–6 mm) wurden mit einem Anteil feinen, trocknen Silikagels (Grösse: 0,3–0,43 mm) vermischt. Es liess sich experimentell zeigen, dass der Hauptwiderstand für den Feuchtigkeitstransport in den Kugeln liegt. Auf diesem Ergebnis wurde ein mathematisches Modell für den Prozess aufgebaut. Das ganze Problem wurde reduziert auf die Diffusion von Flüssigkeit oder Dampf in eine Kugel, die von einer begrenzten Menge gut gerührter feiner Teilchen umgeben ist. Die feinen Gelteilchen und die Luft dazwischen wurden als eine Pseudophase behandelt. Es wurde der Begriff der effektiven Durchlässigkeit eingeführt und die innere Struktur der Kugel wie auch der Mechanismus des Stofftransports berücksichtigt.

Die Werte der effektiven Durchlässigkeit wurden experimentell mit Hilfe zweier Methoden gefunden. Die erste Methode beruhte auf dem hier besprochenen mathematischen Modell, die andere auf der Bestimmung der effektiven Durchlässigkeit einer Einzelkugel, die im trockenen Lufstrom getrocknet wird (turbulente Strömung, $Re = 5510$). Die beiden Methoden brachten ähnliche Ergebnisse.

Аннотация—Мокрые селикагелевые шарики размером 3–4 мм и 5–6 мм смешивались с сухим мелким селикагелем размером 0,3–0,43 мм. Экспериментально доказано, что основное сопротивление переносу влаги проявляется со стороны шариков. Исходя из этого, была разработана математическая модель процесса. Задача в целом сводится к диффузии жидкости или пара в шаре, окруженном ограниченным объемом хорошо перемешанных мелких частиц. Мелкие селикагелевые частицы и воздух, окружающий их, считают одной псевдофазой. Вводится понятие об эффективном коэффициенте диффузии, которое учитывает внутреннюю структуру шара и механизм массопереноса. Значения эффективного коэффициента диффузии определялись экспериментально при помощи двух методов. Первый метод основывался на математической модели рассмотренного в данной работе процесса, а второй заключался в определении эффективного коэффициента диффузии путем исследования одиночных сфер, высушенных в потоке сухого воздуха (турбулентный поток, $Re = 5510$). Этими двумя методами получены близкие результаты.