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MASS EXCHANGE OF DISPERSED MATERIALS ENCAPSULATING IN QUASI-LIQUEFACTION STATE

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Abstract. Experimental and analytical investigations of mass exchange during dispersed materials encapsulating in quasi-liquefaction state are presented. The mass transfer coefficients during encapsulating have been determined for different dispersed materials depending on air rate.

Keywords: mass transfer, quasi-liquefaction, dispersed material.

1. Introduction

Encapsulating kinetics of dispersed materials in a quasi-liquefaction state is determined by intensity of the processes which occur on the particles surface during shell hardening and depend on the nature of film forming agent. While using film forming solutions during encapsulating the mass exchange takes place between a liquid on the particle surface of the solid material and liquefying air. In contrast to the mass exchange in the solid phase–liquefying agent system, the regularities of which are described in the literature [1-3], the particle surface during encapsulating shows itself as a carrier of liquid phase exchanging its mass with gaseous medium. At the same time the liquid content on the particle is periodically renewed due to the constant dispersion of film forming agent into the material layer. To realize the encapsulating process the amount of the solvent introduced on the particle surface should not exceed the amount of solvent removed from the surface to the gaseous medium. To calculate the rate of the solvent evaporated from the particle surface I. Demchuk [4] developed the analytical dependencies. To fulfill the mentioned calculations it is necessary to know the numerical values of mass transfer coefficients.

The mass transfer coefficient of the solvent evaporated from the particle surface to the liquefying air medium may be calculated from the following kinetic equation [5, 6]:

$$W = b\,F(C_{sat} - C) \qquad (1)$$

where β – mass transfer coefficient of the solvent evaporated from the particle surface to the air, m/s; C_{sat}, C – solvent vapors concentration in the saturation state in the air and working concentration, respectively, kg/m^3; F – area of mass exchange surface, m^2; W – solvent flow, kg/s.

In practice the dispersed materials encapsulated in quasi-liquefaction state proceed under the regimes when only a part of the particles surface participates in the mass exchange. It is connected with the necessity of qualitative coating production [4, 7]. Therefore it is necessary to determine this area to establish the real value of mass transfer coefficient. Such determinations are possible on the basis of investigations concerning mass exchange kinetics depending on the height of material layer.

2. Experimental

The solid materials for the experiments were: polydispersed layer – granulated mineral fertilizers (ammonium nitrate, calcium nitrate, carbamide and nitroamophose) and layer of particles with irregular geometry – seeds which may undergo the presowing encapsulating by chemical protectants for plants and chemical elements of additional fertilizing (fodder beet, spinach).

The experiments were carried out in the cylindrical batch reactor of a quasi-liquefaction state. The product reservoir was loaded by $0.5 \cdot 10^{-3}$ m^3 of the solid material. The encapsulating was carried out with the aqueous solution of film forming solution at the temperature of liquefying air 348 K and quasi-liquefaction number of 2.5–3. The solvent was removed from the particle surface by means of heat application. The temperature of liquefying air at different heights of the material layer was measured using 7-channel smart converter PVI-0298. It allows to measure the temperatures in 7 points simultaneously and record them by the computer. The admissible error is $\pm\,0.25\,\%$, interrogation time for all channels is less than 3.5 s.

While generalizing the results we also used literature data obtained for the monodispersed layer: model spherical particles with the diameter of $5.5 \cdot 10^{-3}$ m and chemical pharmaceutical tablets with the diameter of $6 \cdot 10^{-3}$ and $8 \cdot 10^{-3}$ m.

3. Results and Discussion

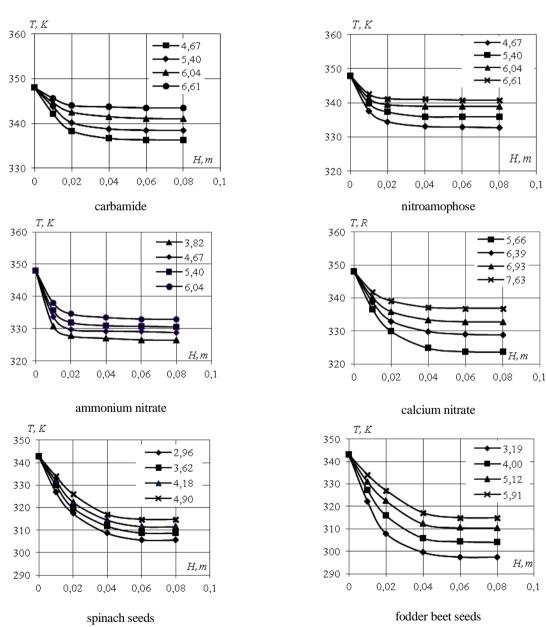The results of experimental investigations of mass exchange of solid dispersed materials encapsulating in a quasi-liquefaction state at different rates of liquefying air are represented in Fig. 1.

The obtained results show that the increase in rate increases air temperature. The reason is that the higher air rate increases heat transfer coefficient and the amount of heat transferred to the particle. Obviously, the amount of heat introduced into the layer is greater than that transferred to the solid phase. Moreover, the most intensive heat-and-mass exchange is observed at low height, directly near sprayer. These observations are well correlated with the data of other authors [1, 9].

carbamide

nitroamophose

ammonium nitrate

calcium nitrate

spinach seeds

fodder beet seeds

Fig. 1. Distribution of air temperature along the height of dispersed materials layer during encapsulating by aqueous solution of film forming agent at different air rates
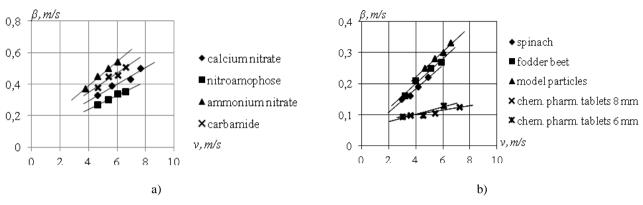
a)

b)

Fig. 2. Dependence of mass transfer coefficient of water steam on fictitious rate of liquefying air
for different types of dispersed material: granulated mineral fertilizers (a); seeds, model particles (according to [4])
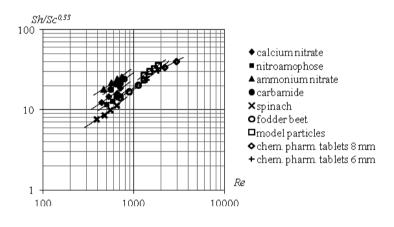and chemical pharmaceutical tablets (according to [8]) (b)

Fig. 3. Generalization of dispersed materials mass exchange process during encapsulating in the quasi-liquefaction state using aqueous solutions of film forming agent

Heat-and-mass exchange of the encapsulating process is finished at the definite height of the layer. The part of temperature curve where the temperature of liquefying air is constant indicates this fact. The surface area of particles which participates in the heat-and-mass exchange is also changed with the change of height. To determine the mass transfer coefficients we used the initial part of the temperature curve that corresponds to the process maximal intensity. We suppose that the whole surface of the particles at this part participates in the heat-and-mass exchange.

Rate of the evaporated solvent at the layer height W' (kg/s) is determined according to the amount of the used heat:

$$W' = \frac{G_a c(T_i - T_h)}{r} \qquad (2)$$

where G_a – air consumption, kg/s; c – air heat capacity, J/(kg·K); T_i – air initial temperature, K; T_h – air temperature at the initial stage and definite height of the layer, K; r – specific heat of solvent evaporation, J/kg.

According to the heat emission equation we determined the surface area of particles F that participates in the heat-and-mass exchange [5]:

$$F = \frac{Q}{a(T_i - T_h)} \qquad (3)$$

where Q – amount of heat transferred from the air to the particles surface, W; a – coefficient of heat transfer from liquefying air to the particles surface, W/(m²·K).

The dependence of mass transfer coefficients b on the fictitious rate of liquefying air w for different types of the solvent is represented in Fig. 2.

To summarize the obtained results the mass transfer coefficients are represented as dimensionless Sherwood (Sh) and Schmidt (Sc)complexes depending on the Reynolds number (Re)[5, 6]:

$$Sh = A\,Re^n\,Sc^m \qquad (4)$$

where $Sh = \dfrac{b d_e}{D}$ – Sherwood number; $Sc = \dfrac{v}{D}$ – Schmidt number; D –coefficient of solvent vapors diffusion in the air, m²/s; d_e – equivalent diameter of particles, m; v – kinematic viscosity, m²/s.

Taking into account the miserable change of air physical parameters we assume that $Sh \sim Sc^{0.33}$ [5, 6].

The unknown values of A and n coefficients are determined from the graphical dependence of $Sh/Sc^{0.33} = f(Re)$ obtained on the basis of experimental data (Fig. 3).

Values of *A* and *n* in Eq. (4) to determine *b*

Material	A	n
Aqueous solutions of film forming agent		
Calcium nitrate	0.097	0.8
Nitroamophose	0.068	0.8
Ammonium nitrate	0.125	0.8
Carbamide	0.112	0.8
Model particles	0.082	0.8
Chemical pharmaceutical tablets with diameter 8 mm	0.332	0.8
Chemical pharmaceutical tablets with diameter 6 mm	0.032	0.8
Spinach seeds	0.065	0.8
Fodder beet seeds	0.069	0.8

Granulometric composition has the main influence on mass exchange. Summarizing the experimental data we determined the unknown constants in Eq. (4) and mass transfer coefficient during encapsulating in the quasi-liquefaction state (Table 1).

The relative error between experimental and calculated results does not exceed 20.4 %. The maximal deviation is observed for the fodder beet because its surface is characterized by sharp irregularity that complicates the measurement of real heat-and-mass exchange area.

4. Conclusions

Based on the experimental investigations we determined the mass transfer coefficients during encapsulating depending on the air rate for different layers of dispersed material. Presented criterial equations allow to determine intensity of encapsulating process by corresponding film forming agents.

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МАСООБМІН ПРОЦЕСУ КАПСУЛЮВАННЯ ДИСПЕРСНИХ МАТЕРІАЛІВ У СТАНІ ПСЕВДОЗРІДЖЕННЯ

Анотація. *Наведено експериментально-аналітичні дослідження процесу масообміну під час капсулювання дисперсних матеріалів у стані псевдозрідження. Визначено коефіцієнти масовіддачі під час капсулювання у залежності від швидкості повітря для різних дисперсних матеріалів.*

Ключові слова*: масовіддача, капсулювання, псевдо-зрідження, дисперсний матеріал.*