Mass transfer in porous capillaries

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Abstract. For widespread introduction of microtechnologies it is necessary to define theoretical bases, to conduct researches and to draw the corresponding conclusions. A cylindrical capillary in which the two-phase gas-liquid mixture moves was considered. In theory describes the motion of gas-liquid mixtures in capillaries in compressed conditions. The device for absorption of gases by liquid is developed and patented. The primary elements - perforated capillary to the outer surface of which is attached gas membrane. It was created a theoretical model of liquid saturation with carbon dioxide, which flows in porous capillaries.

Keywords: porous, capillary, mass, transfer.

INTRODUCTION

Scientific research of process of heat and mass transfer in porous capillaries are relevant for scientists from many lead universities [1 - 9].

Microtechnologies enter for liquid mixing, in warm and mass processes, and also for catalysis and adsorption processes. These processes are carried out in micro and mini channels having capillary structure. Much attention is paid to the gas-liquid processes, which are connected in parallel blocks capillaries with a radius of 2-6 mm. The most effective mode of gas-liquid processes is the shell. Feature of this mode is: good hashing of a liquid stopper at the expense of Taylor whirlwinds; insignificant diffusion way of molecules of gas which get through a liquid film between a bubble and a capillary wall.

In many studies of gas-liquid description of the motion in the capillaries was seen as a movement of gas-liquid systems in pipes with a diameter of 50-70 mm. Thus assumed that speeds of phases are identical, and a consumption of gas connected simple ratios.

One of the first classical works, devoted to dynamics of movement of a gas-liquid mix in a capillary, is executed by Taylor.

The theoretical description of movement of a gas-liquid mix in this mode is given for cases: the bubble rises in a gravitational field; counterflow movement of a bubble and liquid in a capillary; the moving bubble squeezes out liquid.

MAIN PART

Let's consider movement of two-phase system gas-liquid in a cylindrical capillary. Let's allocate the volume limited with a section of I-I and II-II. Section I-I passes through front cylindrical part of a bubble, and section II-II - through a liquid shell, is considerably removed from the ends of gas bubbles.



Fig.1. Movement of two-phase system in a cylindrical capillary

The volume part i-current of a phase isn't equal to part of the space which is occupied by i-me a phase in the allocated volume of a multiphase mix of volume of V. The superficial part of i-that phase is defined

$$\alpha_i = \frac{S_i}{S} \tag{1}$$

In the general form the equation of continuity can be written down

$$\frac{\partial E}{\partial t} + div(\rho_i, \alpha_i, U_i) = q_{vi}$$
⁽²⁾

where: ρ – density, kg/m²; *E* – volume fraction of i-that phase; *q* – volume convective expenses, *m*²/s.

For volume fractions of each of phases

$$\sum_{i=1}^{N} \varepsilon_i = 1 \tag{3}$$

We define expenses of phases:

For a gas bubble

$$q_{2}(x=0) = q_{B} = \int_{A_{B}} U_{2} dA_{B} = 2\pi \int_{0}^{R_{B}} U_{2}(r) dr$$
(4)

$$U_2(x=0) = U_B = \frac{q_B}{A_B}$$
(5)

For a film of fluid around the bubble

$$q_1(x=0) = q_f = \int_{A_f} U_1 dA_f = 2\pi \int_{R_g}^{R} U_1(r) dr$$
(6)

$$U_1(x=0) = U_f = \frac{q_f}{A_f}$$
(7)

For a liquid shell

$$q_1(x=L) = q_f = \int_{A_S} U_1 dA_S = 2\pi \int_0^R U_1(r) dr$$
(8)

$$U_1(x=L) = U_s = \frac{q_s}{A_s} \tag{9}$$

After a number of mathematical transformations we will receive the equation of volume streams of phases

$$q_f + q_B = q_S \tag{10}$$

In the left member of equation (10) we receive the sum of volume streams of the phases entering into the fixed volume V, or which leave it through sections x = 0, and in the right member of equation - streams of the phases entering into the fixed volume V, or leave it through sections x = L.

Speed of movement of a gas bubble more than a speed of movement of liquid in a stopper U_B , U_S , therefore movement of a film can be directed as towards movement of a gas bubble and in the opposite direction.

On the figure 2 this device is represented device absorption of gases by liquid.



Fig. 2 The device for absorption of gases by liquid

The device consists of the extended case 1, a cover 2 and 3, vertical sectors 4, membrane capillaries 5 through passage, the device 6 for a liquid and device 7 supply for branch of a mix, the tight camera 8, the device 9 for supply of gas and the device 10 for periodic removal of not adsorbed gas, membrane lattices 11, fastening of 12 covers.



Fig. 3. Membrane capillary

In figure 3 the membrane capillary through passage is represented. It consists of the rigid punched tube 1. To an external surface of the punched tube the gas membrane 2 fastens. The device works as follows. Initial liquid arrives through a branch pipe 6 in a cavity of membrane capillaries through passage 3. At the same time through a branch pipe 9 in the tight camera 8 it is supplied gas which gets through a membrane 5. Gas mixes up and dissolved by liquid at course on a capillary. Liquid sated with dioxide of carbon is taken away through a branch pipe 7.

Theoretical bases of the diffusive speed of a mass transfer of dioxide of carbon from gas in liquid phases is described by the equation [3].

$$\frac{\partial m}{\partial t} = K_L \cdot A(C_H - C) \tag{11}$$

where: K_L – coefficient of a mass transfer of a liquid film, m/s; A – area of interphase contact, m^2 ; C_H – concentration of dioxide of carbon in gas, kg/m³; C – concentration of the dioxide of carbon dissolved in liquid.

The process, in which the part of a surface of a liquid film moves together with a stream of liquid running on a gas bubble, is described by Higbie's equation.

$$K_{L} = \sqrt{\frac{D_{n} \cdot V_{\delta}}{\pi d_{\delta}}}, \qquad (12)$$

where: $D_{\rm H}$ – coefficient of non-stationary diffusion of dioxide of carbon in liquid, m^2/s ; V_6 – speed of movement of a bubble, m/s; d_6 – diameter of a gas bubble, m.

At a turbulent mode of a mass transfer when whirlwinds on a surface of a bubble are created and they contact to it during certain time, there is an updating of a surface of limit of the section of phases. According to the theory of Dankverts:

$$K_L = \sqrt{D_T \cdot S} , \qquad (13)$$

 D_T – coefficient of diffusion, m^2/s ; S - updating of limit of the section of phases, s^{-1} .

Process of updating of a surface of phases under the influence of turbulent whirlwinds is connected with work which happens on limit of the section of phases.

The size of a new surface which is created for a unit of time S, s⁻¹, at the expense of a turbulent exchange of elements of liquid for surface unit, pays off on the equation:

$$S = \frac{A}{\sigma} = \frac{\xi \rho V_6^3}{2 \cdot \sigma},\tag{14}$$

where: $A = \xi \rho \frac{V_6^3}{2}$ – the work performed for a unit of time on unit of a surface, *W/m*²; σ

- coefficient of a superficial tension, J/m^2 .

Us it is offered to calculate a surface of updating of phases from a condition of balance of work of hydrodynamic resistance and work which is spent on surface updating.



Fig. 4. Capillary and porous saturation element Elementary work of hydrodynamic resistance

$$dA_T = F_{rc} \cdot dL = f_{\delta} \cdot \xi \frac{\rho V_{\delta}^2}{2} \cdot dL, \qquad (15)$$

where: $F_{rc} = f_{\delta} \cdot \xi \frac{\rho V_{\delta}^2}{2}$ – force of hydrodynamic resistance, H; *dL*– elementary length

of a capillary, m; f_6 – bubble cross-section area with carbon dioxide, m^2 .

Elementary work on restoration of an elementary surface

$$dE = \sigma l_{\delta} \cdot dS , \qquad (16)$$

balance work

$$dA_{T} = dE \quad f_{\delta} \cdot \xi \, \frac{\rho V_{\delta}^{2}}{2} \cdot dL = \sigma \cdot l_{\delta} \cdot dS \, ; \quad dL = \vartheta_{\delta} \cdot d\tau \, . \tag{17}$$

$$f_{\delta} \cdot \xi \frac{\rho V_{\delta}^2}{2} \cdot d\tau = \sigma \cdot l_{\delta} \cdot dS ; \quad S = \frac{f_{\delta} \xi \rho V_{\delta}^3 \cdot \tau}{2\sigma \cdot l_{\delta}} = \frac{\xi \rho V_{\delta}^3 \cdot \tau}{2\sigma \cdot K_{\phi}}$$
(18)

where: $K_{\phi} = \frac{f_{\delta}}{l_{\delta}}$ - coefficient of the form of a bubble, ratio of section and bubble

length.

Taking into account equality (17), the equation (11) will become:

$$\frac{\partial m}{\partial t} = A \sqrt{D_T \frac{\xi \rho V_\delta^3 \cdot \tau}{2\sigma \cdot K_\phi}} (C_n - C), \qquad (19)$$

Equation integration (19) in integral of variables ∂m (from 0 to Δm) and ∂t (from 0 to t), we receive:

$$\Delta m = A_{\sqrt{D_T \xi}} \frac{\rho V_6^3 \cdot t^3}{3\sigma \cdot K_{\phi}} (C_n - C) = A_{\sqrt{D_T}} \frac{\xi \rho L^3}{3\sigma \cdot K_{\phi}} (C_n - C) , \qquad (20)$$

In figure 5 the element of a capillary porous saturator length L.



Fig. 5. Element of a capillary and saturator: 1 - Bubble; 2 - Capillary; 3 - Liquid slide

Taking into account the expenditure of liquid and dioxide of carbon it is possible to calculate concentration of dioxide of carbon which is dissolved in liquid.

$$C_{1} = \frac{\Delta m}{M} = \frac{A_{\sqrt{D_{T}}} \frac{\xi \rho L^{3}}{3\sigma \cdot K_{\phi}} (C_{u} - C) \cdot (a - 2b_{1})}{L \cdot m_{1}} = \frac{(a - 2b_{1}) \cdot (C_{u} - C)}{m_{1}} A_{\sqrt{\frac{D_{T} \cdot \xi \rho L}{3\sigma \cdot K_{\phi}}}}, \quad (21)$$

where: m_1 – mass of liquid which is between bubbles; b_1 – big axis of a bubble, m; d_5 – bubble diameter, m; a – distance between bubbles, m.

CONCLUSION

It is possible to use the received dependences in case of calculations of the absorption processes.

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