

Lecture №2. General regularities of diffusion processes of mass exchange

Aim: Discuss equilibrium mass transfer. Analyze the mass emission equation. Bring the mass emission and mass transfer equations. Explain the physical meaning of mass emission and mass transfer coefficients.

Lecture summary: 1.2. Balance of mass transfer. As mentioned above, the driving force of the mass transfer process, which causes the component to transfer from one phase to another, in practical calculations is defined as the difference between the actual concentration value in one of the phases and its equilibrium value with the component content in the other phase. The direction of mass transfer can be determined by comparing *the equilibrium lines* and the lines of working concentrations. At equilibrium, a certain relationship is reached between the equilibrium concentrations of the substance to be distributed in the phases for these conditions. Under the conditions of equilibrium, to a certain value \bar{x} of the concentration of the substance distributed in one phase corresponds to a strictly defined equilibrium concentration \bar{y}^* in the other phase. In general, the relationship between the concentrations of a substance in phases at equilibrium is expressed by the dependence:

$$\bar{y}^* = f(\bar{x}) \quad \text{or} \quad \bar{x}^* = f(\bar{y}) \quad (7)$$

Any of these patterns is represented graphically by *the line of balance*. The working concentration of the substance distributed is not equal to the equilibrium. The relationship between the working concentrations of the component being distributed in phases is represented by a line, which is called *the working line*. The substance to be distributed always passes from the phase, where its content is higher than the equilibrium, to the phase in which the concentration of this substance is lower than the equilibrium one.

1.3. Mass emission (output) equation

The transition of a substance from one phase to another is carried out as a result of a complex transfer mechanism to the interface and from it by molecular and turbulent diffusion. In each phase, *the core*, or the main mass of the phase, and *the boundary layer* near the phase boundary are distinguished. In the core, a substance is transported predominantly by turbulent pulsations; in the boundary layer, the turbulence gradually decreases, and the transfer rate is already determined by the molecular diffusion rate.

Therefore, with the intensification of mass transfer, it is desirable to reduce the thickness of the boundary layer, increasing the degree of flow turbulence (for example, by mixing).

For practical purposes, *the mass emission (output) rate* (transfer of the distributed substance within one phase from the main flow volume to its interface with another phase or in the opposite direction) is proportional to the driving force equal to the concentration difference in the core and at the phase boundary. For example, when a substance passes from phase Ph_y to phase Ph_x , the mass emission (output) equation, which determines the

amount of M transferred per unit time in each of the phases (to the phase boundary or in the opposite direction), is expressed as follows:

$$M = \beta_y F (\bar{y} - \bar{y}_{bod}) \quad (\text{phase Ph}_y) \quad (8)$$

$$M = \beta_x F (\bar{x}_{bod} - \bar{x}) \quad (\text{phase Ph}_x) \quad (8a)$$

where M – the molar flow rate of the component, mol/s; F – surface area of mass transfer, m^2 ; \bar{x}, \bar{y} – the average concentration in the core of each phase; $\bar{x}_{boun}, \bar{y}_{boun}$ – the concentration at the boundary of the corresponding phase; β_y and β_x – the mass transfer coefficients, which show what mass of a substance passes from the interface to the phase core (or in the opposite direction) through a unit of surface per unit of time with a driving force (concentration difference) equal to one.

The mass emission (output) coefficient can be expressed in various units depending on the choice of units for the mass of the distributed substance a and the driving force. The mass emission (output) coefficient is not a physical constant, but a kinetic characteristic, depending on the physical properties of the phase and the hydrodynamic conditions in it. Since the quantity β is a function of many variables, the calculation or experimental determination of the mass transfer coefficient is a complex task. Therefore, for practical purposes of finding the relationship between the variables characterizing the transfer process in the phase flow, methods of the similarity theory in the form of a generalized (criterial) mass emission (output) equation are used.

1.4. Mass transfer equation

The basic equation of mass transfer, which determines the M of the substance transported from phase Ph_y to phase Ph_x (and in the opposite direction) per unit of time through the interface area F , is expressed by the following equations:

$$M = K_y F (y - y^*), \quad \text{or} \quad (9)$$

$$M = K_x F (x^* - x), \quad (9a)$$

where y^* and x^* – the equilibrium concentrations of the substance to be distributed in a given phase, corresponding to the concentrations of the substance in the bulk of the other phase; K_y and K_x – mass transfer coefficients, showing what mass of a substance passes from phase to phase per unit of time through a unit of the contact surface of the phases with a driving force of mass transfer equal to one. Here the driving force of the process is expressed by the difference between the working and equilibrium concentration (9) (or vice versa (9a)), which reflects the measure of the deviation of the system from the equilibrium state.

The transfer coefficients K_y and K_x differ from the mass emission (output) coefficients β_y and β_x by physical meaning, but are expressed in the same units of measurement. In practice, the average driving force (Δy_{av} и Δx_{av}) is introduced into the mass transfer equations. Then the equations of mass transfer take the form:

$$M = K_y F \Delta y_{av} \quad (10)$$

$$M = K_x F \Delta x_{av}, \quad (10a)$$

The relationship between the coefficients of mass transfer and mass emission (output) for the case of transition of a substance through the interface with the linear equilibrium equation ($y^* = mx$, where m – the tangent of the angle of inclination of the equilibrium line to the x axis) is expressed by the relations:

$$K_y = \frac{1}{1/\beta_y + m/\beta_x}, \quad (11)$$

$$K_x = \frac{1}{1/m\beta_y + 1/\beta_x} \quad (11a)$$

The denominators in relations (11) and (11a) are the sum of the diffusion resistances to mass transfer in the phases, and the left parts of the equations are the total resistance to the transfer of substance from phase to phase, i.e. resistance to mass transfer. Therefore, these dependences are *the additivity equations for phase resistances*. From (11) and (11a) it follows that $K_y = K_x/m$. Equations (11) and (11a) were derived for a linear equilibrium dependence, but they remain valid for a nonlinear line of equilibrium. With a nonlinear line of equilibrium, the values of m and mass transfer coefficients K vary in height of the apparatus. In this case, when calculating, it is usually divided into sections and, within each section, m is assumed to be a constant value, and the average K value is used for the entire apparatus.

Questions to control:

1. Give the equation reflecting the relationship between the concentrations of substances in phases at equilibrium.
2. Define the working lines.
3. Due to what is the transition of a substance from one phase to another?
4. Write the mass emission (output) equations for the gas and liquid phases. What is the physical meaning of the mass emission (output) coefficient?
5. Write the mass transfer equations for the gas and liquid phases. What is the physical meaning of the mass transfer coefficient?
6. Give the additivity equations for phase resistances. What is their physical meaning?

Literature:

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