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PROBLEM OF INCREASING THE EFFICIENCY OF TECHNOLOGICAL PROCESSES

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Modernization of industry based on innovation and investment is closely related to improving the efficiency of technological processes.

The effectiveness of any manufacturing process includes four main components: intensity of the process determining the performance of relevant apparatus, product quality, efficiency and safety of the technological process. For many years, researchers have concentrated their main attention on the intensity of processes (including hydrodynamic and heat and mass transfer processes). Much research on this issue was conducted by researchers of the scientific school of the Department for processes, apparatuses of chemical technology and safety of vital activity of MSTU named after A.N. Kosygin [1–4].

A new theory of mass transfer on the basis of generalized equation of Sazhin-Reutsky mass transfer [1...3], theory of active hydrodynamic regimes (AHR), on the basis of which intensive processes and devices for chemical, textile and related industries have been developed [3, 5, 9, 24...26, 28]; a theory of fluidized bed has been developed, new hydrodynamic regimes of fluidized bed have been discovered and patented (free-flowing, passing fluidized bed, etc.) [4, 12...15]. New devices, realizing in an optimum range of their work of AHR have been developed, protected by authors's certificates and patents (vortex disc, with counter-swirl flow, etc.) [3, 15, 28]. Especially large complex of work has been carried out on apparatuses with colliding vortex flow (CVF) as a result of which optimum design and methods for calculating of a number of technological processes have been developed: dust cleaning, drying, etc. [3, 6, 9, 13]. Multi-functional devices and combined apparatuses with AHR for the systems of gas-solid phase, gas-liquid phase, etc. have been developed. [9, 17, 24, 29].

Large volume of fundamental and applied research has been carried out by the scientific school of the Department for processes, apparatuses of chemical technology and safety of vital activity of A.N. Kosygin in the sphere of creating cost-effective processes. A strategy for selecting and optimizing the most energy-intensive process of drying and cleaning, including textile materials, as well as appropriate designs and methods of their calculation has been developed [2...5, 10, 12...15, 25, 26]. Energy-saving technologies for chemical and textile industries have been developed, and a new method of exergic analysis and optimization of power-consuming industrial plants has been developed [7...9] allowing to select objectively the most appropriate technical solution, from the economic point of view, among a number of competing proposals on increasing efficiency of technological processes (criterion is the maximum value of exergic coefficient of efficiency) .

Research and applied development research of the scientific school of the department for processes, apparatuses of chemical technology and safety of vital activity enabled to achieve (especially in recent years) considerable success in enhancing environmental safety of technological processes [3, 6, 11, 16, 18...20, 24...26]. For the first time in conjunction with the efficiency, research has been conducted on providing safety of technological processes and industries with the development of technical solutions and designs of equipment, including for dust and gas treatment, reducing the harmful effects of noise and vibration in the production environment, etc. (theory, methods of calculation) [6, 18...20]. Work on multifunctional vortex devices allowed to equip many production facilities of a number of industries with the highly efficient equipment (more than ten thousand pieces of equipment have been introduced) [3, 6, 9, 11, 13, 15, 17, 24...26, 28, 29]. It should be noted that Russian made dustcatching apparatus with counter swirling flow surpass significantly the basic indices of foreign developments, including the vortex dust collectors (VDC). Unlike VDC devices, in which compressor and two fans of high pressure are installed as a means of blowing, the domestic DCAwCSF devices have only one fan with average pressure installed at the "tail" of installation. In addition, in VDC devices through the upper channel clean ballast gas (65% of total consumption) is supplied in order to avoid "overshoot" of dust, and in the DCAwCSF apparatus both channels operate with a working dusty gas since domestic developments eliminate the "overshoot" of dust; this was proved with the theoretical and experimental research and was fully confirmed in the course of introduction of DCAwCSF apparatus in production. DCAwCSF apparatus have a great prospect of application in various industries, including textile and chemical ones.

Today, long-term development issues are being associated with nanotechnology and mesatehnology [30, 31]. It is important to develop scientific strategies for selection of optimal solutions, to implement the principle of unity of theory and practice, to construct new plants, to interact with government and business, to rise labor productivity, which is directly dependent on the efficiency of technological processes; as well as influx of young professionals in science. Investments in science and education should grow much faster than investment in industry; strategy of "pursuing", "overtaking" is unacceptable.

When solving the problem with efficiency, it is quite important to proceed in studies on the base of the nonlinearity of technological processes [21...33]. Nonlinearity in the mathematical sense means a certain kind of mathematical equations that contain the desired quantities in the powers, other than units or factors, which depend on the properties of the reactive medium. The physical meaning of the nonlinearity - a violation of the principle of superposition and availability of many paths of evolution in accordance with the solution set of nonlinear equations, as well as the possibility of an abrupt change in technological regimes.

Innovative approaches to the theory and calculation processes, including mass transfer processes, as experience shows, can give very significant results in the implementation of standard technological processes. Generalized equation of mass transfer can provide an example [3, 15, 32, etc.]. Description of the kinetics of processes using the equations of generalized mass transfer proceeds from the fact that in general case the curves of the kinetics of heat and mass transfer processes are of S - shape, having two asymptotes [1...3, 32]. Therefore, the generalized equation of mass transfer reflecting the S-shaped character of kinetic curves (in contrast to the traditional equations of mass transfer) enables to describe the process in general, not just its individual periods (as it is done, for example, during the drying process) and does not require the determination of critical points (butt concentrations between the periods):

$$-dC'/d\tau = K(A - C')(C' - B), \quad (1)$$

where, C' – concentration of the distributed component; K – constant of process speed; A, B – asymptotic concentrations of the distributed component.

Value of concentration at the inflection point

$$C'_{\text{ПГ}} = (A + B)/2. \quad (2)$$

If the mass transfer process involves two periods which considerably differ in length of time, the generalized equation can be simplified: instead of A concentration, the initial concentration is to be used C_0'

$$-(dC'/d\tau) = K(C_0' - C')(C' - B), \quad (3)$$

where C_0' – initial concentration of distributed component.

When integrating, we get

$$\tau = \frac{1}{K(A-B)} \ln \frac{(A-C')(C_0-B)}{(A-C_0)(C'-B)} = \frac{1}{K(A-B)} Z, \quad (4)$$

where Z – non-dimensional concentration number (complex).

The most common problems in industrial processes are problems of mass transfer and the motion for two-phase disperse systems.

Material balance of components (mass concentration in the dispersed and continuous phases) in the macroscopic description of mass transfer can be written in the form of equations (5)...(7):

$$\frac{\partial}{\partial t}(\rho C_{1j}) + \frac{\partial}{\partial \vec{r}}(\rho \vec{W} C_{1j}') - \frac{\partial}{\partial \vec{r}}(D_1 \frac{\partial}{\partial \vec{r}})(\rho C_{1j}') = -K_j(\psi_j' C_{1jS}' - C_{2j}') + \rho Q_{1j}, \quad (5)$$

$$\frac{\partial}{\partial t}(\varepsilon C_{2j}') + \frac{\partial}{\partial \vec{r}}(\varepsilon \vec{v} C_{2j}') - \frac{\partial}{\partial \vec{r}}(D_{2j} \frac{\partial}{\partial \vec{r}})(\varepsilon C_{2j}') = K_j(\psi_j' C_{1jS}' - C_{2j}') + \varepsilon Q_{2j}, \quad (6)$$

$$\varepsilon = 1 - \rho, K_j = nK_{0j}, n = \rho\sigma / \sigma = \frac{4}{3}\pi a^3, \quad (7)$$

where $\rho, \varepsilon, \vec{W}, \vec{v}$ – bulk concentrations and the rate of the continuous and disperse phases; n, σ, a – number concentration, volume and radius of the dispersed particles; C_{1jS} – concentration on the particle surface; K_{0f} – mass-transfer coefficient of j-th substance in a continuous medium per particle; ψ_j^2 – equilibrium distribution coefficient of substance between the phases; $C_{1j}', C_{2j}' (j = 1...J)$ - mass concentration in the dispersed and continuous phases. Values Q_{1j} and Q_{2j} - describe the occurrence of the j-th substance as a result of chemical reactions (they are assigned to a unit volume of the corresponding phase). The tensor D_1 characterizes the chaotic mixing of particles, the tensor D_{2j} – chaotic mixing and molecular diffusion of the j-th substance in the solid phase.

It is relevant to take for engineering calculations $C_{1jS}' = C_{1j}; \psi_j$, K_{0j}, Q_{1j}, Q_{2j}, D_1, D_{2j} as some known functions of all concentrations, ρ and other parameters.

Let us supplement the system of equations (5)...(7) with equations of fluid mechanics of two-phase system. The equations of mass conservation phase (8, 9):

$$\frac{\partial}{\partial t}(d_1\rho) + \frac{\partial}{\partial \vec{r}}(\vec{W} d_1 \rho) = \sum_j K_j(\psi_j' C_{1jS}' - C_{2j}'), \quad (8)$$

$$-\frac{\partial}{\partial t}(d_2\varepsilon) + \frac{\partial}{\partial \vec{r}}(\vec{v} d_2 \varepsilon) = \sum_j (\psi_j' C_{1jS}' - C_{2j}), \quad (9)$$

where d_1 and d_2 – the density of materials of dispersed and continuous phases, depending on their composition.

The equations of conservation of momentum phase can be written (excluding the viscous stress) as (10) and (11):

$$\left(\frac{\partial}{\partial t} + \vec{W}\frac{\partial}{\partial \vec{r}}\right)(d_1 \rho \vec{W}) = -\rho \frac{\partial P}{\partial \vec{r}} + d_1 \rho \vec{g} + \vec{F}, \quad (10)$$

$$\left(\frac{\partial}{\partial t} + \vec{v}\frac{\partial}{\partial \vec{r}}\right)(d_2 \varepsilon \vec{v}) = -\varepsilon \frac{\partial P}{\partial \vec{r}} + d_2 \varepsilon \vec{g} - \vec{F}, \quad (11)$$

where $\vec{F}$ – interaction force between phases.

To close the system of equations (5)...(11) the equations of state are to be used (12):

$$d_1 = d_1(\rho, C'_{1j}); d_2 = d_2(\rho, C'_{2j}). \quad (12)$$

Solution of the full system of equations (5)...(12) presents considerable difficulties; however, in most specific cases, this system can be greatly simplified.

Considering the prospects of scientific research to improve the efficiency of technological processes it is expedient to strengthen the work in the field of nano-and mezotehnology [30], [31], macrokinetics in conjunction with research on microkinetics (taking into account the effects of Marangoni, Rayleigh and others) [30], as well as work for the imposition of energy fields (high-frequency current, ultrasonic, etc.).

CONCLUSIONS

1. It has been demonstrated that the problem of increasing the efficiency of technological processes has four main components: intensity, quality of products, efficiency, environmental and industrial safety. The results of fundamental and applied research of the scientific school of the Department for processes, apparatuses of chemical technology and safety of vital activity of MSTU named after A.N. Kosygin in the improvement of efficiency of technological processes have been presented.

2. Examples of the mathematical description of (generalized equation of mass transfer and two-phase process with the presence of the dispersed and continuous phases) have been given.

3. The ways of further research to improve the efficiency of technological processes (nano-and mezotehnology, a combination of macro-and microkinetics, consideration for nonlinearity of technological processes, imposition of energy fields) .

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