METHOD OF DETERMINING THE INTENSITY OF LONGITUDINAL MIXING OF FLOWING LOOSE MATERIALS

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For developing and improving continuously operated units, a method is needed by which the flow characteristics of the substance in the contact volume can be determined.

An analytical description of the velocity field, viz., an analytical description of the trajectories of all moving particles and the changes in velocity of the various particles along their trajectories, will be the most complete characteristic. However, since actual processes are very complex, it is impossible at present to find this characteristic for the overwhelming majority of practically important installations. Therefore, we have to restrict ourselves for the time being to giving a formal characterization of this field by means of a parameter which can be easily determined by experiments.

The one-parameter model of dilution during circulation as proposed by A. P. Zinov'eva and D. I. Orochko [10] constitutes another, more extensively used, way of characterization. Here, the degree of dilution \( r \) is the characteristic parameter.

Zinov'eva and Orochko [10] found that, if mixing is instantaneous and the circulation rate maximum, the initial degree of conversion \( Y_i \) is determined by the degree of dilution, the final degree of conversion \( Y_f \) of the substance fed to the reactor inlet, and the initial degree of conversion \( Y_i \) at the reactor outlet:

\[
Y_f - Y_i = \frac{Y_f - Y_i}{1 + r}; \quad \lim_{r \to \infty} Y_r = Y_f
\]

Figure 1, taken from paper [10], shows how \( r \) and \( B_0 \) (the parameter of the diffusion model) depend on the degree of conversion of the substance supplied.

Mixing becomes ideal as \( r \to \infty \) or \( B_0 \to 0 \).

Theoretical considerations [1-5] lead to the conclusion that the distribution of the residence time of the particles in the apparatus is an important characteristic of the efficiency.

This characteristic can be determined experimentally by pulse- or step-wise variation of the concentration of an admixed substance.

If the first variation type is applied, a definite amount of another substance (indicator) whose properties differ from those of the main flow is admixed very fast (instantaneously) to the stationary flow at the moment \( \tau = 0 \), and, after that, measurements of the indicator concentration at the exit of the apparatus are started.

If the second variation type is used, the supply of "old" substance to the apparatus in which a stationary flow regime has established is stopped completely at a definite moment \( \tau = 0 \) and the supply of "new" substance differing from the old one in some property, for example, in color or electric conductivity, is started simultaneously at the same rate.

The first method has the advantage that only a small amount of indicator is needed; however, uniform distribution of the indicator throughout the cross section of the supply channel and rapid admixture to the flow are hard to realize in the application of this method.

The two tasks are even more difficult during operation with free-flowing solids (catalysts, heat carriers, adsorbents). Whereas liquids or gases might be admixed in very short times, instantaneous admixture of the required amount of indicator to the flow is unfeasible. In practice, the time needed for admixture of the indicator equals some fraction of the mean residence time of the substance in the apparatus. Consequently, in studies on apparatus...
The degree of dilution ($r$) and the parameter ($Bo$) of the diffusion model plotted versus the degree of conversion ($Y_c$).

Fig. 1.

The relative introduction time $\tau_B/\bar{T}$ depends on the intensity of longitudinal mixing. For analysis of systems in which solids move, it is recommended [5] to take $\tau_B = (0.25-0.5)\bar{T}$, where $\tau_B$ denotes the introduction time of the indicator, $\bar{T}$ the mean residence time of the material in the model.

The numerical characteristic of the process of longitudinal diffusion has to be corrected for the supply time of the indicator.

We did experiments in which we determined the coefficient of longitudinal mixing of an aluminum silicate bead catalyst moving through a heap formed during continuous supply of solid particles to, or continuous removal from a zone with a free surface. Such flows establish in equipment containing a moving catalyst bed, for example, in the lower part of a separator, in the upper part of a reactor or regenerator, in a feeder, etc.

To create a continuous flow of 3-4 mm catalyst particles we used a rotating horizontal cylinder model of 200 mm diameter and 400 mm length. The loose material was supplied from a vibrated tray feeder via the inlet tube to the rotated cylinder the two ends of which were constrained by rings. The internal diameter of the ring at the cylinder exit was larger than that of the ring at the inlet. On leaving the cylinder the material was fed to a container. The indicator used was colored aluminum silicate particles of the same particle size as the main material. The indicator was admixed to the stationary flow at a constant rate $v = 192$ g/min for $\tau_B = 2$ min. Samples for determination of the concentration of tagged particles were taken at the exit immediately after admixing had been started.

The primary experimental data are plotted along the coordinates $C$ versus $\tau$ in Fig. 2.

The residence time of the particles in the apparatus is a stochastic variable, which is distributed according to some law governed by the differential distribution function of the residence time $E(\tau)$.

It is known [1] that

$$\int_0^\infty E(\tau)d\tau = 1. \quad (1)$$

The area under the $C(\tau)$ curve (Fig. 2) represents the amount of indicator forced out of the apparatus

$$\epsilon_u = v \int_0^{\tau_K} C d\tau = v \sum_0^{\tau_K} C \Delta \tau. \quad (2)$$

where $v$ denotes the volume flow rate, $\tau_K$ the duration of the experiment.

To transform the $C(\tau)$ curve into the curve representing the differential distribution of residence times $E(\tau)$ it is necessary to divide the instantaneous $C$ values (see Fig. 2) by the sum $\sum_0^{\tau_K} C \Delta \tau$, for condition (1) is fulfilled...