BRIEF COMMUNICATIONS

NONSTATIONARY MASS TRANSFER IN A SOLID-FLUID SYSTEM

G. A. Aksel'rud, O. M. Shapovalov, and G. L. Stavrovskii

Inzhenerno-Fizicheskii Zhurnal, Vol. 12, No. 4, pp. 532-534, 1967

UDC 66.01+66.04

The authors examine a method of nonstationary mass transfer employing a flow of fluid with suspended particles in a tube with a periodically changing cross section. A considerable increase in mass transfer as compared with simple suspension has been confirmed experimentally.

There has recently been a distinct trend toward combining mass transfer processes with hydraulic transport through vertical tubes. One of the authors [1] has studied the laws of the suspension thus obtained; the corresponding kinetic equation has the following form:

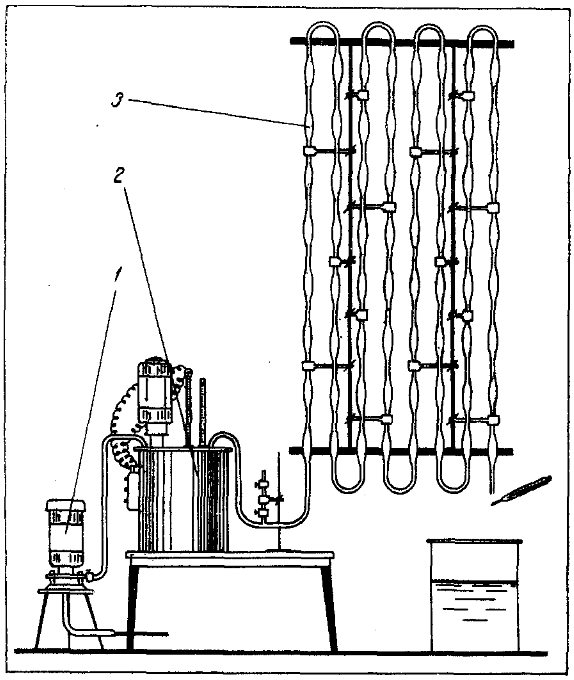

Fig. 1. Diagram of experimental apparatus for investigating mass transfer.

$$\mathrm{Nu} = 0.4\sqrt[3]{\mathrm{Pr}}\sqrt[3]{\mathrm{Ar}}.$$

As subsequent investigations have shown [2], mass transfer in this system can be intensified by means of low-frequency mechanical vibrations produced by a mechanical or electric vibrator.

The relative increase in mass transfer rate due to superposing the mechanical vibration field is proportional to the product of the frequency and the amplitude of the vibrations. I. T. El'perin and A. L. Parnas have proposed a method of creating a nonstationary mass transfer regime without the use of mechanical or electric vibrators. Hydraulic and diffusional nonstationarity is created in a tube with a periodically varying cross section, as a result of which the fluid velocity periodically changes. A solid particle participating in this fluid flow also changes velocity periodically, now lagging behind the fast-flowing fluid in the narrow sections, now overtaking the slow-flowing fluid in the broad sections. Thus, as a result of the inertia of the particle, an additional flow velocity is created, and this should play a part in accelerating mass transfer.

A theoretical study of nonstationary mass transfer in these circumstances presents considerable difficulties, as is usually the case in investigating a nonstationary boundary layer under complex hydrodynamic conditions. It is quite clear that an increase in fluid velocity, like an increase in the particle size d, must lead to a relative increase in the mass transfer coefficient. In the first case the velocity drop between different sections increases, in the second the inertia of the particle. It should be kept in mind that the fluid velocity W must be greater than the particle suspension velocity W_g; when these velocities are equal the method is inapplicable, and the mass transfer intensification effect must be equal to zero.

Thus we arrive at the following qualitative relation:

$$\frac{k - k_0}{k_0} = A\,(W - W_g)\,d. \tag{1}$$

The mass transfer kinetics were studied experimentally under the conditions described in the apparatus shown in Fig. 1.

Water supplied by pump 1 was fed into the thermostated vessel 2, where it was heated to the constant temperature $t^0 = 20°$ C, after which it flowed through a tube with periodically varying cross section 3. The total length of tube 3 was 15 m. The ratio of maximum to minimum cross section was 4. In the tube particles of pressed potassium nitrate underwent mass transfer (solution) in the water. The particles were cylindrical (height of cylinder equal to its diameter) and varied in size from 0.3 to 0.5 cm. The mass transfer coefficient was determined from the formula

$$k = \Delta\,G/c_s\,tF.$$

At the same time we performed experiments to determine the coefficient k in a stationary suspended column (process in smooth tube).

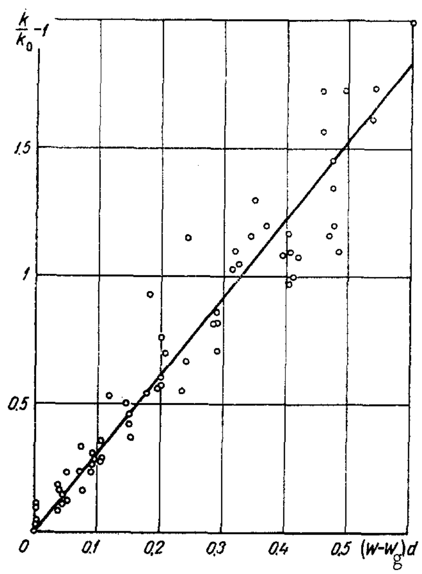

Fig. 2. Relative increase in mass transfer coefficient $k/k_0 - 1$ as a function of flow velocity and particle size.

In both cases the fluid velocity fluctuated from 0.35 to 1.43 m/sec, calculated for the mean cross section of the tube. It was found that under stationary conditions (smooth tubes) k does not depend either on the velocity or on the particle diameter and is $9.37 \cdot 10^{-3}$ cm/sec (mean of 25 experiments). In Fig. 2 the relative increase in mass transfer coefficient is shown as a function of the product $(W - W_g)d$. Thus, we arrive at a relation of type (1) with the coefficient $A = 3$.

From our analysis of the experimental data we conclude that there is a substantial increase in the mass transfer coefficient under the conditions described (in our experiments up to a factor of 3 at velocities not exceeding 1.5 m/sec).

NOTATION

k is the mass transfer coefficient under nonstationary flow conditions; k_0 is the mass transfer coefficient for motion of the suspension in a tube of constant cross section; A is an empirical coefficient; ΔG is the particle weight loss (determined by weighing before and after dissolution); F is the surface area of the particle; t is the residence time in contact with the liquid; c_s is the saturation concentration of potassium nitrate; W is the fluid velocity; W_g is the particle suspension velocity.

REFERENCES

1. G. A. Aksel'rud, Theory of Diffusional Extraction from Porous Bodies [in Russian], L'vov, 1959.
2. I. N. Fiklistov and G. A. Aksel'rud, collection: Heat and Mass Transfer in Disperse Systems [in Russian], Minsk, 1965.
3. I. T. El'perin and A. L. Parnas, IFZh [Journal of Engineering Physics], **10**, no. 3, 1966.

25 June 1966 L'vov Polytechnic Institute

EFFECT OF NEIGHBORING BOILING SECTIONS ON THE CRITICAL HEAT FLUX IN FORCED CHANNEL FLOW

A. A. Ivashkevich

Inzhenerno-Fizicheskii Zhurnal, Vol. 12, No. 4, pp. 535-537, 1967

UDC 536.423.1

It is assumed that the critical heat flux is affected by nucleate boiling in neighboring channel sections upstream from the burnout point.

In performing critical heat flux experiments it is usual to measure or calculate the flow parameters (velocity, temperature, vapor content) averaged over the channel cross section. In the general case the distribution of velocity, temperature, and vapor content over the channel cross section is not known. It is natural to assume that burnout depends not only on the averaged values of the flow parameters but also on their distribution over the channel cross section which, in turn, depends on the intensity of the nucleate boiling process in neighboring parts of the channel upstream from the burnout point. The effect of nucleate boiling on burnout diminishes with distance. Therefore it is possible to speak of an effective length on which nucleate boiling affects the critical heat flux:

$$q_{cr} = f_1(w\rho,\ X_b,\ D,\ L,\ \bar{q}_L,\ \bar{X}_L,\ \ldots). \tag{1}$$

In this equation the effect of nucleate boiling in neighboring cross sections is taken into account by the mean heat flux, the mean relative enthalpy of the flow of liquid or vapor-liquid mixture in neighboring cross sections of the channel, and the length of the neighboring boiling sections. Equation (1) does not contain all the parameters affecting burnout: in particular, it does not contain the physical properties of the liquid and the vapor, since since their effect is not considered. Equation (1) has been written for the boiling of both a subcooled liquid ($X < 0$) and a vapor-liquid mixture ($X > 0$).

We will not consider in detail the reason why nucleate boiling in neighboring parts of the channel affects burnout. An explanation has been offered in [1] and the matter is also examined in [2].

The enthalpy of the liquid flow in neighboring cross sections of the channel is linked by the heat balance equation with the enthalpy of the flow in the section in which burnout occurs. If it is less than the heated length of the channel, the length of the neighboring boiling sections depends on the liquid flow parameters in neighboring cross sections of the channel. Thus Eq. (1) may be rewritten as

$$q_{cr} = f_2[w\rho,\ X_b,\ \Gamma_b,\ D,\ l_0,\ q_L(l),\ \ldots]. \tag{2}$$

The effect of nucleate boiling in neighboring cross sections of the channel on the critical heat flux in Eq. (2) is taken into account by the liquid enthalpy gradient, the law of variation of the heat flux in neighboring parts of the channel, and the heated length of the channel if it is equal to the length of the neighboring boiling sections of the channel. Although Eq. (2) does not contain all the parameters affecting burnout, it is important to note that it does include a new parameter—the gradient of the liquid enthalpy along the length of the channel. The enthalpy gradient itself does not directly affect burnout; its effect is manifested through the effect of nucleate boiling in neighboring parts of the channel, this effect always existing whenever there are neighboring boiling sections.

In a number of cases the liquid enthalpy gradient is an independent parameter, for example, in annular channels with independent two-sided heating. However, in certain cases it is a dependent parameter, for example, in uniformly heated tubes.

We will consider whether the existing experimental data on critical heat fluxes confirm that nucleate boiling in neighboring sections of the channel affects nucleate boiling burnout. In the light of what has been said [Eq. (2)], as a result of this influence the critical heat flux should depend: 1) on the heat flux distribution along the length of the channel over the neighboring boiling sections; 2) on the liquid enthalpy gradient along the length of the channel, which, in turn, depends on the heat flux distribution over the perimeter of the channel and on the ratio of the heated perimeter to the cross-sectional area of the channel; 3) on the heated length of the channel if it is equal to the length of the neighboring boiling sections of the channel. In fact, in various experiments on the boiling of subcooled liquids and vapor-liquid mixtures the following factors have been found to affect the critical heat flux: 1) the heat flux distribution along the length of