METHOD OF STUDYING LOCAL HEAT EXCHANGE OF A HORIZONTAL GAS-SUSPENSION STREAM

N. I. Gel'perin, V. G. Ainshtein,
L. I. Krupnik, and S. V. Efimova

UDC 536.244:532.582.7

A method of studying local heat exchange between a gas-suspension stream and a surface is proposed which allows one to bring out the contribution made to the heat transfer by different physical effects produced by the velocity and concentration fields of the stream.

The motion of horizontal gas-suspension streams is characterized [1] by considerable transverse nonuniformity of the distribution of the solid phase (the true and flow-rate concentrations μ_t and μ_f and the mass velocities) and the carrying medium (velocity fields, shear stresses τ, and momentum). Because their motion is not in union with the gas stream most of the solid particles are concentrated in the lower zones of the pipeline, displacing the gas into its upper zones where the concentration of the solid material is low. Thus, the velocity field of the gas stream is deformed and a new field (asymmetrical relative to the axis of the pipe) arises with its characteristic gradients of velocity, wall shear stress, and dynamic velocity, these being different in different sections of the perimeter of the pipe cross section. Naturally, the heat fluxes are formed differently under the conditions of heat exchange in these sections; this is taken by the investigator as a difference in the values of the local coefficient α_l of heat exchange between the walls of the tube and the gas-suspension stream [2-4].

The literature data on the local heat-exchange intensity are very scanty and contradictory. It was shown earlier [2] that the relative heat-exchange intensity α_l/α_g (α_g is the coefficient of heat exchange with an undisturbed gas stream) is maximal in the upper zones of the pipe, where because of the deformation of the velocity field of the gas the wall shear stresses are higher and thickness of the viscous sublayer is smaller [5]. At the same time, there are data [3, 4] that the heat-exchange coefficient is higher in the lower zones of a pipeline, which is evidently connected with the greater thermal heads in the lower zones owing to the increased concentration of the solid material. Finally, [6] indicates the absence of a difference in the intensity of heat exchange with the lower and upper elements of the pipe surface.*

It seems obvious that the relative intensity of heat exchange in different zones of a pipe changes in accordance with the different velocity and concentration fields of the stream in the concrete hydrodynamic environment. In order to reveal the physical essence of the heat-exchange process under consideration and the true values of the local heat-transfer coefficients it is necessary to preserve and record the local values of the heat fluxes, formed under the effect of the structural characteristics of the system, along the perimeter of the pipe cross section.

---

*The data compared differ in the ranges of measurement of the flow-rate concentration μ_f, in the average velocities w_{av} of the carrying medium, and in the physical properties of the solid particles.

M. V. Lomonosov Moscow Institute of Fine Chemical Technology. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 29, No. 2, pp. 205-208, August, 1975. Original article submitted January 20, 1975.

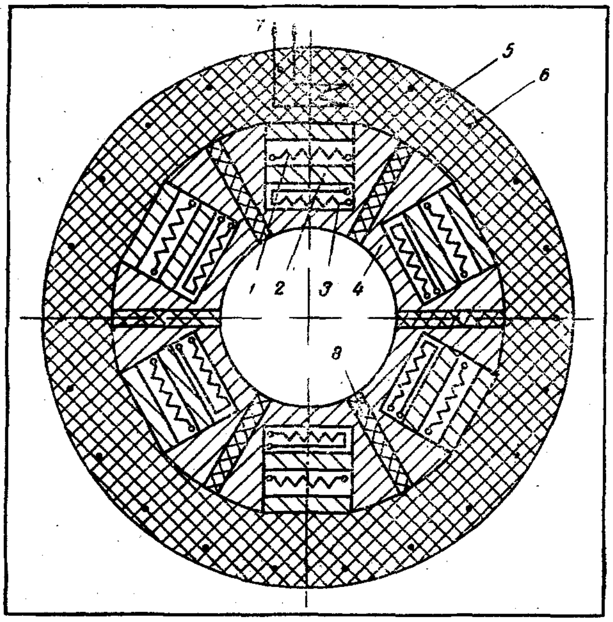

Fig. 1. Thermoelement for the study of local heat exchange: 1) heater; 2) copper plate; 3) resistance thermometer; 4) segment of thermoelement; 5) thermal insulation of pipe; 6) compensating winding; 7) differential Chromel–Copel thermocouple; 8) thermally insulating interlayer.

In certain studies on the heat-exchange process under consideration [3, 4, 6] measurements were made of the local temperature differences Δt between the gas-suspension stream and individual points of the perimeter of the cross section of a pipe of stainless steel with wall thicknesses of 0.36, 0.5, and 6.4 mm, respectively. Then from the measured current strength and the electrical resistance of the pipe* the amount of transferred heat was determined and the sought values of α_l were calculated. In doing this the conductive heat transfer along the pipe wall (in its cross section) was neglected because of the low thermal conductivity of the wall material. Actually, the authors ignored the asymmetry of the heat flux caused by the hydrodynamic structure of the horizontal gas-suspension stream. Nevertheless, the different local temperature differences between points on the surface of the pipe and the gas-suspension stream correspond to different heat fluxes. This indicates the incorrectness of calculating the local heat-exchange coefficients from the total values of the heat flux Q and the pipe surface F:†

$$\alpha_l = \frac{Q}{F\Delta t}. \tag{1}$$

It is more legitimate to calculate α_l on the basis of the local quantity q of heat transferred, taken over the heat-exchange zone f of the surface under consideration:

$$\alpha_l = q/f\Delta t. \tag{2}$$

Of course, in the general case $Q/F \neq q/f$.

---

*The heating was accomplished by the direct passage of an alternating current through the wall of the pipe.

†According to the data of Depew et al. [3] the ratio α_l/α_g is 2.5 times higher for the lower zones of the stream than for the upper zones [glass beads with a diameter $d = 30\ \mu$; $w_{av} = 12$ m/sec; $\mu_f = 7.24$ (kg/h)/(kg/h)]; according to the data of Sukomel et al. [4] this difference is ~10 times [graphite, $d = 65\ \mu$; $w_{av} = 13$ m/sec; $\mu_f = 12.5$ (kg/h)/(kg/h)].

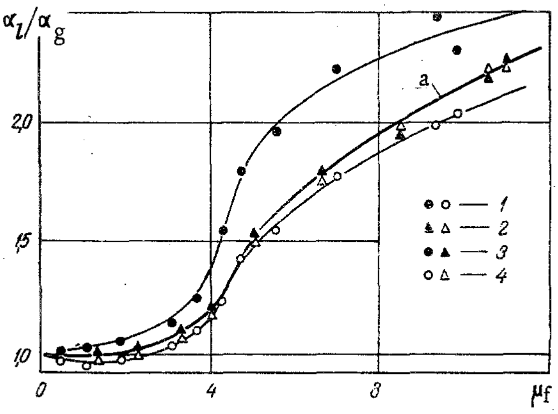

Fig. 2. Intensity of heat exchange along the perimeter of the pipe cross section for a horizontal gas-suspension stream: 1) thermoelement with insulating interlayers; 2) continuous thermoelement; 3) upper zones; 4) lower zones; a) average values of α_l/α_g along perimeter.

To estimate the error in the calculation of local heat-exchange coefficients α_l by Eq. (1) and to obtain the true values of α_l in horizontal gas-suspension streams a special experiment was set up in the range of flow-rate concentrations μ_f = 0.2-12 (kg/h)/(kg/h) at an average air stream velocity w_{av} = 13 m/sec. Quartz sand with an average particle size d_{av} = 0.172 mm was used as the solid material.

The thermoelement was mounted on the dispersal section of a pipe with a diameter of 50 mm and a length of 7 m (at a distance of 1 m from the point of insertion of the solid particles). In the first series of tests it consisted of (Fig. 1) a hollow copper cylinder (length 210 mm and wall thickness 10 mm, inner diameter 50 mm) formed by six segments thermally insulated from each other by interlayers 8 of a mixture of chamotte and asbestos (the thermal conductivity of the wall was 330 kcal/m·h·deg and that of the insulation was 0.2 kcal/m·h·deg). Each segment was heated independently by a Nichrome heater whose power was fixed by a D-533 battery. The temperature of the segments was measured with standard platinum resistance thermometers connected by an MO-47 direct-current bridge. The tests were performed with a heat flux density which was strictly constant and identical for each segment.

In the second series of tests the values of the heat-exchange coefficients were obtained under the same conditions with a thermoelement not divided into separate thermally insulated segments (the interlayers 8 were absent).

The results of the study are presented in Fig. 2 in the form of the dependence $\alpha_l/\alpha_g = f(\mu_f)$. The experimental values of the true heat-exchange coefficients for the upper and lower zones of the stream cross section differ very considerably in the range of tests conducted, clearly indicating the determining role of the structural characteristics of the system. At the same time, the values obtained for the lower and upper zones almost coincide in the case of a continuous thermoelement and are grouped near the average values* for the entire stream (curve a in Fig. 2).

From the data obtained it follows that the conductive heat fluxes along the wall of the pipe in its cross section even out the influence of the various effects and make it difficult to clarify the causal relationships of the phenomenon and the physical model of the process (to a greater extent for pipes of materials of high thermal conductivity). In this connection the quantitative data of the works mentioned above [3, 4, 6] and the character of the distribution of heat-transfer coefficients along the perimeter of the cross section of a gas-suspension stream presented there require correction.

LITERATURE CITED

1. N. I. Gel'perin, V. G. Ainshtein, and L. I. Krupnik, Teor. Osnovy Khim. Tekhnol., 2, No. 4 (1968).
2. N. I. Gel'perin, V. G. Ainshtein, and L. I. Krupnik, Teor. Osnovy Khim. Tekhnol., 2, No. 5 (1968).
3. C. A. Depew and E. K. Cramer, J. Heat Transfer, Trans. ASME, 92, No. 1 (1970).
4. A. S. Sukomel, F. F. Tsvetkov, and R. V. Kerimov, Inzh.-Fiz. Zh., 22, No. 3 (1972).
5. N. I. Gel'perin, V. G. Ainshtein, and L. I. Krupnik, in: Proceedings of the Moscow Institute of Fine Chemical Technology, [in Russian], Vol. 3, No. 1, Mosk. Inst. Tonk. Khim. Tekhnol., Moscow (1973), p. 164.
6. R. Briller and R. L. Peskin, J. Heat Transfer, Trans. ASME, 90, No. 4 (1968).

---

*We note that according to the calculated data the average values of α_l/α_g do not depend on the construction of the test thermoelements.