DETERMINATION OF TRANSPORT POTENTIAL FIELDS IN STREAMS OF COARSELY DISPERSED GAS SUSPENSIONS

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The authors examine a means of describing transport processes in a gas suspension, based on determination of the rate of change of transport potential fields.

Much existing and newly designed power and technological equipment is characterized by processes involving interphase transfer of energy and mass in coarsely dispersed gas suspension flows.

The development of methods for engineering calculations of the size of such equipment presupposes the formulation of laws of space and time variation of transport potential fields (temperature, chemical potential, flux energy).

The considerable complications stemming from the multiplicity of variations and the inadequate study of the component processes are evidenced in the given case by the variety of methodological systems [1–4]. We may also remark upon the basic difficulty of maintaining the invariance during modeling [4].

We will consider a gas suspension stream to be a quasi-homogeneous medium with distributed sources or sinks. Reconstruction of the fields of potentials Θ_i in the stream of fluid is a consequence of interaction with the disperse phase from time $\tau = 0$. The initial conditions are therefore characterized by a definite distribution of transport potentials, depending on the flow prehistory and on the conditions of thermal and technical coupling:

$$\Theta_i = f(x, y, z, \tau). \tag{1}$$

A special case of initial conditions may be Θ_i = const, i.e., an equilibrium condition of the stream.

When a disperse phase is introduced into the stream (liquid drops or solid particles), a reconstruction of the potential fields begins, this being a relaxation process.

The rate of reconstruction (relaxation rate) is determined by the intensity of transfer in the stream, which is a system tending towards a new equilibrium condition.

The time required to create the new equilibrium state depends on the transfer coefficients in the stream, as well as on the degree of the original (at $\tau = 0$) deviation of values of Θ_i from the equilibrium value when the disperse phase was introduced. This deviation is determined by the power of the sources or sinks, i.e., by the sizes (and the size distribution) of particles of the disperse phase, the motive force of interphase transfer, and the rate of internal reconstruction of the potential fields in the particle volume. This last is described by the Biot number $\mathrm{Bi}_{q(m)} = \alpha_{q(m)} d/\lambda_{q(m)}$.

To accelerate the reconstruction of the potential fields we must try to reduce $\mathrm{Bi}_{q(m)}$, and also to create conditions for more intense transfer in the disperse medium. Considering the gas suspension to be quasi-homogeneous, the flux of the corresponding substance may be written as

$$Q_{q(m)} = \int_0^\tau \int_V \frac{\partial \Theta_i}{\partial \tau} C_{q(m)} \rho \, dV d\tau, \tag{2}$$

where

$$\frac{D\Theta_i}{d\tau} = \frac{1}{C_{q(m)}\rho} \operatorname{div}(\lambda \operatorname{grad} \Theta) + \frac{\omega}{C_{q(m)}\rho}. \tag{3}$$

In cases where there is a notable interaction of transport processes, we insert ahead of the division sign a linear relation containing terms taking interaction into account [5].

In order to analyze a system of transfer equations of type (3) together with the boundary conditions, without knowledge of the kinetic coefficients, we require to know the specific relations

$$\omega = \omega(x, y, z, \tau). \tag{4}$$

Of course, the determination of the general or particular solutions of the system is appreciably simplified for one-dimensional cases, and even more so for stationary (or quasi-stationary) cases. This occurs, for example, in the investigation of the steady-state regimes of ideal expulsion equipment [6].

In some cases a theoretical determination of the form of relation (4) is possible. This may be done comparatively simply for cases of "dry" heat transfer, if $\mathrm{Bi}_q < 0.1$ and we neglect interaction and mixing of the particles.

However, experimental determination of (4) is more likely to be required. This applies especially to cases of transfer in gas suspensions, complicated by physical and chemical and by structural and mechanical transformations. We have in mind, for example, the case of spray drying, accompanied by formation of dry particles, by the complex kinetics of evaporation and heating of drops. For the experimental determination of transport potential fields in gas suspension streams, the methods developed at the Moscow Power Engineering Institute [9–11] may prove useful, as well as the well-known methods [7, 8].

The proposed method of determining the mean temperatures of particles or drops is based on sealization of the compensation principle for a through-flow differential calorimeter (Fig. 1). The calorimeter consists of a channel 1 along which a heat transfer agent

3 is caused to flow, this being chemically inert with respect to the substance of the particles or drops. The heat transfer agent is introduced into the channel through the tube 4 and removed through tube 8. By means of measurements of temperatures T_1 and T_2, a determination is made of the minimum disturbance introduced into the stream by the moving particles or drops. The desired temperature is assumed to be equal to the mean temperature in the section of the calorimeter channel between T_1 and T_2. For measurement of the temperature of the stream, the motion of which is produced by a blower 5, a heater 6 and a mixing device 7 are provided. The sizes of the channel 1, the inlet aperture 2, the flowrate of liquid, and the thickness of the insulator may be determined by ordinary balance calculations.

For measurement of the temperature of the gas stream in cases when protection of the temperature sensors from the action of particles or drops with the aid of inertial systems, grids, etc., proved ineffective, the following method of measurement is recommended.

The basis of the method is the principle of minimization of the disturbance introduced into the temperature field of the stream being analyzed due to jets of the variable temperature control stream.

A variant of the basic scheme is shown in Fig. 2. A stream whose temperature may be varied with the aid of heater 4 or mixer 5 is injected through tube 1 into the stream under examination, which is confined by the walls, the variable stream being driven through tube 3 by blower 2. Inside the tube is located a temperature sensor (e.g., a thermocouple) to measure T_1. In addition, outside the tube there are sensors T_2 and T_3, T_3 being outside the influence of the control jet stream, while T_2 is washed by the jet. With the objective of minimizing the influence of control stream humidity on the readings of T_2 and T_3, the sensors were continuously washed with a nonaqueous liquid (e.g., toluene) to remove any particles (or drops) adhering to their surfaces.

The initial velocity of the control stream jet should be about equal in magnitude to that of the stream being examined and is determined by two main considerations:

1) The dynamic action of the jet on the structure of the main stream must be a minimum.

2) The flowrate of the control stream must produce measurable temperature differences in the immediate vicinity of the tube, with negligibly different control and main stream temperatures.

The minimum value of the measurable difference of the readings of the sensors T_1 and T_2 corresponds to equal stream temperatures. The temperature of the control stream, measured at that time with the aid of T_1, is equal to the desired temperature of the main stream, this being a mean for the volume immediately adjoining the tube.

The elements of the equipment must be specially designed for each specific case, as a function of the level of the measured temperatures, the velocities of the streams, the corrosive properties of the medium, etc.

For measurement of the mean velocities of drops (or particles) a method is suggested which is based on the use of a moving trap, equipped with a high-speed shutter and with its inlet aperture facing the drops (or particles). The axis of the trap is located along the direction in which the velocity is determined. The trap is traversed by a special drive mechanism, whereby, during motion toward the drops (or particles) being caught, its inlet aperture is open, and during progress in the reverse direction—it is closed. The measured weight of particles precipitated in the trap when at rest is less than the weight of particles caught when the trap is moving toward the particles, by the same factor as the velocity of the particles is less than the sum of the velocities of the particles and the velocity imparted to the trap, i.e.,

$$G'/G'' = v_p/(v_p + v_t). \qquad (5)$$

Hence the desired value v_p is determined.

For rapid wide measurement of the size spectra of drops of a dispersed liquid, a fast method is recommended, based on the fact that the kinetics of evaporation of a drop lying on a solid lyophobic surface, other conditions being equal, is uniquely determined by the initial drop size.

Implementation of the method amounts to analysis of the evaporation curve of the sample of polydisperse drops being studied on the basis of laws established by calculation or by previous calibration for evaporation of individual drops of the disperse liquid under examination. An analysis is effected in a similar way by treatment of the precipitation curves in a sediment measuring method [12].

All the above-mentioned methods of measurement have been tested at the Moscow Power Engineering Institute, and their basic feasibility has been proved. They are currently being investigated with the object of evaluating accuracy, constructional design features, and areas of application.

The mean temperature values of the phases that have been found, and their relative rates and dispersion, allow an estimate to be made, for each region of space, of the intensity of the mass source and the heat sink.

If the particle size distribution is known, then, from a knowledge of the dependence of the drying kinetics of an individual particle, the temperature, and the particle velocity on the size, we may obtain some idea of the distribution in the region of space studied, of sources and sinks, when there is an experimentally established law of distribution according to size and to mean values of temperature, velocity, and concentration. The specific nature of such dependences on the size of the particles or drops is determined for various disperse systems by the relations given, for example, in [3, 8].

The experimentally determined values of the mean temperature and velocity of all phases, for known laws of size distribution of drops (or particles) for various sections of the stream, permit a quantitative

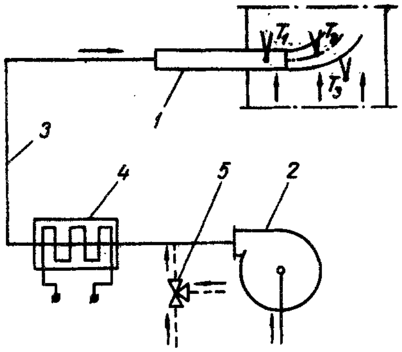

Fig. 1. Scheme for measurement of mean temperatures of drops or particles.

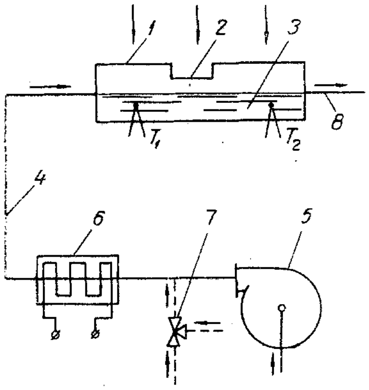

Fig. 2. Scheme for measurement of temperature of a stream containing particles or drops.

definition of the field of heat sinks in gas suspension flows. In addition, measurements may be made of the mean concentration fields for determination of mass source fields.

To do this it is necessary to refine the kinetic relations of heat and mass transfer, the laws of motion of individual drops and particles, and also the special features of the influence of the combination of a multitude of drops and particles. The discrete picture of the distribution of potentials, sources, and sinks may be replaced by a continuous one.

A generalization of experimental data regarding the development of local processes in equipment (transfer in atomizer jets, in jets, in streams, etc.) is basic to the design of the equipment as a whole. The use of new methods of measurement of the parameters of gas suspension flows, as well as the inclusion in the theoretical analysis of the principle of distributed parameters [13] and of a unified system of transfer equations [14], determine the methodological differences of the proposed complex treatment. In this case it is worthwhile to be able to use a combination of the measured mean values in analysis, generalization, modeling, and calculation. It may be possible to include successfully the theory of nonstationary transfer [14].

The task of experimental investigations of interphase transfer in this regard is the acculation and generalization of experimental material to describe the laws of action of sources and sinks.

We have in mind the determination of the rate of external transfer between particles and a stream, as a function of the size, composition, velocity, and nature of motion and concentration of the particles and of the parameters of the stream.

NOTATION:

Θ_i—transfer potential of i-th species; τ—time; $\alpha_{q(m)}$—coefficient of external heat (q) or mass (m) transfer; d—characteristic dimension of particles; $\lambda_{q(m)}$—coefficient of heat (q) or mass (m) conductivity; $C_{q(m)}$—heat (q) or mass (m) capacity; ρ—density; ω—power of source or sink; G' and G''—respectively, weights of drops or particles deposited in the motionless and moving trap; v_p, v_t—linear velocities of particles and trap.

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