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AN APPROACH TO THE DESIGN CALCULATION OF CONTACT HEAT EXCHANGERS OPERATING IN THE REGIME OF COMPLETE EVAPORATION OF A SPRAYING LIQUID

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A calculation technique for contact heat exchangers operating in the regime of complete evaporation is proposed that employs two basic approaches to solution of the problem on evaporative cooling of gases. The first approach is based on balance equations, and the second on determination of local parameters of the process.

The cooling of gases due to complete evaporation of a spraying liquid is of importance for a whole number of technological processes concerned with gas cleaning. First of all, these are cooling and moistening of gases in systems of dry cleaning of suspended particles prior to entering electric filters and bag filters, whose reliable operation is determined to a considerable degree by the temperature of the gases being cleaned (usually not higher than 150–200°C) and their moisture content (in trapping of high-resistance dust in electric filters). Recently, so-called "semidry absorption," in which the gas components are absorbed by suspended particles at temperatures of the gases being cleaned that approach the dew point, has come to the forefront in systems for cleaning gases of harmful gas components (e.g., SO_2). However, in this case, preliminary cooling and moistening of gases by complete evaporation of a spraying liquid play a decisive role as well.

Despite the seeming simplicity, evaporative cooling of gases represents a rather complicated problem in practice and, moreover, sometimes one fails to achieve it at all. This is mainly associated with the fact that a process of evaporative cooling that proceeds at an insignificant temperature potential (usually the initial temperatures of the cooled gases do not exceed 300–350°C) needs a considerable length of the working zone of the contact heat exchanger, the absence of which leads to incompleteness of the process and, as a result, to carry-over of liquid spray. The process slows down its rate especially at the final stage, when the differences in the gaseous and liquid phases that determine its course become smaller. Therefore, in the context of practice the process of evaporative cooling must be carried out with allowance for the parameters of the cooled gas flow really attained at the outlet of the contact heat exchanger.

Moreover, it is necessary to account for side phenomena that affect adversely the process of evaporative cooling. These include possible contact of the spraying liquid with suspended particles and, as a consequence, formation of dust sedimentation and fall-out of some droplets onto the internal surfaces of the heat exchanger, whereupon complete evaporation is hard to attain.

In developing the design technique, we have employed two basic approaches to the solution of the problem of evaporative cooling of gases. The first approach is based on balance equations characterizing the total amount of heat and mass transferred from one medium to another, the values of boundary parameters of heat and mass transfer, and coefficients of heat and mass transfer determined from empirical (dimensionless) relations. The second approach is based on determination of local parameters of the process in a heat exchanger, i.e., it accounts for the change in the moisture content of the gas flow, temperature, flow velocity, and mass of the media with time upon contact of the latter.

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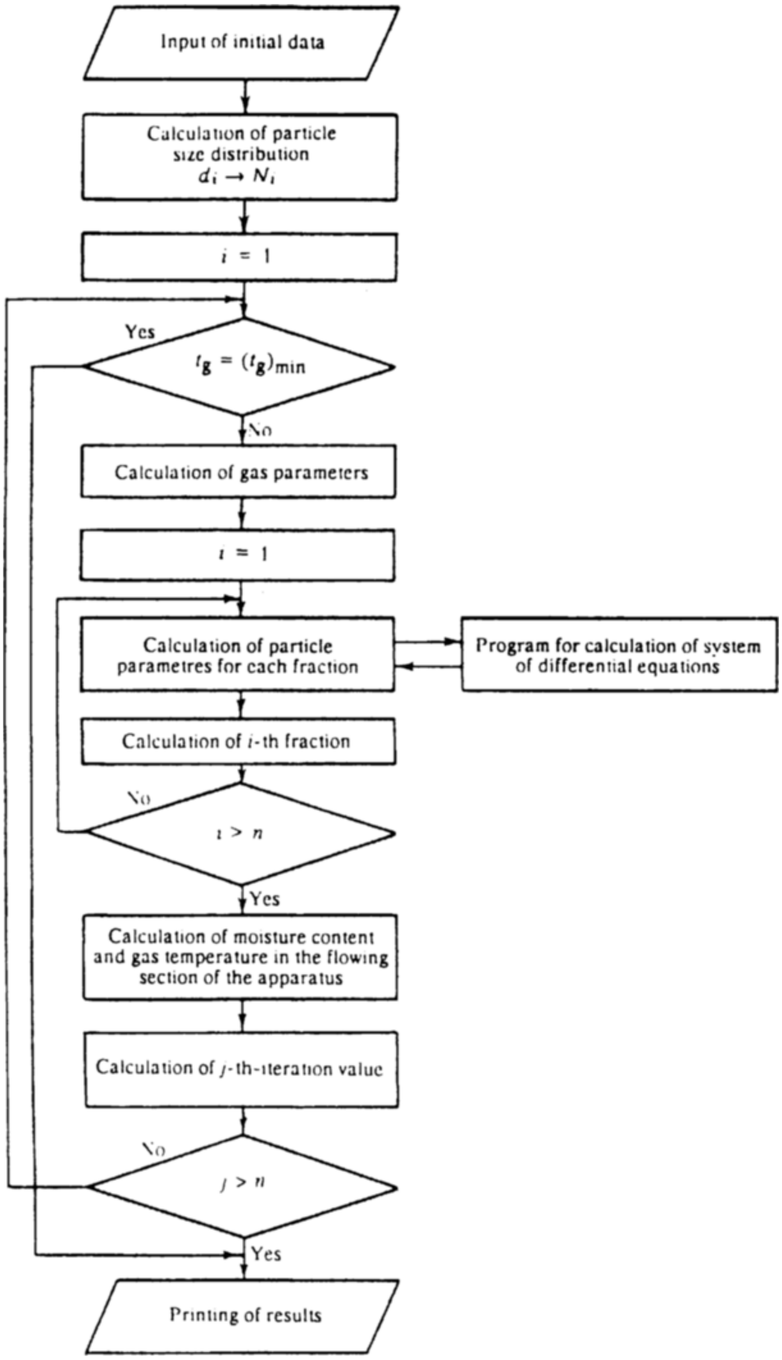

Fig. 1. Block diagram for calculating the evaporative cooling process in a contact heat exchanger.

The balance equations allow determination of the flow rate of the spraying liquid necessary for reaching the prescribed temperature and moisture characteristics of the gas flow at the outlet of the contact heat exchanger. In this case, the possibility of implementation of the regime of complete evaporation can be established by an empirical equation [1] obtained by generalizing numerous industrial and laboratory data that characterize the operation of contact heat exchangers in a wide range of the parameters of the gas flow. As contact heat exchangers, use has been made, as generally adopted in practice, of scrubbers of different constructions (hollow and plate-type scrubbers, an impingement scrubber, a scrubber with a converging supply of gases, etc.).

Provided the spraying liquid is completely evaporated in the apparatus, the equation given in [1] can be reduced to the form

$$m - 1.46 \cdot 10^{-4} (i_s - m c_{liq} \Delta t_{liq})^{1.072} + x' = 0 ,$$

which allows determination of the specific spraying and the minimum possible gas temperature at the apparatus outlet

$$(t_g)_{min} = \frac{i_{m.g} + c_{liq} (x'' - x') \, t_{liq} - 2.943 x''}{c_g + 1.97 x''} .$$

In deriving the equation of [1] it has been assumed that the outlet parameters of the gas flow are mainly affected by the initial "gas–liquid" system. The disperse composition of the droplets evaporating in the contact heat exchanger has not been practically taken into account. Such an approach is motivated by the fact that in the scrubbers utilized in practice the liquid spray is of a polydisperse nature whose characteristics (median diameter and droplet dispersion) are rather similar. However, subsequent analysis has shown that the median droplet diameter in the scrubbers discussed in [1] varies from 60 to 600 μm, i.e., the median droplet diameter can differ by an order of magnitude. This circumstance has obviously influenced the scatter of experimental data observed in deriving the equation. The deviation of individual results of an experiment from the empirical curve was up to 25%.

This has been confirmed by further investigations. For instance, on a laboratory bench with low-pressure pneumatic nozzles (with a median droplet diameter of 15–20 μm) at an initial dew point of 37^{o}C a final moisture content of 0.052 kg/kg of dry gas, instead of the predicted value 0.03 kg/kg, has been obtained.

It is necessary to emphasize that the empirical equation of [1] characterizes operation of well-known designs of apparatuses having a limited volume (definite overall dimensions) and, therefore, a fixed residence time of the gas–liquid flow in it. These apparatuses were originally developed for cleaning of gases of suspended particles, in which the governing mechanism of sedimentation is an inertia one and the role of the process time is insignificant.

The first approach has proved itself in practice from the engineering viewpoint since it has allowed a sufficiently accurate evaluation of the potentialities of existing contact heat exchangers when they are used as the complete-evaporation apparatuses.

The method has been implemented in practice in conditioning flue gases before entering the electric filters in a thermal power station [2].

The method based on an analysis of local parameters of the evaporative cooling process makes it possible to determine the main geometric dimensions of an apparatus with allowance for the sprayers used and the initial parameters of the gas–liquid flow. The local parameters are calculated by solving simultaneously the equations that describe the motion of liquid droplets in a gas flow and their heat-mass exchange with the medium, provided that for the time interval Δt_{min} (which is prescribed) the process is assumed to be quasistationary.

In developing the mathematical model the following assumptions were made:

- droplets with the same initial diameter (d_d = idem) move with the same velocities along identical trajectories;
- on passing through the analyzed apparatus volume, the droplet dimensions, temperature, velocity, etc. remain unchanged; these parameters change jumpwise in passing from one volume to another;
- the possibility of droplet coalescence and fragmentation is excluded.

The motion of the droplets is considered in a two-dimensional coordinate system, which is sufficient for characterization of cylindrical volumes inherent to contact heat exchangers. Parameters of the polydisperse droplet flow are calculated in fractions. In determining the thermophysical parameters of a gas flow the additivity principle is adopted. The change in the moisture content of a gas is the total change in the gas due to evaporation of each fraction of the droplets for the same time interval.

The calculation made by the iteration technique is completed on reaching the temperature $(t_g)_{min}$ ± (where ε is the prescribed accuracy of the calculation).

The block diagram for solving the formulated problem (Fig. 1) allows determination of the length of th working section of a heat exchanger in which the evaporative cooling of a gas proceeds.

Use of the two mutually supplementing approaches has made it possible to obtain a design technique tha has been implemented successfully in developing a number of processes of evaporative cooling in gas-cleanin systems. In particular, a design of a reactor-activator for "semidry absorption" of sulfur oxides has been developec

NOTATION

c_g, c_{liq}, specific mass heat capacity of the gas and the liquid, respectively, kJ/(kg·K); $i_{m.g}$, initial enthalp of the moist gas, kJ/kg of dry gas; i_s, initial enthalpy of the gas–liquid system, kJ/kg of dry gas; m, mass flo rate ratio of the liquid and the gas, kg/kg of dry gas; d_i, droplets diameter of the i-th fraction; N_i, number o droplets; $(t_g)_{min}$, minimum possible gas temperature at the oulet of the heat exchanger, °C; t_{liq}, liquid temperatur at the inlet of the heat exchanger, °C; Δt_{liq}, change in the liquid temperature in the heat exchanger, °C; x', x'' moisture content of the gas at the heat exchanger inlet and outlet, respectively, kg/kg of a dry gas.

REFERENCES

1. N. M. Savitskaya, A. Yu. Val'dberg, and É. Ya. Tarat, Inzh.-Fiz. Zh., 26, No. 2, 353-356 (1979).
2. A. A. Rusanov (ed.), Handbook on Dust and Ash Trapping [in Russian], Moscow (1983).