EFFECT OF SPECIFIC ENTHALPY OF GAS—LIQUID SYSTEM ON FINAL MOISTURE CONTENT OF GAS IN CONTACT EXCHANGERS

N. M. Savitskaya, A. Yu. Val'dberg,
and É. Ya. Tarat

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Evaporative cooling in contact heat exchangers is investigated. A relation between the final moisture content of the gases and the specific enthalpy of the gas—liquid system is obtained.

In gas-purifying systems precooling and moistening of the gases before they enter the apparatus for thorough purification are very often affected by contact heat exchangers in which the technological gases are moistened by a liquid sprayed on by some method or other. For the design of these exchangers it is necessary to know the possible increase in moisture content of the gases, which provides an indirect estimate of the degree of cooling of the gases in these devices. The increase in moisture content depends on a whole series of parameters of the gas—liquid system (the temperatures of the gases and liquid, the initial moisture content of the gases, the size of the evaporating drops, the velocity of the gases in the apparatus, and so on). This quantity can be determined theoretically by means of known semiempirical equations for the drop evaporation rate. Such a calculation, however, is fairly difficult and requires specification of the conditions of evaporative cooling — the residence time of the liquid drops in the apparatus.

From conducted experiments we tried to establish a simple correlation for calculation of the final moisture content of a gas in contact heat exchangers from the initial thermophysical parameters of the gas and liquid. As experimental models, we used a scrubber with a convergent entrance duct [1] and a cavity scrubber with mechanical and pneumatic sprayers. We also used known experimental heat-transfer data for a foam apparatus with grid plates [2], a tube evaporator [3], a spraying absorber [4], and a self-regulating "rotoclone" gas washer [5].*

Neglecting the heat loss to the surroundings and taking into account the heating (or cooling†) of the liquid from the initial temperature to the temperature of equilibrium evaporation, called the wet-bulb temperature, we can regard the evaporative cooling of the hot gases in contact heat exchangers, to a final temperature above the dew point, as adiabatic evaporation [6].

In the considered evaporative cooling process the increase in moisture content of the gases will depend on the thermodynamic potential of the gas—liquid system, which in this case when $\Delta Q = 0$ and $P = \text{const}$ is the enthalpy of the system [7].

Evaporative cooling of gases to temperatures above the dew point can be regarded as an isoenthalpic process if the slight change in enthalpy of the moist gas due to heating or cooling of the liquid is ignored. In this case one can expect that the change in moisture content of the gas flow will depend on the initial moisture content and specific enthalpy of the moist gas, determined for the initial parameters of the system with a correction for the change in enthalpy of the liquid when the temperature changes from the initial temperature to the wet-bulb temperature.

The results of experimental investigations were treated in the form of a correlation between the final moisture content of the gases and the specific enthalpy of the system, de-

*The results of investigation of heat transfer in the rotoclone were obtained by Yu. F. Sarzhant.
†Cooling of the liquid occurs in the case where its initial temperature is above the wet-bulb temperature.

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fined in the following way:

$$i_{syst} = i_{vgm} \pm i_l\, m. \tag{1}$$

The values of the unknown parameters A and b of the correlation

$$d = A i_{syst}^{b} \tag{2}$$

were determined by the usual methods of regression analysis. Figure 1 shows, in double logarithmic coordinates, the results of laboratory and industrial investigations of heat transfer in contact heat exchangers of the above-mentioned types and two empirical correlation curves with equations of the form

$$d = 1.348 \cdot 10^{-4} i_{syst}^{1.085}, \tag{3}$$

$$d = 1.462 \cdot 10^{-4} i_{syst}^{1.072}. \tag{4}$$

The first equation was obtained from the results of investigations of heat transfer in a plant and pilot-plant scrubber with a convergent entrance duct and a laboratory cavity scrubber (curve 1, sample size 50 points). To determine the parameters of relation (4) we also used the results of plant and laboratory investigations of other authors (curve II, sample size 125 points). These two curves practically coincide.

In addition to the usual regression analysis we made a statistical estimate of the deviations of the individual results of the experimental investigation from the empirical correlation curve (4). The most accurate and mathematically correct method of estimating the deviations of individual points from the empirical regression line is the method of constructing the so-called permissible or tolerance limits for prescribed values of the fiducial probability and confidence coefficient [8, 9].

One-sided confidence limits can be used to determine the "safe" values of the initial specific enthalpy of the gas–liquid system for which the final moisture content in each case is not less than a prescribed fixed level (with some prescribed fiducial probability).

Figure 1 shows the lower confidence limit (curve III), constructed from the 90% fiducial probability and confidence coefficient equal to 99%. This method of constructing the lower tolerance limit can be used to assess the reliability of the obtained values of the final moisture content (d) of the gases in contact heat exchangers in relation to the initial specific enthalpy of the gas–liquid system (i_{syst}) from Eq. (4).

For instance, for an initial specific enthalpy of the system equal to 600 kJ/kg of dry gas the final moisture content of the gases in the apparatus will be 140 g/kg of dry gas [from (4)]. This value is determined with a probability of 50% (correlation curve II), and from curve III the value of d for the same value of i_{syst}, determined with probability 90%, will be 90 g/kg of dry gas; i.e., out of 100 measurements of d this value was less than 90 g/kg of dry gas in only ten cases.

Figure 1 shows the experimental points 10 and 11 which were not included in the determination of the unknown parameters of the correlation and in the construction of the lower confidence limit. Point 10 was obtained in an investigation of evaporative cooling of gases in the gas-duct cooler in the Novo-Yaroslavl Carbon Black Factory [10], and point 11 was obtained in an investigation of gas cooling in a laboratory scrubber with floating packing.* These points do not lie outside the lower confidence limit, which confirms the reliability of the obtained correlation between the final moisture content of gases in contact heat exchangers and the specific enthalpy of the system.

The obtained relation, in conjunction with the initial parameters of evaporative cooling, allows simultaneous determination of the boundary conditions of heat transfer in contact heat exchangers when the latter are used for partial evaporation.

NOTATION

i_{syst}, enthalpy of gas–liquid system in initial conditions of process; i_{vgm}, enthalpy of gas–vapor mixture; i_l, change in liquid enthalpy due to heating or cooling from initial

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*The data were obtained by V. M. Kotov.

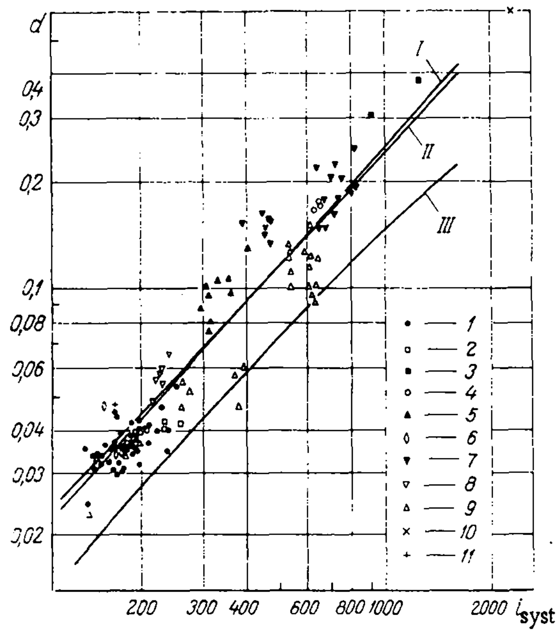

Fig. 1. Correlation between final moisture content d (kg of vapor/kg of dry gas) in contact heat exchangers and initial specific enthalpy of gas—liquid system i_{syst} (kJ/kg of dry gas): 1) Apparatus with grid plates [2]; 2) rotoclone; 3) tube evaporator [3]; 4) model scrubber with convergent entrance duct installed in the Crimean Titanium Oxide Factory; 5) spray absorber [4]; 6) laboratory cavity scrubber with low-pressure pneumatic sprayer; 7) scrubber with convergent entrance duct installed in pilot plant of Engineering Institute; 8) laboratory cavity scrubber with mechanical sprayers; 9) scrubber with convergent entrance duct installed in Moscow Factory for Industrial Sanitary Products; 10) gas-duct cooler in gas purification system in Novo-Yaroslavl Carbon Black Factory [10]; 11) laboratory scrubber with floating packing.

temperature to final temperature or to wet-bulb temperature; m, ratio of liquid mass flow rate to gas mass flow rate; d, final gas moisture content.

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