HEAT AND MASS EXCHANGE IN COOLING OF SATURATED VAPOR – GAS MIXTURES

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Results of experimental investigation of cooling of saturated mixtures are described. On the basis of these are derived relationships for calculating the complete quantity of transferred heat by means of modified equations of heat and mass exchange.

In cooling of a saturated vapor–gas mixture the transfer of heat is dependent on both "dry" cooling and condensation of vapors, in which its quantitative proportion depends on the temperature of the mixture.

The coefficient of heat transfer, calculated from the heat of condensation, depends on the temperature of the mixture. At t_{mix} = 40 to 80°C the basic quantity of heat (80-95%) is transferred by condensation, and hence together with calculation for heat exchange it is possible to calculate the process for mass exchange.

It is shown in [3] that it is useful to carry out calculation of the total quantity of heat rejected by cooling of a saturated mixture using modified equations of heat and mass exchange which have the following form:

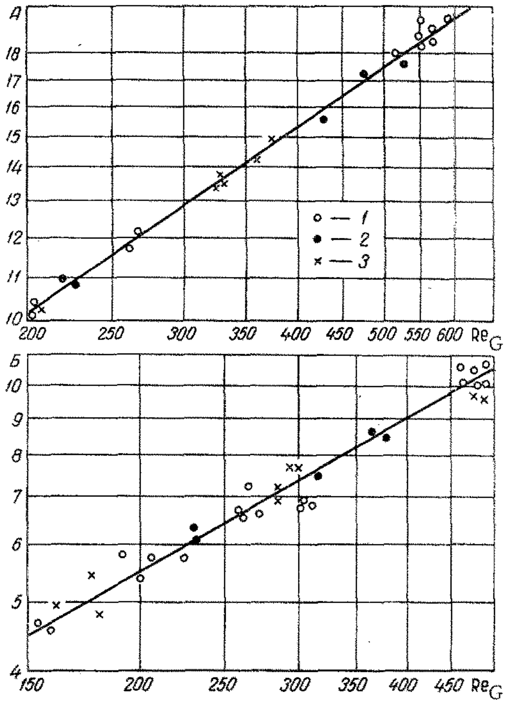

Fig. 1. The relationship between A = $\text{Nu}^*/(1+\xi X_{\text{me}}^{0.55})\text{P}_{\text{r}}^{0.33}$ and B = $\text{Nu}_D^*/(1+1/0.9\cdot 10^{-2}\,\xi X_{\text{me}}^{0.8})\text{Pr}_D^{0.33}$ and Re_G: 1) X_{me} = 0.05 0.06, 2) 0.011 to 0.013, 3) 0.18 to 0.20.

in calculating heat exchange

$$\text{Nu}^* = \frac{\alpha^* d_{\text{e}}}{\lambda_{\text{r}}} = C\,\text{Re}_G^n \text{Re}_{\text{li}}^m (1 + \xi X_{\text{me}}^p)\,\text{Pr}^q, \tag{1}$$

in calculating mass exchange

$$\text{Nu}_D^* = \frac{\beta^* d_{\text{e}}}{\delta} = C_1 \text{Re}_G^{n_1} \text{Re}_{\text{li}}^{m_1} \left(1 + \frac{1}{\xi X_{\text{me}}^{p_1}}\right) \text{Pr}_D^{q_1}\,. \tag{2}$$

In calculating (1), additional heat of mass exchange is taken into account by the second component in the brackets ($\xi X_{\text{me}}^{\text{p}}$), and in the equation (2) the magnitude ($1/\xi X_{\text{me}}^{\text{p}_1}$) takes into account the additional heat of dry cooling.

The advantage of equation (2) is that the magnitude of the correction factor in the brackets depends significantly less on the temperature of the mixture. Hence by varying the temperature from 80 to 30°C the magnitude ($1 + \xi X_{\text{me}}$) varies from 20.1 to 3.2 while the value of ($1 + [1/\xi X_{\text{me}}]$) varies from 1.052 to 1.34.

The experimental investigation was carried out in order to verify the possibility of describing the processes of heat and mass exchange in cooling of saturated mixtures by means of equations (1), and (2).

The experimental apparatus had a column of diameter 1100 mm, filled with Raschig rings of dimensions 25 × 25 × 3 mm. The column was separated into a lower and upper part in each of which were arranged spray collectors. The

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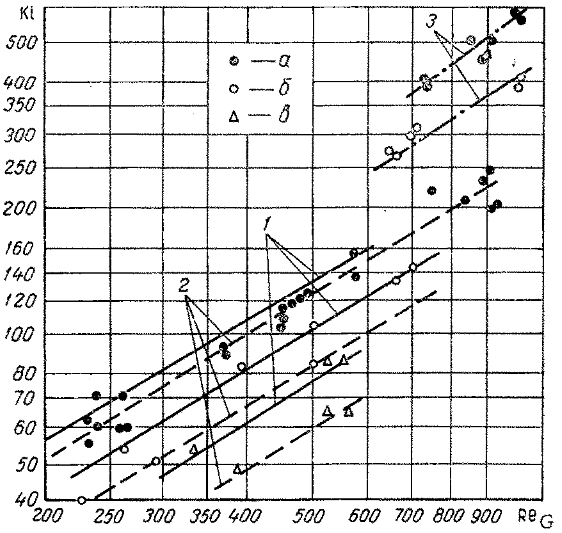

Fig. 2

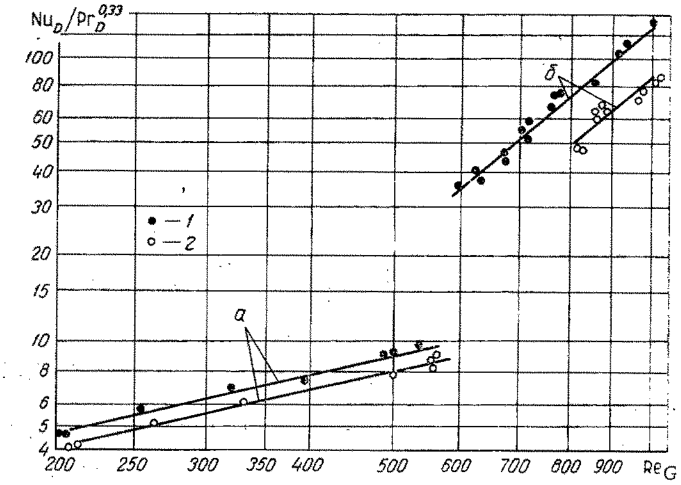

Fig. 3

Fig. 2. Comparison of experimental data of heat exchange in cooling of saturated mixtures: a) $p_1'' = 0.5$ atmospheres, b) 0.4, c) 0.3; 1) data from the present work, 2) data [1]. 3) data [3].

Fig. 3. Comparison of data of mass exchange in cooling of saturated mixtures 1) $X_{me} = 0.05$ to 0.06, 2) $X_{me} = 0.18$ to 0.30; a) data of the present work, b) data [3].

TABLE 1. Design Data of the Experimental Apparatus and the Experimental Conditions

Diameter of the column, mm	Dimension of the packing, mm	Height of packing layer, mm	Temperature of the mixture, °C	Initial moisture content, kg/Nm^3 of dry gas
300	Raschig rings 25×25×3	750—1000	50—80	0,10—0,75
257	25×25×3	750—1000	51—90	0,10—1,7
1100	25×25×3	500	55—83	0,11—0,905

Gas flow rate, m/sec	Density of sprinkling, m^3/m^2·h	Re$_G$	Re$_{li}$	Literature reference
0,15—0,70	5—25	200—800	50—350	[1]
0,4—1,13	16—32	550—1100	150—200	[2]
0,19—0,81	5,0—5,15	150—550	60—60	Present work

lower part of the column, which was sprayed with hot water at the temperature of the wet thermometer, was used to prepare the gaseous mixture which is saturated with water vapor. The moisture content is regulated by the water temperature. The saturated mixture was admitted to the upper part of the column where the condensation of the vapors of cold water was carried out.

The basic dimensions of the experimental apparatus and the experimental conditions are given in Table 1.

Experimental results of the heat transfer are shown in Fig. 1.

The data obtained were processed by means of the equation (1) and generalized by the formula

$$\mathrm{Nu}^* = 0.102\,\mathrm{Re}_G^{0.52}\,\mathrm{Pr}^{0.33}(1 + \xi X_{me}^{0.55}). \quad (3)$$

Analogous data for mass transfer are described by the equation

$$\mathrm{Nu}_D^* = 0.15\,\mathrm{Re}_G^{0.7}\,\mathrm{Pr}_D^{0.33}\left(1 + \frac{1}{0.9\cdot 10^{-2}\xi X_{me}^{0.80}}\right). \qquad (4)$$

The equations (3) and (4) are obtained by the density of sprinkling which is $L = 5\ \mathrm{m}^3/\mathrm{m}^2\cdot\mathrm{h}$.

Comparison of experimental data for heat and mass transfer obtained in the present work with those of [1, 2] is shown in Figs. 2, and 3. Here comparison data were reduced to unit sprinkling by means of a correction factor (2).

The observed discrepancy between experimental data [1] and the present work is explained by two circumstances: the first is the higher efficiency of the distribution of the liquid by sprayers in relation to jet sprinkling which was used in experiments [1]; the second is that with a slightly lower depth of the layer of the packing the process of the heat exchange in the author's experiments included cooling of a richer mixture of vapor.

Data for heat and mass exchange in cooling of saturated mixtures, obtained in the work [3], are placed on the graphs considerably higher (2-3 times) than those of [1] and of the present work. So significant a discrepancy between experimental data can be explained by the fact that in the work [3] higher loading of gas and liquid was observed, ($\mathrm{Re}_G = 600$ to 1100, $\mathrm{Re}_{li} = 400$ to 600), and the regime was almost emulsified.

NOTATION

a	is the thermal diffusivity, m/h;
d_e	is the equivalent packing diameter, m;
I	is the mean gas enthalpy;
ΔI	is the mean difference of enthalpies, kcal/m^3;
k	is the heat transfer coefficient, kcal/m$^2\cdot$°C$\cdot$h;
L	is the density of spraying, m^3/m$^2\cdot$h;
p_i''	is the initial partial pressure of the water vapor in the mixture, abs atm;
w	is the mean gas velocity m/sec;
X_{me}	is the mean moisture content of the gas-vapor boundary layer, kg/m^3 of dry gas;
β	is the mass transfer coefficient, kg/m$^2\cdot$h;
λ_G	is the heat transfer coefficient of gas, kcal/m $\cdot$°C$\cdot$h;
δ	is the diffusivity, kg/m$\cdot$h;
ν_G, ν_{li}	are the gas and liquid viscosities, m^2/h;
ξ	is the coefficient dependent on mixture temperature; its values are: 93 at $t_{mix} = 20$°C and 159 at $t_{mix} = 80$°C;
Ki	is the Kirpichev number;
Nu*	is the heat transfer coefficient calculated by considering the excess heat supplied by mass transfer;
Nu_D^*	is the mass transfer number calculated by considering heat transfer due to mass transfer;
Re_G	is the Reynolds number of the gas;
Re_{li}	is the Reynolds number of the liquid;
Pr	is the thermal Prandtl number of the liquid;
Pr_D	is the diffusion Prandtl number;

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