HEAT EXCHANGE DURING EVAPORATION FROM A FALLING WATER FILM

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Works devoted to the experimental and theoretical study of the heat-exchange coefficient during the evaporation of water in a falling film are briefly surveyed. The results of an estimate of the effect on α of the heat flux, density of flow, etc., are described.

An analysis of works devoted to the study of the heat-exchange coefficient α in falling liquid films [1-14] shows that the data obtained by different authors are contradictory.

Results of the studies of these authors are presented in Fig. 1. It is seen from Fig. 1 that, for water, the heat-exchange coefficient of a falling liquid film increases with increase in the temperature head according to the data of some authors, while it either remains unchanged or decreases according to the data of other investigators. Data on the heat exchange during the evaporation of falling films of different solutions [7-10] are also very contradictory, the dependence $\alpha = f(\Delta t)$ having the same nature as for water.

Most of the papers, except [2, 9], present experimental results obtained on short pipes with $l = 0.7$-2.0 m. Therefore there are not enough data characterizing the variation in α along tall pipes. Were such data available, it would be possible to judge whether results obtained on short pipes may be applied in the design of long-pipe industrial film apparatus and to determine the optimum height of an evaporator.

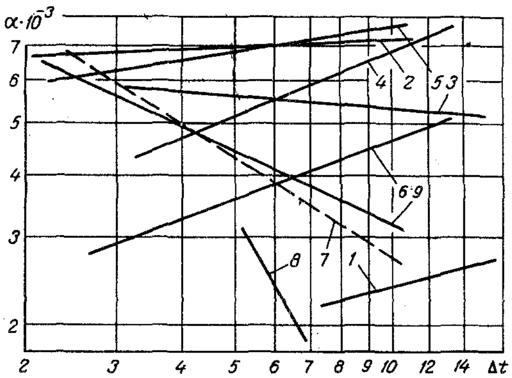

Fig. 1. The dependence $\alpha = f(\Delta t)$ according to the data of various authors: 1) sea water [5], $l = 7.9$ m, G = 1.18-4.7; 2, 3) water [3], G = 0.06-1.03 kg/m·sec, $l = 0.71$ m; 4) water [2], G = 0.156-1.66, $l = 4.9$ m; 5) water [7], $l = 1.2$ m; 6) apple juice [8], $l = 2$ m; 7) distillate, according to author's data G = 3.4, $l = 6$ m; 8) water [10], inclined surface; 9) water [1], $l = 0.6$ m, G = 0.06-0.3 kg/m·sec.

The existing experimental data on α in the evaporation of falling liquid films are insufficient to establish the actual mechanism of the process and to obtain the equations necessary for the design and exploitation of evaporators with falling films in distilling saline water and in chemical, food, and other branches of industry.

The existing theoretical works [4-6, 11, 14, 15] on heat exchange during the evaporation of falling films cannot explain the contradiction in the experimental data on the dependence of α on the temperature head Δt, the flow density G (flow rate of the film), and especially the dependence of α on Δt obtained in some experiments (see Fig. 1, curves 3, 7, 8, and 9, and [13]). Three possible mechanisms of heat transfer to a falling liquid film are examined in [4]. According to mechanism I an analogy between film condensation and the evaporation of liquid in a thin film is used. This mechanism is also used in [6, 11]. An analogous mechanism for heat transfer to a falling liquid film is examined by McAdams [14]. According to mechanism II, also examined in [5], the formation of bubbles in the film is proposed, while according to mechanism III there is a vapor film at the wall–liquid boundary [12].

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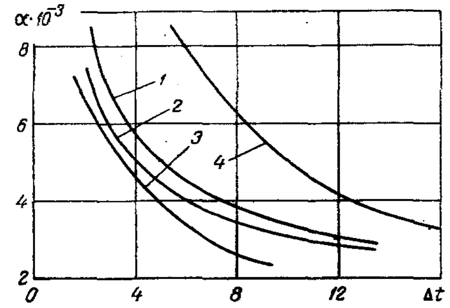

Fig.2

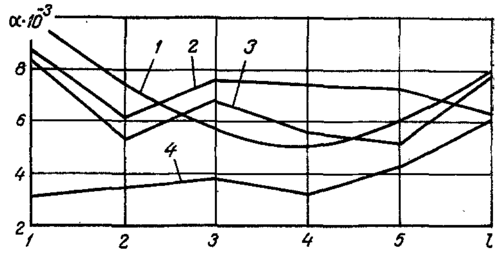

Fig.3

Fig.2. The dependence $\alpha = f(\Delta t)$ according to authors' data: for 6 m pipe: 1) G = 3.4; 2) 2.1; 3) 1.5 kg/m ·sec; for plane surface: 4) G = 0.6 kg/m ·sec.

Fig.3. Variation of heat-exchange coefficient along height of pipe: 1) according to [2], G = 1.1 kg/m ·sec, Δt = 5.2°C. Author's data: 2) G = 2.85 kg/m ·sec, Δt = 1.72°C; 3) 1.5, 1.75; 4) 1.5, 8.0.

T. A. Kolach and I. A. Korchikov [15] assume that heat transfer to a film of bubbling liquid is caused by heat conduction through the film layer with transfer of heat to the vapor bubbles. In general, this model gives an equation identical to that of A. D. Labuntsov for boiling in pipes. However, not one of these mechanisms allows an explanation of the variation in experimental results or the derivation of a mathematical model satisfactorily describing the process. In connection with this there arises the problem of the further study of heat exchange during the evaporation of a falling film, the accumulation of experimental data on the dependence of α on various factors ($q(\Delta t)$, G, l), and on the basis of these data the derivation of equations permitting approximate designs of evaporators having falling liquid films.

The authors of the article conducted a series of experimental studies on the function α during the evaporation of a falling film of distillate. The experiments were conducted on two experimental devices described in [9, 12] having the following working sections: 1) a vertical plane surface of 1Kh18N9T stainless steel 2.5 mm thick, 165 mm wide, and 1000 mm high; 2) a boiler pipe made of 1Kh18N9T stainless steel with outer and inner diameters of 40 and 34 mm and 6 m long.

On the plane surface the experiments were conducted at atmospheric pressure. The flow density varied from 0.1 to 0.8 kg/m ·sec, and the pressure of the heating vapor was 1-2 bar. On the 6 m pipe the experiments were conducted in the range of specific heat fluxes q = 5-45 kW/m^2 and at secondary vapor pressures P = 0.6-1.1 bar. The flow density was 0.65-3.4 kg/m ·sec.

The results of the experiment on the devices are presented in Figs.2 and 3. A study of the dependence of the heat-exchange coefficient on the factors of the experiment shows the significance of the dual correlation of α on Δt and G. This dependence is obtained in the form

$$\alpha = A \Delta t^m G^n.$$

The coefficient A and the exponents m and n were determined using a standard program of treatment of the experimental data on a Razdan-2 computer (A = 5600, m = −0.246, n = 0.04).* The precision of the correlation function (1) is determined by the degree of deviation of the calculated from the actual indices with respect to the Fisher number. For the experiments conducted the Fisher number was determined from tables [13] as a function of a number of secondary observations and the reliability factor and was equal to 2.4. The residual dispersion of the function obtained was equal to 0.03, while the dispersion of the experiment was S^2 = 0.02. $D/S^2 = 1.5 < 2.4$, i.e., there is satisfactory agreement between the calculated and experimental data.

NOTATION

α is the coefficient of heat transfer to the evaporating liquid film, W/m^2·deg;
q is the heat-flux density, kW/m^2;
Δt is the temperature difference between wall and evaporating film, °C;

*The coefficient and exponents were determined by A. A. Legkii.

l	is the length of working section, m;
G	is the density of flow, kg/m · sec;
m, n	are exponents;
A	is a coefficient depending on the thermophysical properties of the liquid;
D	is the residual dispersion;
S	is the dispersion of the experiment.

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