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Specific Features of Change in Surface Temperature of Evaporating Liquid from Hydrodynamic and Temperature-Humidity Conditions

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Abstract: The article deals with the study of the dependence of the surface temperature of evaporating water on hydrodynamic and temperature-humidity conditions. This is especially relevant for practical calculations that occur during the evaporation of a liquid from a free surface of heat and mass transfer processes, as well as for the study of the temperature of the surface of a liquid, is of great importance.

Keywords: temperature conditions, heat and mass transfer, evaporating water, environment, convection.

In the eighties of the last century and further, numerous studies were carried out to study the dependence of the surface temperature of evaporating water on hydrodynamic and temperature-humidity conditions. For practical calculations that occur during the evaporation of a liquid from the free surface of the processes of heat and mass transfer, it is necessary to know the parameters of the temperature of the liquid surface is of great importance. Usually this temperature is unknown, with the exception of the adiabatic evaporation process, in which there is no temperature gradient in the boundary layer of the liquid and the surface temperature is equal to the temperature of the liquid itself (in the absence of radiant heat transfer). In all other cases, the surface temperature of the evaporating liquid differs from the temperature of the liquid itself and depends on a number of factors.

In practice, the following temperature conditions are possible under which liquid evaporation can occur (provided that φ <100%):

a) $t_o > t_n < t_м (t_n > t_{росы})$,

b) $t_c > t_n = t_м$ (adiabatic process),

c) $t_c < t_n > t_{м,}$

d) $t_c = t_n > t_{м,}$ (isothermal process).

In the processes proceeding under the temperature conditions specified in paragraphs (a) and (b), the heat flux is directed from the environment to the surface of the liquid, and in the processes proceeding under the temperature conditions specified in paragraphs (c) and (d) - in the opposite direction (under conditions corresponding to item (d), we mean the transfer of heat with steam).

In all cases of temperature conditions, with the exception of those specified in point (b), a temperature field arises in the boundary layer of water, the nature of which depends on the direction of the heat flow and the intensity of heat and mass transfer.

The results of experimental studies have shown that the surface temperature of an evaporating liquid depends on the direction of the heat flow and the intensity of heat and mass transfer. The latter, in turn, depends on the hygrothermal state of the environment and the hydrodynamic conditions of the process. At the same time, it can be assumed that the temperature of the liquid surface can also be influenced by the determining size and thermal conductivity of the evaporating liquid.

On the basis of experimental studies, the dependence of the temperature of the surface of an evaporating liquid on the hygrothermal and hydrodynamic conditions of the process was established when the heat flow is directed from the surface of the liquid to the environment (the influence of the determining size and thermal conductivity of the evaporating liquid was not considered in these studies). This dependence has the form:

for natural convection conditions

$$\varphi = f_1\left[K, (Ar \cdot Pr)_{усл}\right]; \qquad (1)$$

for forced convection conditions

$$\varphi = f_2\left(Re_{усл,} K\right), \qquad (2)$$

where $\varphi = \frac{t_{ж} - t_п}{t_c - t_м}$ - is a non-determining temperature criterion;

$t_{ж}$- liquid temperature

$t_п$ - is the temperature of the liquid surface;

t_c and $t_м$ - air temperatures on dry and wet thermometers;

$K = \frac{t_c - t_м}{t_{ж} - t_м}$ - defining temperature criterion, taking into account the hygrothermal state of the environment and the temperature of the liquid;

$(Ar \cdot Pr)_{усл}$ - is a generalized criterion that takes into account the hydrodynamic conditions of the process and the physical properties of the environment;

$Re_{усл}$ - Reynolds criterion.

Processing the results of experimental studies made it possible to establish the following power-law form of expressions (1) and (2):

for natural convection conditions

$$\varphi = 0{,}0135 K^{-1{,}5} (Ar \cdot Pr)_{усл}^{0{,}06}, \qquad (3)$$

for forced convection conditions

$$\varphi = 0{,}00615 K^{-0{,}96} R_{усл}^{0.34} \qquad (4)$$

It can be seen from expressions (3) and (4) that hygrothermal environmental conditions have a significant effect on the surface temperature of an evaporating liquid both during natural and forced convection. The influence of hydrodynamic conditions affects differently: if during natural convection it is insignificant, then during forced convection the influence of the hydrodynamic factor becomes quite noticeable.

Using expressions (3) and (4), it is possible to determine the surface temperature of evaporating water for any hydrodynamic and hygrothermal conditions. However, it should be borne in mind that these dependencies refer to the direction of the heat flux from the surface of the liquid to the environment, the working fluid to water and the determining dimension L = 0.21 m.

To date, a generalized dependence has not yet been established that takes into account the influence of the direction of the heat flux and the determining size on the surface temperature of the evaporating liquid, as well as the effect on it of the thermal conductivity of the liquid and some other less significant factors.

It should be noted that due to the lack of data for determining the surface temperature of an evaporating liquid, in practical calculations of heat and mass transfer processes, instead of the surface

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temperature, the temperature of the liquid itself is usually taken, which leads to very significant errors. Since the research was carried out with the determining size of the vessel L = 0.21m, then the use of expressions (3) and (4) to determine the surface temperature of the evaporating liquid with the determining dimensions differing from L = 0.21m, allows us to obtain only its approximate value.

The calculated dependence, based on the solution of the differential equation of the heat balance at the water - air interface and the results of experimental studies, has the following form:

$$t_n = t_{ж} - \frac{ANu'\left(\sqrt{1+\frac{544lБ}{A^2 Nu'_{H}}}-1\right)}{272l} \qquad (5)$$

where: l - defining size, m.

Formula (5) includes parametric complexes A and B:

A=$b\lambda + rmD$

$Б = b\lambda\,(t_{ж} - t_c) + rmD(t_{ж} - t_p)$;

where: λ - is the coefficient of thermal conductivity of air, kcal/m·h·deg;

r - is the latent heat of vaporization, kcal / kg;

m - coefficient of proportionality, kg / m3 · deg;

D - diffusion coefficient, m2 / h

t_k - water temperature in the water column, deg;

$t_п$ - water surface temperature, deg;

t_c - air temperature by dry temperature, deg;

t_p - dew point temperature, deg.

The value of b is taken depending on the hydrodynamic conditions of the process:

at Re<$2\cdot10^4$; Ar·Pr >$2\cdot10^6$ – b = 0,858;

at Re> $2\cdot10^4$; Lo≤ $P_r^{1/3}$- b = 0,89.

The value of the proportionality coefficient m is determined by the ratio

$$m = \frac{c_{n} - c_o}{t_{n} - t_p}, \qquad (6)$$

where $c_п$ and c_o - are the concentration of water vapor above the surface and in the environment, kg/m^3. Since the value of the surface temperature is the desired value, then at the beginning of the calculation it is necessary to roughly set it or, with some assumption, determine the value of m by the formula

$$m \approx \frac{c_{ж} - c_o}{t_{ж} - t_p}, \qquad (7)$$

where $c_ж$ - is the concentration of saturated water vapor corresponding to the temperature in the water column, kg / m3.

On the basis of theoretical studies of the issue under consideration, analyzes were made, and on the basis of the analysis, a curve was constructed that characterizes the dependence of the temperature of

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the liquid surface on the temperature of the liquid itself and other factors. Comparison of the research results with the data obtained on the basis of the above dependences showed their quite satisfactory convergence.

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