Physical and numerical simulation of two-phase flow in the area of mini-channel

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Abstract. The results of physical and numerical modeling to determine the rate of evaporation of ethanol, at a flow of air flow velocities in the range of 0.0139 - 0.139 m/s and temperature in the range of 10 - 45 °C are placed. The time of the establishment of the diffusion equilibrium in the work area and differences in the results of numerical and physical modeling are have determined.

1 Introduction

Currently, there are an increasing number of studies in the field of heat and mass transfer and hydrodynamics of currents in minichannel. There are growing need for installations able to transfer large thermal flows in the limited space and volume. These equipments have a wide range of applications, from compact evaporators and condensers of power devices to cryogenic cooling systems of computer processors.

Not enough studies on the heat-mass transfer when driving two-phase flow in the area of Mini- channels and so often the experimental date are difficult evaluatived and are explaned. To solve these problems the numerical simulation is applied.

The aim of the work is physical and numerical modeling of heat and mass transfer on the surface of a thin liquid film with air stream.

2 Physical modeling

Sufficiently detailed description of the methodology for determining the mass evaporation rate is contained in [1].

Work area (Figure 1) consists of a liquid chamber-term expanse 40 mm and a height of 3 mm and a rectangular gas duct with height of 3 mm, width 40 mm and length 150 mm. The upper wall of the liquid passage - stainless plate with a square neckline 100 mm2 of area , tin which occurs contact of liquid with the gas and formed a local area of evaporation.

We study the dynamics of evaporation of ethanol fixed film (ГОСТ Р 51723-2001) with a thickness of 3 mm at a flow of air. Work area is horizontal with the atmospheric pressure in the circuit. During the experiment, the gas flow rate ис varied ranged from 100 to 1000 ml / min, which corresponds to a gas velocity of 0.0139 to 0.139 m /s. Gas mixture

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flow rate was determined at the outlet of the working area. The experiment was repeated for gas and liquid temperatures ranging from 10 to 45 ° C, respectively.

3 Numerical Simulation

The two-dimensional problem of two-phase flow in the rectangular mini-channel with length L = 120 mm and height H = 3 mm (Figure 1) is investigated. The liquid is in saturation condition, at the saturation pressure determined for a given temperature.

The following assumptions have been taken to solve this problem:

a) Since the gas channel is much greater than its height and width, a flat case is considered.
b) Maximum velocity of the gas in the channel in agreement Re≈100, so it is assumed laminar flow regime.
c) The pressure drop in the channel and the gas velocity are low.
d) Liquid temperature and gas is the same, which excludes the effect of temperature gradient on heat and mass transfer process in the channel.
e) Couples vaporized of fluid not introduce substantial changes to the dynamic of flow, since the density of gas in the mixture is about 9 times higher than the density of the vapor.

From these assumptions, it follows that the gas in the channel profile corresponds to the profile Poiseuille, which is used for modeling the concentration field in the moving medium:

$$\frac{\partial c}{\partial \tau} + u_g(y)\frac{\partial c}{\partial x} = D\left(\frac{\partial^2 c}{\partial x^2} + \frac{\partial^2 c}{\partial y^2}\right), \tag{1}$$

where c - the concentration of the substance, τ - time, c; D - the diffusion coefficient, m^2/s; $u_g(y)$ - distribution of the horizontal component of gas velocity along the channel height, m /s; wherein u_g - averaged over the cross section rate of gas flow.

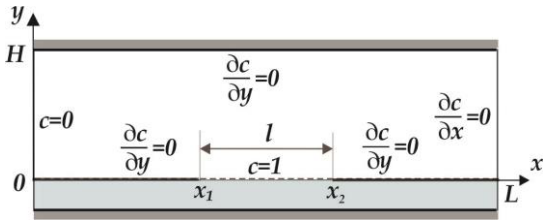

Fig. 1. Schema of simulation area.

At the initial time are believed that the velocity of the gas and liquid vapor concentration is equal to zero:

$$\tau = 0,\ 0 < x < L, 0 < y < H:\ u_g = 0,\ c = 0. \tag{2}$$

It is believed that the gas entering the work area is a clean air:

$$\tau > 0,\ \ x = 0,\ \ 0 < y < H:\ c = 0. \tag{3}$$

On the right edge is believed that the concentration profile and speed profile are installed and there are no further changes of its:

$$\tau > 0, \quad x = 0, \quad 0 < y < H: \ \frac{\partial c}{\partial x} = 0. \tag{4}$$

On the solid boundaries of the channel set impermeability conditions:

$$\tau > 0, \ \left(0 < x < x_1; \ x_2 < x < L, y = 0 \right) \cup \left(0 < x < L, y = H \right): \ \frac{\partial c}{\partial x} = 0. \tag{5}$$

On the border of the "gas – liquid" section relies presence of saturated vapor in volume:

$$\tau > 0, \ y = 0, \ x_1 < x < x_2 : \ c = 1. \tag{5}$$

The differential equation (1) was solved by the sweep method for implicit scheme with second-order approximation in space.

4 Analysis of the results

Figure 2 shows how the rate of evaporation of the liquid is changed over time in numerical modeling. Parish mass due to evaporation of the liquid from the gas-liquid interface per unit time is denoted as J_1, the mass of the evaporated liquid from the outlet channel is denoted as J_2.

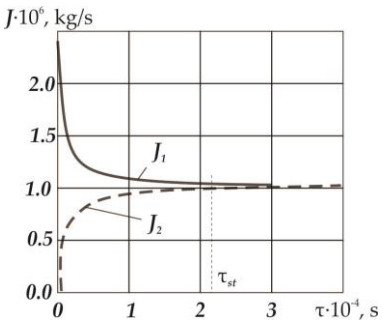

Fig. 2. The dependence of the rate of evaporation of the liquid from the experiment: J_1- flow mass vapor from the liquid surface, kg/s; J_2 - mass flow of vapor through the outlet section of the working part of the channel, kg/s.

From the analysis of the results (Figure 2) shows that with increasing time of the experiment, the difference between the values of J1 and J2 is reduced and becomes almost zero, which corresponds to the steady process of convective diffusion in the work area. The time required to establish equilibrium is referred to as τ_{st}. It is selected so that the difference in the values of J_1 and J_2 does not exceed 4%. It is with such an accuracy was fixed volumetric flow of vapor-gas mixture at the outlet of the channel during the experiment. The result found that τ_{st} is placed in the range of $17.8 \cdot 10^4$ s to $2.3 \cdot 10^4$ s.

Figure 3 shows a comparison of the results of determining the rate of evaporation of the liquid in the numerical and physical modeling, depending on the temperature of the gas and liquid. Analyzing the difference in the results of numerical and physical modeling, it can be concluded that the maximum discrepancy is observed at a temperature of liquid and gas ~ 23.5 °C and further significantly decreases with increasing temperature. In general, the difference was between 1 and 36%.

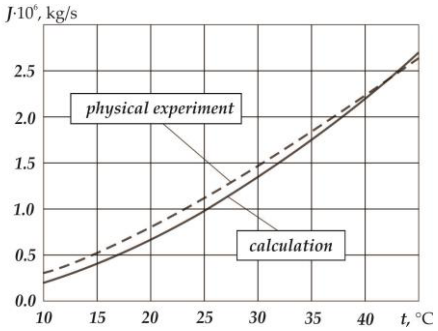

Fig. 3. The velocity of evaporation of the liquid at the temperature of a liquid and a gas and u_g =0.1 m/s.

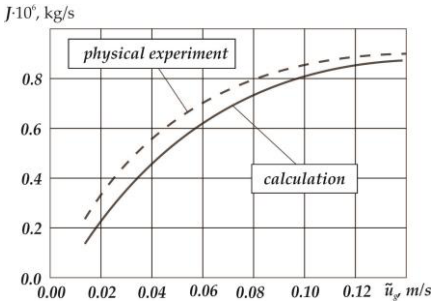

Fig. 4. The dependence of the rate of evaporation of the liquid at gas velocity and at T = 20 ºC.

The discrepancies in the results of numerical and physical model-ing, depending on the velocity of the gas, have a similar relationship, the maximum is observed at lower gas velocities of ~ 0,035 m/s and decreases with increasing speed. In general, the difference is from 4 to 38%.

It is assumed that the differences in the results are explained by the difference in the duration of the experiment. Physical experiment was performed at the same setting temperature of the liquid and gas, to eliminate the influence of a temperature gradient in the process mass-transfer liquid film and the gas flow, however, is not taken into account the beginning of a stationary diffusion. Numerical modeling results show that the time required to establish equilibrium of about 5-6 hours, while the experiment was carried out in about 5 -. 60 minutes after the start of the plant work.

4 Conclusion

Thus, have done physical and numerical study of the dynamics of evaporation of ethanol in dependence on the gas velocity, as well as different temperature and gas liquid.

The value of the rate of evaporation. The discrepancy between the results of the numerical and physical modeling is in the range from 1% to 38%. Detected discrepancies maxima at 23.5 °C and a constant gas velocity of 0.1 m / c, and at a rate of 0.035 m/s and a constant temperature of 20 °C.

Reference

1. E.S. Chachilo , M.N. Grekhov, D.V. Feoktistov, MATEC Web Conf. **19**, 1 (2014)