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HEAT TRANSFER DURING BOILING OF SOME AQEOUS-ALCOHOL SYSTEMS

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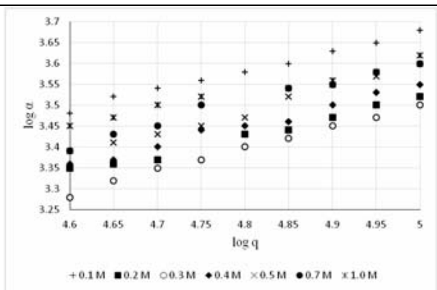
The paper presents the results of experimental studies on boiling heat transfer coefficients of some aqueous-alcohol solutions on a vertical cylindrical stainless steel tube. Higher values of boiling heat transfer coefficients of aqueous solutions were observed with the increase of the specific thermal flux (q). The heat transfer during boiling of these solutions is getting worse with the increase of the solution concentration. Empirical equations were established for the heat transfer coefficients at different concentrations and thermal fluxes.



INTRODUCTION

As one of the most effective heat transfer modes, boiling heat transfer for applications in cooling and energy conversion systems has been extensively studied.[1]

Boiling is a common process in many chemical and food industries, as well as in steam generating operations. This explains the continuous interest for the study of the mechanism of the boiling process, and for the calculation of boiling heat transfer coefficients. Most of the studies address aspects of boiling water, organic liquids and mixtures thereof, as well as aqueous or organic systems containing small amounts of other substances that can affect the boiling behavior.[2-4]

The boiling heat transfer coefficients are used routinely in calculations and design of industrial boiling equipment. Many researchers calculate boiling heat transfer coefficients using different types of heat surface[5-10]. This paper presents an investigation of boiling in the case of aqueous-alcohol solutions, which are very important for food industry. The literature doesn't present experimental results on boiling of such systems on a vertical, cylindrical surface, where the boiling mechanism is different from the one on plane surfaces or horizontal wires. The literature also presents aspects regarding the control performances improvements.[11-12]

Heat transfer at boiling of alcohol solutions was only investigated on pool boiling[13-14] or in vertical annulus space.[15] The calculations of heat transfer at boiling of alcohol-water solutions on tubular surfaces were not yet investigated.

This paper presents the results of the investigation of heat transfer during boiling in the above conditions, establishing dependence of boiling heat transfer coefficient on the heat flux, and of parameter ε on molar fraction of the water-alcohol solutions, as well.

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EXPERIMENTAL SECTION

The experiments were performed in a glass boiling vessels with H = 0.150 m and D = 0.055 x 0.002 m, containing a vertical cylindrical stainless steel tube, having the external diameter of 0.0112 m, the thickness of the wall of 0.001 m, and the length of 0.0505 m.

High amperage alternating current is supplied through thick copper connectors attached to the heating tube. The control of the thermal flux resulting from the Joule – Lenz effect is achieved by adjusting the amperage of the electrical current supplied.

The glass vessels were filled with the solution and then the heating process started by applying an appropriate current. After reaching the boiling state, the following parameters are measured: the current, the voltage differential on the heating tube, the boiling temperature and the heating tube inside face temperature. These measurements permit the calculation of the thermal flux (q), the temperature of the heating tube external face, and the boiling heat transfer coefficient.[16]

The schemes for the experimental facility are presented in the article.[17]

RESULTS AND DISCUSSION

Experimental data were collected in order to establish the boiling heat transfer coefficient of water, alcohol-water solutions of different concentrations in alcohol, and of pure alcohol. Heat flux density, q, variation domain was: 30000–50000 W/m^2. Boiling heat transfer coefficient, α, for ethanol – water solutions varied between 2410 – 3286 W/(m^{2}K) for 0.1M solution to 2253-3062 W/(m^{2}K) for 1.0M. Boiling heat transfer coefficient for n-propanol – water solutions vary between 2515–3523 W/(m^{2}K) for 0.1M solution to 2480-3498 W/(m^{2}K) for 1.0M.

The results are presented in Figs. 1 to 3.

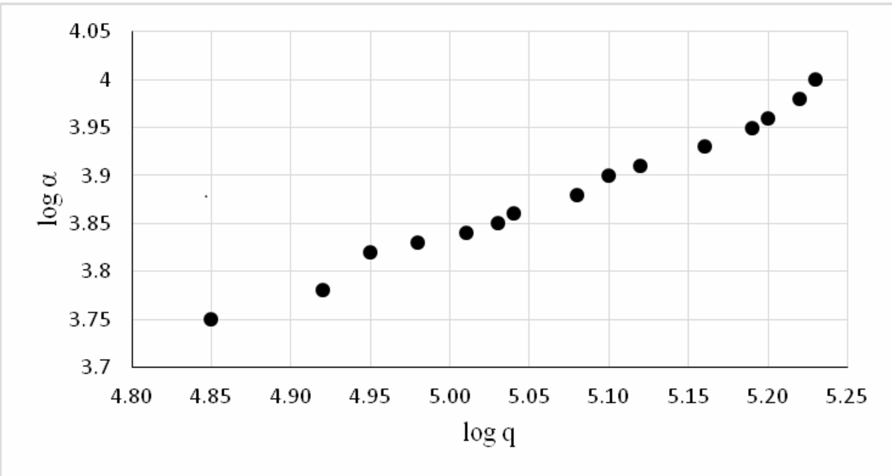

Fig. 1 – Boiling heat transfer coefficient as a function of heat flux for water.

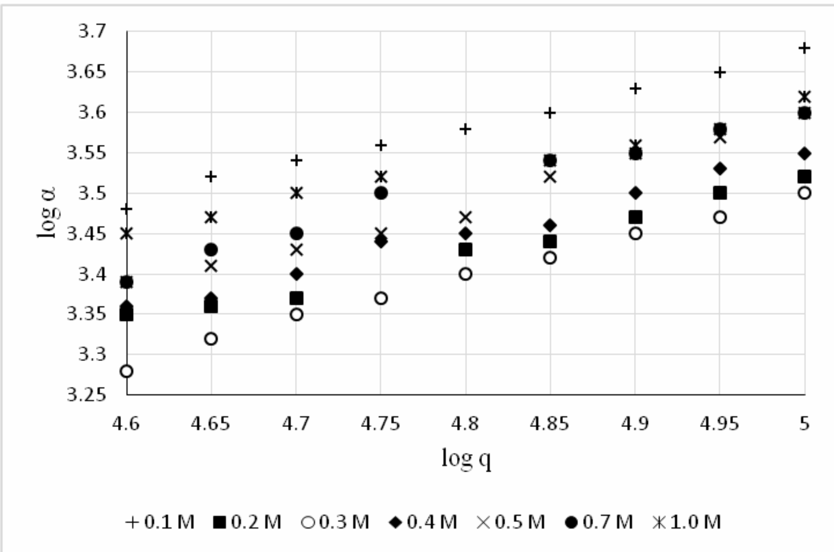

Fig. 2 – Boiling heat transfer coefficient as a function of heat flux at different molar concentrations of ethanol – water solutions.

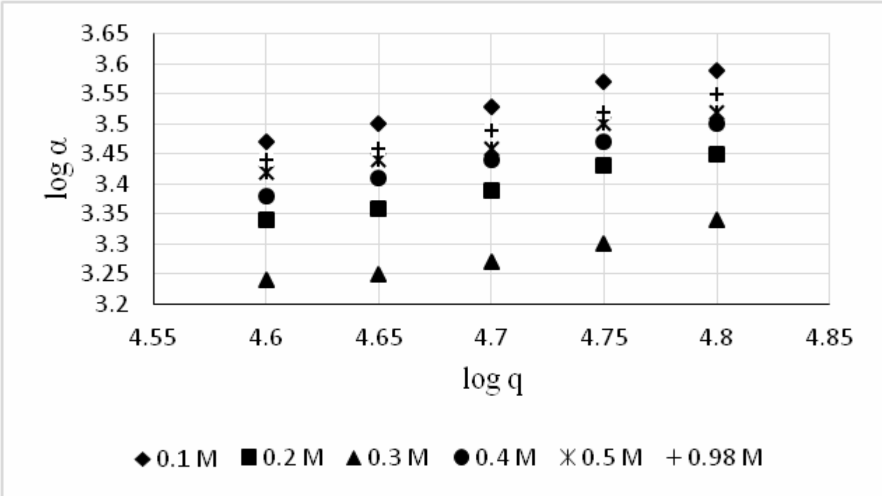

Fig. 3 – Boiling heat transfer coefficient as a function of heat flux at different molar concentrations of n-propanol – water solutions.

On the basis of these logarithmic diagrams, it can be observed the linear dependence of ***log α*** on ***log* q**, fact that leads to general equations having the form:

$$\alpha = \varepsilon \cdot q^{m} \quad (1)$$

where: ε – coefficient depending on the concentration;
m – slope of the line

The dependence equations of partial heat transfer coefficient on the thermal flux are presented in Table 1 for water – ethanol solutions and in Table 2 for water – *n*-propanol solutions.

Table 1

Dependence equations of partial heat transfer coefficient on the thermal flux for ethanol – water solutions

Molar concentration	$\alpha = \varepsilon \cdot q^{m}$
0	$\alpha = 5.56 \cdot q^{0.6}$
0.1	$\alpha = 4.98 \cdot q^{0.6}$
0.2	$\alpha = 3.68 \cdot q^{0.6}$
0.3	$\alpha = 3.40 \cdot q^{0.6}$
0.4	$\alpha = 3.70 \cdot q^{0.6}$
0.5	$\alpha = 3.95 \cdot q^{0.6}$
0.6	$\alpha = 4.15 \cdot q^{0.6}$
0.8	$\alpha = 4.43 \cdot q^{0.6}$
0.9	$\alpha = 4.55 \cdot q^{0.6}$
1.0	$\alpha = 4.64 \cdot q^{0.6}$

Table 2

Dependence equations of partial heat transfer coefficient on the thermal flux for n-propanol – water solutions

Molar concentration	$\alpha = \varepsilon \cdot q^{m}$
0	$\alpha = 5.56 \cdot q^{0.6}$
0.1	$\alpha = 2.79 \cdot q^{0.6}$
0.2	$\alpha = 1.98 \cdot q^{0.6}$
0.3	$\alpha = 1.78 \cdot q^{0.6}$
0.4	$\alpha = 1.88 \cdot q^{0.6}$
0.5	$\alpha = 2.09 \cdot q^{0.6}$
0.6	$\alpha = 2.23 \cdot q^{0.6}$
0.7	$\alpha = 2.36 \cdot q^{0.6}$
0.8	$\alpha = 2.49 \cdot q^{0.6}$
0.9	$\alpha = 2.75 \cdot q^{0.6}$
1.0	$\alpha = 2.77 \cdot q^{0.6}$

In order to establish simple equations for correlating the thermal coefficient, α to thermal flux, q and the concentration, dependences of the parameter ε on the molar concentration of the solutions were performed (Figs. 4 and 5).

The equations for these dependences are (2) for the ethanol – water solutions, and (3) for the n-propanol – water solutions.

$$\varepsilon = -12.868x^6 - 26.996x^5 + 178.5x^4 - 266.47x^3 + 173.17x^2 - 49.106x + 8.4111 \quad (2)$$

$$\varepsilon = -46.528x^6 + 119.31x^5 - 79.292x^4 - 32.838x^3 + 60.769x^2 - 23.195x + 4.5417 \quad (3)$$

where: x – molar concentration of alcohol

It can be seen that for lower solution concentrations, coefficient ε decreases, and then it grows starting with the 0.3 molar concentration of the solution; the dependence having similar shapes using both alcohol solutions.

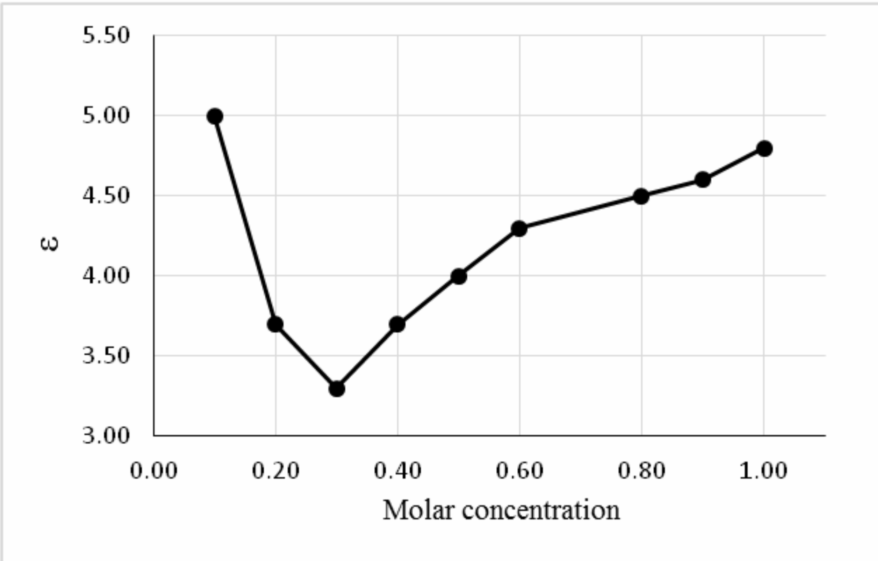

Fig. 4 – Dependence of parameter ε on molar concentration of the ethanol – water solutions.

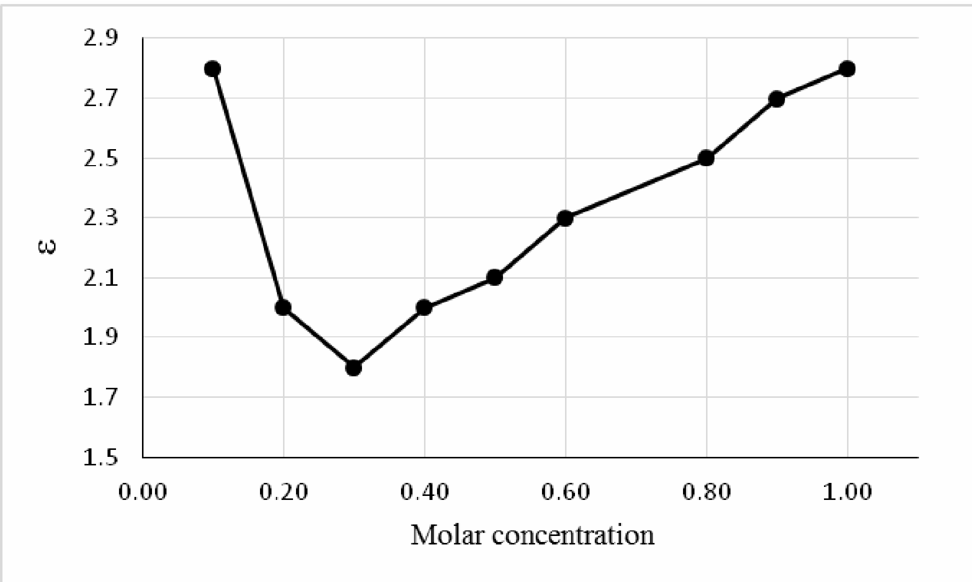

Fig. 5 – Dependence of parameter ε on molar concentration of the n-propanol – water solutions.

CONCLUSIONS

Experimental studies on boiling heat transfer coefficients of aqueous solutions of alcohols were carried out using two such systems: water – ethanol and water – *n*-propanol.

Higher values of boiling heat transfer coefficients of aqueous solutions are observed with the increase of the specific thermal flux (q). The heat transfer at boiling of these solutions is getting worse with the increase of the solution concentration.

Empirical relations were established in order to determine the boiling heat transfer coefficient (α) of aqueous solutions as function of specific thermal flux (q), for the range of concentrations covered by the experiments performed in this study.

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