ELECTROCONVECTIVE HEAT EXCHANGE IN GAS-LIQUID EMULSIONS

SAJIN TUDOR[1*]

[1] *"Vasile Alecsandri"University of Bacău, Calea Mărăşeşti 156, Bacău, 600115, Romania*

Abstract: The complex experimental investigations were carried out with the aim of revealing of the physical mechanisms of electric field influence on heat transfer processes in gas–liquid emulsions. Concrete the heat removal and interphase heat transfer in gas-liquid emulsions are considered.

Key words: gas-liquid emulsion, electroconvection, electric field, heat removal, interphase heat transfer.

1. INTRODUCTION

The elaboration of compact heat exchangers and apparatus is connected with the intensification of hydrodynamic and heat mass transfer processes. The mentioned processes arrangement under the influence of electric fields is one of the effective methods of transfer processes enhancement [1-4]. The influence of electric fields on two-phase systems shows the following electrohydrodynamic (EHD) phenomena: liquid dispersion with the generation of thin films, jets, droplets; fracturing, mixing and phases relative velocity motion and their contact surfaces increasing; interphase surface resonance oscillation of bubbles; electroconvection; boundary layers turbulization, etc. Under these conditions transfer processes enhancement achieves about ten times.

Thermodynamic analysis of these processes under the influence of electric field and special experiments made it possible to conclude, that enhancement mechanism is connected with reconstruction of hydrodynamic state and structure of two-phase system. At the same time phenomena caused by phase equilibrium displacement [5], electrocapillary effects and heat carrier properties dependencies upon field parameters have insufficient contribution in the intensification mechanism.

The action of electric fields can significantly intensify heat exchange in gas-liquid media. To a certain extent such questions have been investigated in bubble boiling [2]. It follows from data available in the literature on the problem of heat exchange in bubble-layer processes that in the dependence of the bubbler plate heat liberation coefficient on gas velocity one can distinguish at least three regions, with the dependence being selfsimilar in two of these [6]. There are studies which indicate that under certain conditions an electric field can intensify interphase heat exchange.

The mechanism of electric-field action in bubbling processes is related to the effect of electroconvection on the hydromechanical state of the phases: the change in the phase thermodynamic properties in an electric field is negligibly small compared to electroconvective phenomena [1]

In case of dielectric gas-1iquid (or vapour-liquid) emulsions the intensification of heat and mass transfer is determined by the effects of electromechanical convection on structure-hydrodynamic characteristics of a disperse flow. The thermogravity medium convection increasing. bubbles detached diameter's decreasing and their frequency detachment increasing are the heat transfer enhancement mechanism which takes place in vapour

* Corresponding author Sajin Tudor, e-mail sajin_tudor@yahoo.com

and gas-liquid emulsions. Besides mentioned mechanisms in alternating electric fields important role belongs to phases boundary oscillations, which result in maximum interphase heat transfer intensity in resonance regimes.

2. HEAT REMOVAL IN GAS-LIQUID EMULSIONS

In exerting a significant influence on the structural-hydrodynamic characteristics of the bubble layer, the electric field leads to intensification of heat liberation and interphase heat exchange. To study these questions use was made of the experimental arrangements described in [7].

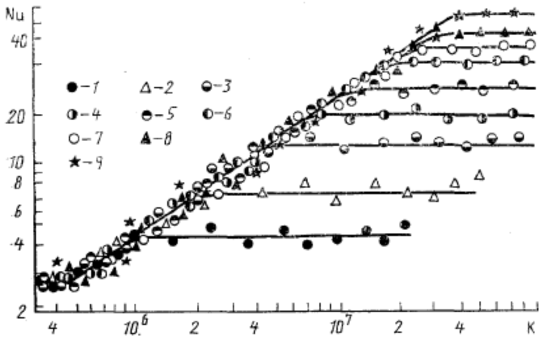

Fig. 1. Heat liberation of gas permeable electrode oriented opposite gravitation, under bubbling conditions with dc electric field: 1) $\left(Ar + 0.2 \cdot Ar^e\right) \cdot \mathrm{Pr}_l$ = 0.19; 2) 0.52; 3) 1.52; 4) 3.18; 5) 5.52; 6) 8.52; 7) 12.2; 8) 16.6; 9) 21.5

The first series of experiments studied heat liberation from the electrodes of a horizontal planoparallel capacitor in a bubbling medium for a transformer oil-air system. In contrast to the upper one, the lower electrode was gas-permeable and served simultaneously as the bubble source. Using the method of [6], Fig. 1 generalizes the experimental data on heat liberation from the gas permeable electrode. With increase in gas velocity (quantity K) for all field intensities (quantity Ar^e) there are three regions in the dependence of the number Nu on the dynamic parameters. In the first region, the heat liberation intensity depends weakly on gas velocity, which can apparently be explained by the laminar character of the gas escape into the liquid. However, with increase in gas velocity to some critical value, dependent on field intensity, the intensity of heat liberation, as in boiling, increases by a rule $Nu = K^{2/3}$ (second region). Upon exceeding a critical gas velocity the heat liberation exits into a regime self-similar with respect to K, but Nu depends on field intensity (third region). In this region the dispersed phase and the electrical field lead to a stable turbulent flow regime of the phases in the electrode region and heat liberation reaches a stable maximum value. The effect of field intensity on heat liberation is most marked at gas velocities greater than 5 mm/s; at E = 40 kV/cm and a gas velocity of 1 m/s, heat liberation increases by ten times. Thus, the criterial equations of heat liberation of the gas-permeable electrode have the form:

$$Nu = \begin{cases} 2.75, & when \quad K < 5 \cdot 10^5; \\ 4.45 \cdot 10^{-4} \cdot K^{2/3}, & when \quad 5 \cdot 10^5 \le K \le K_1; \\ 0.01\left(A \cdot \mathrm{Pr}_l\right)^{0.5}, & when \quad K_1 \le K \le K_2, \end{cases} \tag{1}$$

where $A = Ar + 0.2 \cdot Ar^e$; $Ar^e = \varepsilon_0 \varepsilon_1 E^2 l^2 \left(\rho_1^0 - \rho_2^0\right) / \rho_1^{0\,2} \nu_1^{\,2}$; $K_2 = 1976.42 \cdot \left(A \cdot \mathrm{Pr}_l\right)^{3/4}$; $K_1 = 106.53 \cdot \left(A \cdot \mathrm{Pr}_l\right)^{3/4}$.

These expressions are valid within the limits $1.9 \cdot 10^5 \le A \cdot \mathrm{Pr}_l \le 2.2 \cdot 10^7$.

A qualitatively different pattern can be seen for the dependence of heat liberation on field intensity at the upper electrode. In the absence of field the heat-liberation coefficient, as at the lower electrode, increases proportionally to gas velocity, which is related to the increased intensity of renewal of liquid transported by bubbles from the flow core to the heat-exchange surface. When some critical gas velocity is reached (about 1 cm/s) the intensity of bubble renewal stabilizes and the heat-liberation coefficient is practically independent of gas velocity. In an electrical field the intensity of heat liberation is inversely proportional to gas velocity. With increase in field intensity the heat liberation coefficient increases due to scattering of bubbles from the interelectrode space and increase in electroconvection in the closed phase, which leads to turbulization of the boundary layer and flow of liquid from the flow core to the electrode region. However, with increase in gas velocity, the liquid circulation zone is restricted by bubbles from the electrode region and the heat-liberation coefficient falls. Only at sufficiently high field intensities (35-40 kV/cm) is the heat-liberation coefficient self-similar relative to gas velocity and controlled by the intensity of liquid electroconvection. The heat liberation coefficient at the upper electrode and the field intensity are directly proportional to each other at all gas velocities. Thus, heat liberation in the given case can be generalized to an accuracy of $\pm 15\%$ by a dependence of the type

$$Nu = a \cdot K^n + b, \tag{2}$$

where $n = -24.214 \cdot B^{-0.15}$ at $1.87 \cdot 10^5 \le B < 6.86 \cdot 10^7$; $n = -1.634 \cdot 10^{-3} \cdot B^{-0.45}$ at $6.86 \cdot 10^7 \le B < 8.22 \cdot 10^7$; $b = 0.757 \cdot B^{-0.04}$ at $1.87 \cdot 10^5 \le B < 1.86 \cdot 10^6$; $b = 4.736 \cdot 10^{-3} \cdot B^{-0.55}$ at $1.86 \cdot 10^6 \le B < 8.22 \cdot 10^7$; $a = \left(3.1 \cdot 10^{-3} \cdot B^{-0.45} - b\right) / \left(3.92 \cdot 10^5\right)^n$ at $1.87 \cdot 10^5 \le B < 8.22 \cdot 10^7$; $B = \left(Ar + Ar^e\right) / \Pr_l$. The effect of temperature head and thermal flux density on the heat-liberation coefficient is one of linear proportionality over the entire range of field intensities and gas velocities studied.

3. INTERPHASE HEAT EXCHANGE IN GAS-LIQUID EMULSIONS

Interphase heat exchange during bubbling of a high-resistance liquid was studied under the action of the electrical field of a multisection planoparallel capacitor oriented vertically [7]. Field intensity, temperature head and gas velocity were varied at both polarities of the applied potential in a dc field and a 50 Hz field for phase motion with and against the main flow. In the absence of a field the heat-exchange intensity increases with increase in gas velocity due to increase in the interphase surface and change in the gas flow regime. There is also some intensification of heat exchange with increase in temperature head due to decrease in the detachment diameter of bubbles and liquid viscosity.

In an electrical field polarization and deformation of the bubbles occur, which with an inhomogeneous distribution and variable field induction leads to oscillations of the phase boundary, and at high intensity to breakup of the phases. Therefore, growth in field intensity leads to intensified heat exchange (Fig. 5a). It is also evident that in ac fields the intensification effect is greater than in a constant field. With increase in frequency of the applied voltage the intensity of heat exchange increases, reaching a maximum in resonant bubble oscillation regimes, where the field frequency is equal to the bubble natural oscillation frequency [8]. However, with increase in gas velocity, the degree of heat exchange intensity falls off (Fig. 5b), since the effect of the field becomes comparable to the turbulizing action of the gas phase. Similarly, increase in temperature head leads to

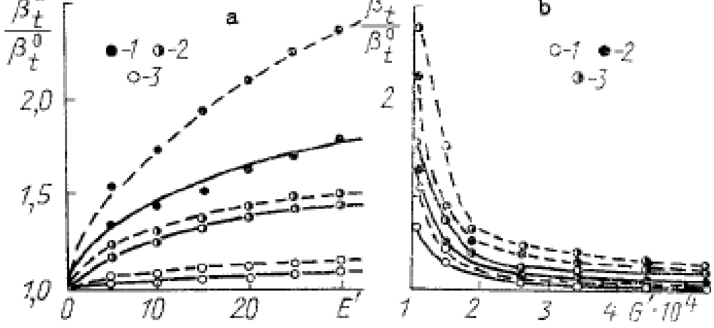

Fig. 5. Effect of field intensity E', [kV/cm] (a) and gas velocity G', [m/s] (b) on intensity of interphase heat exchange for bubbling of air through transformer oil: a) G': 1) $1.0 \cdot 10^{-4}$; 2) $1.5 \cdot 10^{-4}$; 3) $5.3 \cdot 10^{-4}$; b) E': 1) 5; 2) 20; 3) 30. Solid lines - dc field; dashes - ac field

intensification of heat exchange only in the region of laminar gas escape, while with increase in gas velocity this dependence becomes self-similar. The qualitative pattern of these results is identical for flow with and opposite the main flow; the only differences are quantitative.

Thus obtained similarity equations have the form:

$$\frac{Nu_E}{Nu_0} = 1 + c\frac{\left(Ar^e\right)^{0.25}}{K^n}. \qquad \textbf{(3)}$$

Thus, intensity of heat exchange in bubbling processes proves to be strongly dependent on gas velocity and electrical field parameters, which makes possible flexible regulation and decrease in metallic bulk of the equipment used.

3. CONCLUSION

The investigation of thermophysic electrohydrodynamic and surface phenomena in two-phase systems suppose the complex studying of heat processes, which take place in electrically controlled compact heat exchangers. The main idea for investigating processes occurring under the influence of electric field is the statement that heat transfer in two-phase systems is mainly determined by the influence of electric field on EHD phenomena development.

The promise of studies in this direction has resulted in wide application of results in practical problems. The main practical contribution of these results is the creation of modern heat transfer EHD installations and equipment, the application of which is effective in conditions of micro- and low gravity and a1so varying of mass forces and apparatus space orientation. Thus, use of an electric field, aside from the traditional struggle with loss phenomena in chemical technology and vapor-based energy production, has permitted development of new technical approaches for volume boiling and condensation, temperature stabilization and heat-exchange regulation, etc.

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