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CONDENSATION OF VAPOR-GAS MIXTURE IN AN ELECTRIC FIELD

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Abstract: *Condensation of a gas -vapor mixture in a direct electric field is discussed in the paper. At a noncondensable gas concentration of 5%, approximately two-fold increase in the condensed liquid amount is obtained. The condensation process enhancement is explained by the cooperative effect of the condensate film turbulization and the decrease in the diffusion resistance of the noncondensable gas layer in an electric field.*

Key words: *condensation, electric field, gas-vapor mixture, noncondensable*

1. Introduction

The processes of condensation in the presence of noncondensable gases are common in power engineering; chemical, oil-refining, and food industry; in refrigeration and cryogenic engineering; in air conditioning systems. An increase in generating capacities is connected with an increase in weight and dimensions of heat interchangers, for the production of which a great amount of doped and nonferrous metals are utilized. Therefore, a decrease in weight and dimensions of heat-exchanging units is still a problem of high priority. The most promising line of attack on the problem is enhancement of heat-exchange processes. To date, various methods of condensation enhancement have been studied and proposed, in particular, the use of ribs as turbulizers of condensate films, nonwettable coatings, liquid stimulating agents for initiation of drop condensation, vortex generation, and rotation of the heat-exchange surface. A very promising method for condensation enhancement is the application of electric fields. The condensation in vertical tubes was studied theoretically and experimentally in works of Chato [2].

Chen et al. [3] analyzed film condensation in a vertical tube and obtained an analytical dependence for mean Nusselt number. In works of Webb [15], Cavallini et al. [1], Muir [7], Yang and Webb [16] the enhancement of condensation of R-134 and R-22 cooling agents by microribbing was considered (at a change in the rib height from 0.1 to 0.25 mm). Gerstman and Choi [5] have shown a possibility to enhance condensation on a vertical plate by exposure of the film thickness to an electric field. Velkoff and Miller [8] studied condensation of R-113 vapors on a vertical copper plate at different field intensities and electrode geometries. The experimental studies carried out by Seth and Lee [12] showed a possibility to enhance vapor condensation from a gas-vapor medium in an electric field. Later on, results of detailed studies on

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condensation vapors of dielectric liquids from a gas-vapor mixture were obtained by other authors as well [9-11, 13-14]. However, data on the electric field influence on condensation of conducting liquids, including water, can hardly be found at all. The relevance of such researches imposed by a necessity to reveal is specific character of the interaction of two-phase conducting systems and electric fields and a possibility to use the condensed liquid in electrohydrodynamic generators [4].

In the first part of the carried out researches [6] we have shown a possibility of the atmospheric moisture use in an electrohydrodynamic generator and have studied the condensation of a gas -vapor mixture in the electric field absence.

The following formula was derived for the amount G_c of obtained condensed water

$$\frac{G_c}{G_{co}} = 5.88\times10^{-3}\Pi(Gr\,\mathrm{Pr})^{0.25}\,\mathrm{Re}^{0.6} \qquad (1)$$

where G_{co} is the mass flow rate of vapors entering into the condenser $\Pi \equiv \frac{\Lambda\theta_0 s}{G_{co} rd}$

$R_e \equiv \frac{\upsilon d}{\nu}$; $\Pr \equiv \frac{\nu}{a}$; S is the lateral area of condenser; d is the diameter; υ is the air flow speed; θ_0 is temperature difference between the surface of condenser and ambient air.

The aim of this work is the experimental study of the electric field influence on condensation of water vapor from a gas-vapor mixture.

The study of the condensation process was carried out by means of an experimental installation; its diagram is shown in Fig. 1. The working liquid was heated to boiling in vessel 9. The formed vapor proceeded into the lower part of a vertical tube with a length of 80 cm and a diameter of 28 mm, where it was mixed with air and condensed on the inner surface of the tube. The formed condensate flew down and arrived into a measuring vessel. From the outside the tube was blown over by a flow of air with controlled velocity. A copper wire electrode in varnish insulation with a diameter of 3 mm with scratches was placed in axial alignment inside the tube. Direct voltage from a high-voltage supply of the AII-70 type was applied to the inner electrode; the tube used for the second electrode was connected to ground through a milliamperemeter.

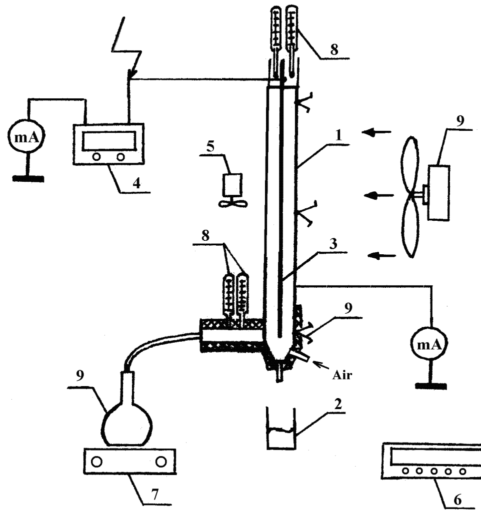

Fig. 1. *Diagram of the sector of gas-vapor mixture condensation: 1 is the tube-condenser of vapor; 2 is the condensate receiver; 3 is the high-voltage electrode; 4 is the high-voltage supply; 5 is the anemo-meter; 6 is the temperature measurement unit; 7 is the vapor generator; 8 is thermo-meters; 9 is the blower.*

Vapor consumption was measured according to mass of evaporated water and duration of the experiment; the tube surface temperature, by means of thermocouples installed in the beginning, in the center, and in the end of the tube. Humidity and temperature of vapor at the output of the tube were determined by virtue of a psychrometer; consumption of air fed into the condenser was measured with a rotameter. The velocity of the air blowing over the outer surface of the tube was measured by means of an anemometer. The experiments were carried out with measurement of the process parameters in the following ranges: 0 – 35 % for the noncondensable gas concentration, 0 - 3.5 m/s for the airflow velocity, up to 15 kV for voltage. The choice of the variation range for the velocity of tube surface blowing over is determined by a characteristic range of wind velocities in conditions of Moldova.

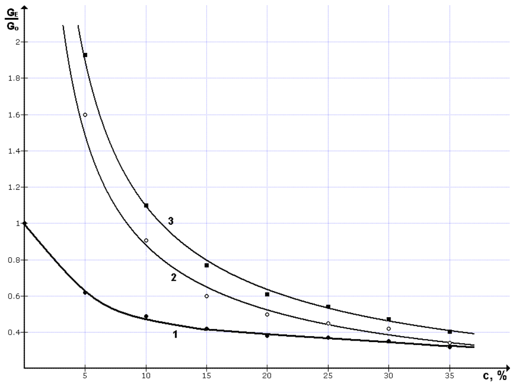

Fig. 2. *Dependence of the condensate fraction on air concentration at different current intensities, mA,*
V_{air} *= 3.5 m/s: 1- 0 ; 2 – 1 ; 3 – 2*

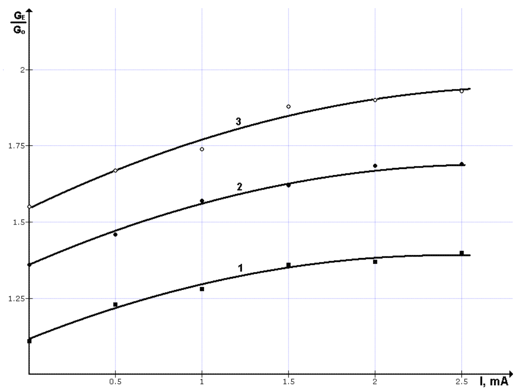

Fig. 3. *Dependence of the condensate fraction on current intensity at different velocities of blowing, c = 5%:*
1 – 1.3 m/s; 2 – 2.0 m/s ; 3 – 3.5 m/s

The maximum voltage value was limited by a breakdown of the interelectrode gap.

Figure 2 presents dependences of the obtained condensate fraction on air concentration at different current intensities of corona discharge. The maximum degree of intensification is 1.9.

The obtained results testify to a monotonous decrease in the degree of enhancement with increasing gas concentration both in the presence of electric field and in its absence. The rate of the curves may be explained by the fact that the diffusion thermal resistance plays the key role even at very small concentrations of noncondensable gas.
Dependences of the condensate fraction on current intensity at different velocities of the air blowing over the tube are given in Fig. 3. As the current intensity increases up to a breakdown of the interelectrode gap, an increase in amount of obtained condensate was observed. The corona discharge appearing at certain potential difference causes an intense dispersion of the condensate film and its thinning. In addition, an intense agitation of the gas - vapor mixture occurs, which contributes to a decrease in the diffusion resistance. An increase in the velocity of tube blowing over causes turbulization of the blowing airflow, which also favors the process enhancement.

Thus, a possibility of considerable enhancement of the condensation process in an electric field due to condensate film turbulization and to a decrease in the diffusion resistance to vapor transfer has been experimentally confirmed. At a noncondensable gas concentration of 5%, approximately two-fold increase in the condensate amount has been obtained. The results can be used for the design of electrohydrodynamic generators and for the preparation of compact vapor condensers.

References

1. Cavallini, A., Censi, G., Del Co, D., Doretti, L., Longo, G.A., and Rossetto L.: *In-Tube Condensation of Halogenated Refrigerants.* In: ASHRAE Trans., vol. 108, no. 1, 2002, p. 146.
2. Chato, J.C.: *Laminar Condensation inside Horizontal and Inclined Tubes.* In: Ph.D. Dissertation, Cambridge, Department of Mechanical Engineering, MIT, MA, 1960.
3. Chen, S.L., Gerner, F.M., and Tien C.L.: *General Film Condensation Correlations.* In: *Experimental Heat Transfer*, vol. 1, 1987, p. 93.
4. Cojuhari, I. and Bologa, M.: In: Moldova Inventor's Certificate no. Md -2199, (13) B1, 2003.
5. Gerstman, J. and Choi, H.Y.: *Electrohydrodynamics Effects in Condensation.* In: Report 62-3, Department of Mechanical Engineering, Tufts University, 1962.
6. Grosu, F.P., Bologa, M.K., Polikarpov, A.A. and Motorin, O.V.: *On Modeling of Processes of Moisture Circulation and Electric Charge Separation in the Atmosphere*. In: *Elektron. Obrab. Mater.,* 2007, no. 3, p. 29.
7. Muir, E.B.: *Commercial Refrigerants and CFCs, in CFCs: Today's Options - Tomorrow's Solutions*. In: Proc. ASHRAE's CFC Technology Conference, 1989, p. 81.
8. Sadek, H., Robinson, A.J., Cotton, J.S., Ching, C.Y. and Shoukri, M.: *Electrohydrodynamic Enhancement of In-Tube Convective Condensation Heat Transfer*. In: *Int. J. Heat Mass Transfer,* vol. 49, issues 9 -10, 2006, p. 1647.
9. Savin, I.K., Bologa, M.K., and Didkovskii, A.B.: *The Electric Field Influence on Heat Transfer at Film Condensation of Vapor in the Presence of a Noncondensable Gas*. In: Elektron. Obrab. Mater, no. 2, 1981, p. 41.
10. Savin, I.K., Didkovskii, A.B., and Bologa, M.K.: *Enhancement of Heat Exchange at Film Condensation of Vapor from a Gas -Vapor Mixture under the Electric Field Influence*. In: Elektron. Obrab. Mater., no. 2, 1983, p. 59.
11. Savin, I.K., Didkovskii, A.B., and Bologa, M.K.: *Features of Heat Exchange at Vapor Condensation from a Gas -Vapor Mixture in the Range of Low Temperature Drops under the EHD Influence*. In: *Elektron. Obrab. Mater.*, no. 5, 1983, p. 52.
12. Seth, A.K. and Lee, L.: *The Effect of an Electric Field in the Presence of Noncondensable Gas on Film Condensation Heat Transfer*. In: Journal of Heat Transfer, Trans. ASME, vol. 9, no. 1, 1970, p. 616.
13. Velkoff, H.R. and Miller, J.H.: *Condensation of Vapor on a Vertical Plate with a Transverse Electrostatic Field*. In: *J. Heat Transfer* ASME, 1965, p. 197.
14. Wawzyniak, M., Motte, E., and Seyed-Yagoobi, J.: *Experimental Study of Electrohydrodynamically Augmented Condensation Heat Transfer*. In: *Industry Applications Society Annual Meeting*, 1994, Conference Record of the 1994 IEEE, vol. 3, 1994, p. 1653.
15. Webb, R.L.: *Principles of Enhanced Heat Transfer.* New York:. Wiley-Interscience, 1994.
16. Yang, C.Y. and Webb, R.L.: *A Predictive Model for Condensation in Small Hydraulic Diameter Tubes Having Axial Microfins.* In: *J. Heat Transfer*, vol. 119, 1997, p. 776.