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# TOWARD CALCULATION OF HEAT-ENGINEERING CHARACTERISTICS OF TWO-PHASE THERMOSIPHONS FILLED WITH ETHYLENE GLYCOL
## II. HEAT-ENGINEERING CHARACTERISTICS

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*We present experimental results obtained for the thermal and technical characteristics of two-phase thermosiphons with ethylene glycol as a heat carrier.*

To calculate the heat-engineering characteristics of two-phase thermosiphons (TTS) and heat-exchange systems based on them, one needs reliable data on the processes occurring in them and laws governing heat exchange in the zones of heating and condensation. Analysis of the available relevant works shows that numerous investigations were carried out and reliable data were obtained for such heat carriers as water, Freons, and alcohols, making it possible to calculate heat-exchange coefficients and other thermal and technical characteristics of TTS in a wide range of inclination angles, degrees of filling, and geometric and operational parameters [1-3]. However, no such investigations were conducted with ethylene glycol, evidently due to the insufficiency or uncertainty of its thermophysical properties. This prevents calculation of the thermal and technical characteristics of TTS with ethylene glycol as a heat carrier and, as a result, creation of heat-exchange systems based on them.

The aim of the present work is to study the heat-engineering characteristics of TTS filled with ethylene glycol, derive dimensionless relations for calculating heat exchange in the zones of heating and condensation using the data on its thermophysical properties obtained in [4], and to compare experimental data with the results of calculation.

We carried out investigations on thermosiphons that differ in the manufacturing technologies, filling with a heat carrier, and hermetic sealing. In all cases, heat was supplied by ohmic heaters made of nichrome, and cooling was accomplished by natural convection. The temperature fields around the perimeter and along the length of the TTS, as functions of operational parameters, were measured by copper-constantan or chromel-copel thermocouples fixed on the outer surface of the tubes. The temperature of the inner surface of the TTS was determined computationally with account for the temperature drop over the wall, whereas the saturation temperature was determined using a thermocouple placed in a capillary sleeve in the internal cavity of the TTS. Using values of the temperatures along the length and around the perimeter of the zones of heating and condensation and the saturation temperature of the intermediate heat carrier, we determined the mean values of the heat-transfer coefficients for each regime. The range of change in the geometric, operational, and other parameters of the TTS, as well as the heat carriers, are listed in Table 1.

Experimental data on the change in the coefficient of heat transfer in the zone of heating as a function of the heat-flux density are presented in Fig. 1. Analysis of the experimental data shows that there are two characteristic sections of nondeveloped and developed boiling, which are typical of different working fluids, geometrical dimensions, and inclination angles of the zones of heating, as well as of the degrees of filling. This agrees with experimental data and model concepts on the processes of heat exchange in the heating zone of TTS [1, 2].

Analysis of the results obtained in the heating zone of the TTS (Figs. 2, 3) showed that for water and ethanol the experimental data are described satisfactorily by the relations suggested in [1, 2]. At the same time,

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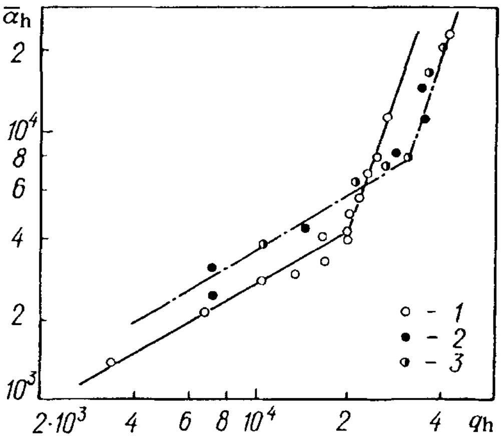
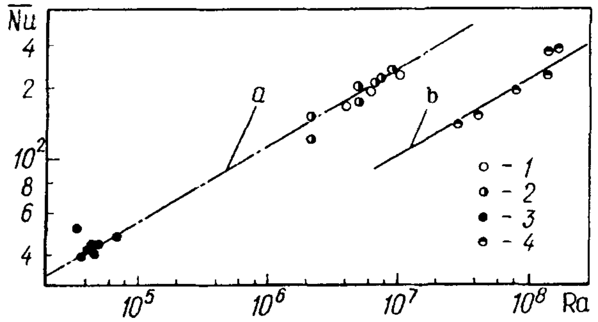


Fig. 1. Dependence of the heat-transfer coefficient $\bar{\alpha}_h$, W/m$^2$·K, on the heat-flux density $q_h$, W/m$^2$: 1) ethylene glycol; 2, 3) water.



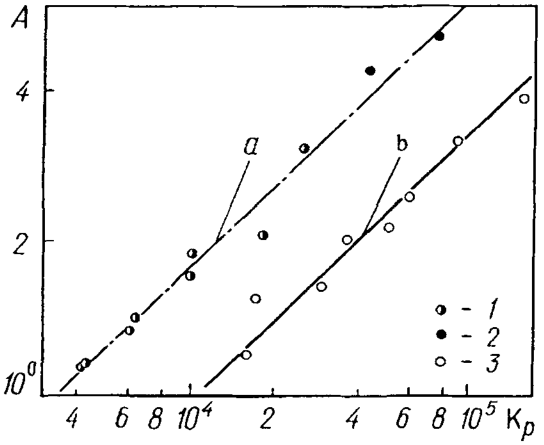


Fig. 2. Correlation of experimental data for the region of nondeveloped boiling: 1, 2) water; 3) ethanol; 4) ethylene glycol. a) Calculated relation [2]; b) calculation by Eq. (1).

Fig. 3. Correlation of experimental data for the region of developed boiling: 1, 2) water; 3) ethylene glycol. a) Calculated relation [1]; b) calculation by Eq. (2). $A \equiv \mathrm{Nu}_*/\mathrm{Re}_*^{0.5}\mathrm{Pr}^{0.35}(d_{\mathrm{in}}/l_*)^{0.17}$.

it should be noted that for ethylene glycol the heat-transfer coefficients were much smaller in the entire range of operational parameters. Taking into account the fact that all the experiments, as well as processing and correlation of the results, were carried out following the same procedure, such a discrepancy seems to be associated not with the error of experimental and computational methods, but rather with the substantial difference in the physicochemical properties of water, ethanol, and ethylene glycol, which in turn exert their influence on the thermophysical characteristics of the heat carriers indicated. Because of this, under adequate experimental conditions the degree of the effect of numerous factors (number of active nucleation sites, critical radius of a vapor bubble, structure of an axial vapor flow, etc., which depend on the thermophysical properties of a heat carrier) on the processes of heat exchange in nondeveloped and developed boiling may differ sharply for different heat carriers, and this ultimately leads to the difference in the heat-transfer coefficients in the heating zone of the TTS.

Taking as a basis the procedures recommended for correlating experimental boiling heat-transfer data in the heating zones of the TTS [1, 2], we obtained the following relations:

(a) for nondeveloped boiling

$$\mathrm{Nu} = 0.51\,\mathrm{Ra}^{1/3}, \quad \delta = \pm\,15\%\,, \tag{1}$$

TABLE 1. Geometric and Operational Parameters of the TTS

| Material of the body | Heat carrier | $L$, mm | $L_h$, mm | $L_c$, mm | $d_{in}$, mm | $q_h$, kW/m$^2$ | $\varepsilon_h$, % | $\varphi_h$, deg | $t_{sat}$, °C |
|---|---|---|---|---|---|---|---|---|---|
| St. 10 | $C_2H_6O_2$ | 843 | 225 | 515 | 21 | 3.4–25 | 85 | 90 | 184–328 |
| Same | $H_2O$ | 700 | 150 | 335 | 20 | 10.6–36.6 | 100 | 90 | 75–194 |
| Same | $H_2O$ | 1850 | 275 | 1420 | 32 | 0.72–50.6 | 85 | 35 | 82–153 |
| Copper | $C_2H_5OH$ | 250 | 50 | 130 | 5 | 2.1–3.6 | 75 | 10–90 | 54–60 |

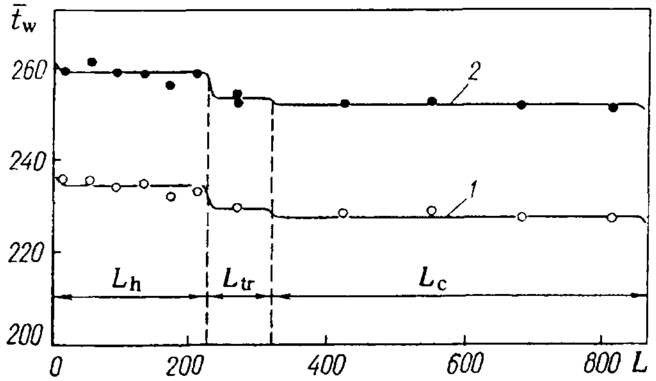


Fig. 4. Distribution of temperature fields $\bar{t}_w$, °C over the TTS length $L$, mm depending on the heat-flux power $Q$, $W$: 1) calculation and experiment, $Q$ = 200 W; 2) same, $Q$ = 300 W.

(b) for developed boiling

$$\mathrm{Nu}_* = 0.0066\,\mathrm{Re}_*^{0.5}\,K_p^{0.54}\,\mathrm{Pr}^{0.35}\,(d_{in}/l_*)^{0.17}\,, \quad \delta = \pm\,20\%\,, \tag{2}$$

As a determining dimension in Eqs. (1) and (2), we adopted the internal diameter of the TTS, with the saturation temperature of the intermediate heat carrier being taken as the determining temperature. The correlation of the experimental data and comparison with the data of [1, 2] confirm that in both nondeveloped and developed boiling of a heat carrier in the TTS, the inclination angle of the heating zone in the range 5–90° and the degree of filling do not exert any effect on heat transfer.

Analysis of the results of experimental investigation of heat exchange in condensation of ethylene glycol vapor on the inner surface of thermosiphons showed that all the data are described satisfactorily by the Nusselt formula for film condensation of pure quiescent vapor on a vertical surface and a falling laminar condensate film [5].

In addition to determining heat-transfer coefficients in the zones of heating and condensation, of great practical value is the calculation of temperature fields along the length of the TTS. Moreover, the results of such a calculation must not only give reliable information on the distribution of temperature fields under different operational conditions of TTS and heat-exchange systems based on them, but also afford a direct confirmation of the correct understanding of the processes of heat exchange in the heating and condensation zones of TTS and the adequacy of the relations obtained for their description.

Therefore, after carrying out investigations of the heat-transfer coefficients in the heating and condensation zones, we calculated the temperature fields of the TTS and compared them with the data measured. The determining parameter was taken to be the saturation temperature of the intermediate heat carrier, whereas the outer-surface temperature along the length of the TTS was calculated with account for the temperature drop over the wall of the tubes.

The results of such an analysis are presented in Fig. 4. From this figure, it is seen that the predicted and experimental data are in satisfactory agreement.

Thus, the investigations carried out made it possible to obtain new data on heat-exchange coefficients in the zones of heating and condensation of ethylene glycol-filled TTS, making it possible to use them for calculating temperature fields and other thermal and technical characteristics for devising and manufacturing TTS and various heat-exchange equipment based on them.

## NOTATION

$\overline{\alpha}_h$, mean heat-transfer coefficient; $q_h$, heat-flux density; $L$, length of a thermosiphon, zone; $d_{in}$, diameter of the thermosiphon; $t$, temperature; $\varepsilon_h$, degree of volume filling; $\varphi_h$, angle of inclination; Nu, Ra, $\mathrm{Re}_*$, Pr, Nusselt, Rayleigh, Reynolds, and Prandtl numbers, respectively; $K_p$, pressure criterion; $l_*$, capillary constant; $Q$, heat-flux power; $\delta$, relative error. Subscripts: w, wall; h, heating zone; c, condensation zone; tr, zone of transport; in, internal; sat, saturation.

## REFERENCES

1. M. G. Semena and Yu. F. Kiselev, Inzh.-Fiz. Zh., 58, No. 1, 211-217 (1978).
2. M. K. Bezrodnyi and D. V. Alekseenko, Izv. VUZov, Énerg., No. 12, 96-101 (1976).
3. M. K. Bezrodnyi and D. V. Alekseenko, Teploénergetika, No. 7, 83-85 (1977).
4. A. I. Rudenko, V. N. Savina, A. P. Nishchik, and A. E. Koloskov, Inzh.-Fiz. Zh., 71, No. 2, 195-198 (1998).
5. V. P. Isachenko, V. A. Sukomel, and A. S. Osipova, Heat Transfer [in Russian], Moscow (1975).