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BOUNDARIES OF REGIMES WITH IMPROVED HEAT TRANSFER AT A SUPERCRITICAL PRESSURE OF ORGANIC COOLANTS

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Based on experimental data on the heat transfer of organic coolants, the authors developed an empirical equation for determining the boundary of occurrence of the stable regime of improved heat exchange.

Investigations of the processes of convective heat exchange at supercritical pressures of different coolants are among the important but comparatively new trends in heat exchange, which, therefore, have not yet received sufficient study. The need to perform such investigations stems from the practical work itself, i.e., the intensification of technological processes and apparatuses at supercritical pressures of coolants. Because of this, over a period of more than 30 years, work on studying the heat exchange in various regimes of forced and free motion of organic coolants under the conditions of supercritical pressures has been conducted at the Azerbaijan State Academy [1–18].

The results of numerous experimental investigations carried out with different organic coolants (toluene, benzene, ethyl benzene, *n*-heptane, *n*-hexane, and TS-1 jet fuel) confirmed that, irrespective of the nature of occurrence of liquid motion, orientation of the channel in space, direction of liquid flow, and kind of organic coolants, on attaining the pseudocritical value by the temperature of the inner surface of a tube wall there comes a regime with improved heat transfer; this regime is characterized by constancy of the wall temperature or a certain decrease in it as the heat-flux density increases ($t_w \approx t_m \approx$ const).

It is established that the intensity of the above type of heat exchange is substantially affected not only by the value of the mass velocity of a moving flow but by the liquid pressure as well. A decrease in the first quantity and an increase in the second one lead to a noticeable attenuation of the intensity of heat exchange in the region $t_w \approx t_m$. When $t_w > t_m$, with increase in the heat-flux density the tube-wall temperature grows, obeying approximately a rectilinear law, just as for $t_w < t_m$. We note that here segment CD is entirely displaced toward larger values of the heat-flux density and straight lines occurring under the conditions $t_w < t_m$ and $t_w > t_m$ differ in slope (Fig. 1).

At large values of the heat-flux density and a high temperature of the inner surface of the tube wall there comes a stable regime of improved heat exchange that first is characterized by a decrease and then by constancy or slow growth in the wall temperature as the heat-flux density increases (segment DEF).

As the analysis of the results of experimental investigations shows, the onset of the stable regime of improved heat exchange (point D in Fig. 1) depends mainly on the value of the liquid pressure and the mass velocity of the moving flow. In view of the fact that the regime with improved heat transfer is the main condition for designing and creating small-size heat exchangers, a designer must know in advance the initial boundaries of occurrence of the indicated type of heat exchange that occurs at larger values of the heat-flux density and a high temperature of the tube wall.

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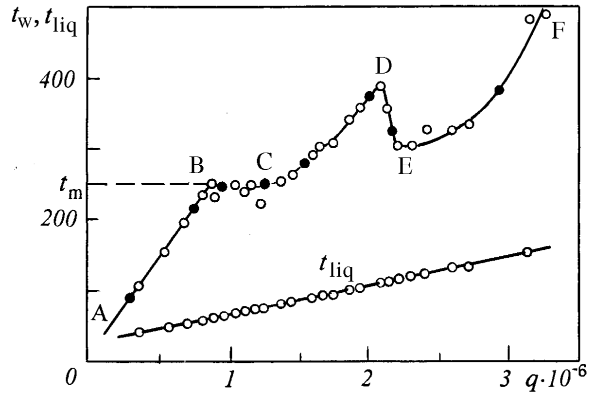


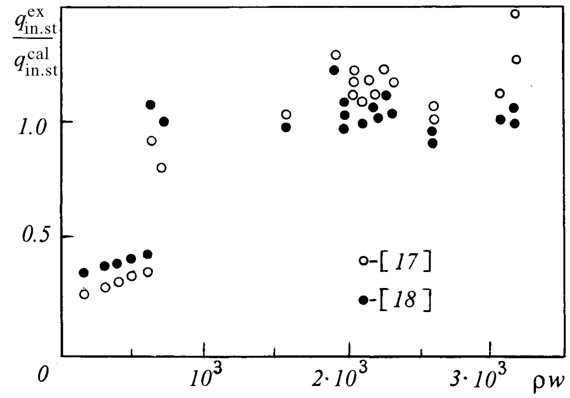
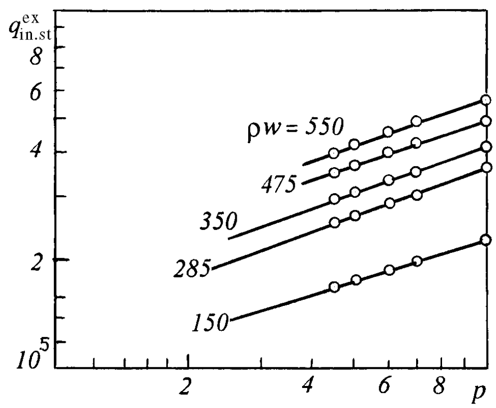


Fig. 1. Change in t_w and t_{liq} as a function of the heat-flux density for the ascending motion of *n*-hexane under the conditions p = 4.0 MPa, ρw = 1585 kg/(m^2·sec), and t_{liq}^{in} = 22.5°C; the temperature points denote the results of measurement of reverse sequence (measurement with a decrease in the heat-flux density).

Fig. 2. Dependence $q_{in.st}^{ex}/q_{in.st}^{cal} = f(\rho w)$.



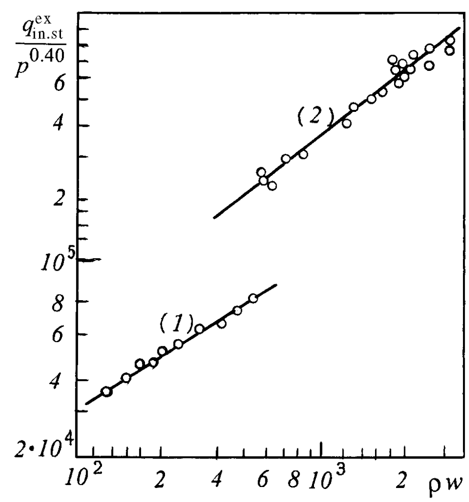


Fig. 3. Dependence $q_{in.st}^{ex} = f(p)$ for different values of the mass velocity.

Fig. 4. Dependence $q_{in.st}^{ex}/p^{0.40} = f(\rho w)$.

With consideration of the aforesaid, the present work seeks to determine the boundary of occurrence of the stable regime of improved heat exchange in the case of different regimes of forced motion of organic coolants under the conditions of supercritical pressures. It should be emphasized that this problem was considered earlier in [17, 18], and based on experimental data on the heat transfer of toluene [17] and *n*-heptane [18], covering mainly the transient regime of forced motion, empirical equations for determining the boundary of occurrence of the stable regime of improved heat exchange were developed. Therefore, in the initial stage we verified the equations proposed in the above-mentioned works in a wide range of variation of the mass velocities of the moving flow and, in addition, we used the experimental data on the heat transfer of organic coolants obtained in [1–16]. The results of calculations are given in Fig. 2 in the form of the dependence $q_{in.st}^{ex}/q_{in.st}^{cal} = f(\rho w)$.

It can be seen from the figure that the experimental and calculated values of $q_{in.st}$ agree well in the range of mass velocity of the moving flow from 600 to 3200 kg/(m^2·sec). It should be noted that the equation proposed in [18] gives more exact results (dark points) compared to that from [17].

In the range of mass velocity from 150 to 550 kg/(m^2·sec), the experimental and calculated values of $q_{in.st}$ differ greatly. Therefore, the results corresponding to the indicated range of variation of the mass velocity of the moving flow were first treated in the form of the dependence $q_{in.st} = f(p)$ and it was established that this dependence in logarithmic coordinates has the same form as for ρw = 600–3200 kg/(m^2·sec) established in [18], i.e., it represents a family of parallel lines, which made it possible to define the exponent of p as the tangent of the slope of the indicated straight lines ($n = \tan \varphi = 0.40$) (Fig. 3).

Thereafter the results of the investigations carried out in the range ρw = 150–3200 kg/(cm^2·sec) were treated in the form of the dependence $q_{in.st}^{ex}/p^{0.40} = f(\rho w)$ (Fig. 4), and for finding the boundary of the beginning of the stable regime of improved heat exchange two equations were proposed.

The first of these, having the form

$$q_{in.st} = 1615 p^{0.40} (\rho w)^{0.629} , \qquad (1)$$

holds for $p = (1.09–2.70)p_{cr}$ MPa and a mass velocity of ρw = 150–550 kg/(m^2·sec), while the second equation,

$$q_{in.st} = 1640 p^{0.40} (\rho w)^{0.775} , \qquad (2)$$

also proves itself well in the indicated range of variations of the pressure and a mass velocity of ρw = 600–3200 kg/(m^2·sec).

NOTATION

p, pressure, MPa; p_{cr}, critical pressure, MPa; t_w, temperature of the inner surface of the tube wall, ^{o}C; t_{liq}, liquid temperature, ^{o}C; t_{liq}^{in}, liquid temperature at the inlet, ^{o}C; t_m, pseudocritical temperature, ^{o}C; ρw, mass velocity, kg/(m^2·sec); q, heat-flux density, W/m^2; $q_{in.st}^{ex}$ and $q_{in.st}^{cal}$, experimental and calculated values of the heat-flux density that correspond to the initial boundary of the stable regime of improved heat exchange, W/m^2.

REFERENCES

1. G. I. Isaev, *Prom. Teplotekh.*, **3**, No. 4, 33–37 (1981).
2. G. I. Isaev and R. S. Mamedov, *Izv. Vyssh. Uchebn. Zaved., Énergetika*, No. 12, 95–97 (1981).
3. G. I. Isaev, *Inzh.-Fiz. Zh.*, **4**, No. 1, 136–137 (1983).
4. G. I. Isaev, *Izv. Vyssh. Uchebn. Zaved., Énergetika*, No. 6, 53–57 (1985).
5. G. I. Isaev and R. S. Mamedov, *Inzh.-Fiz. Zh.*, **46**, No. 6, 1019–1020 (1984).
6. G. I. Isaev, *Izv. Vyssh. Uchebn. Zaved., Énergetika*, No. 9, 112–114 (1990).
7. G. I. Isaev, *Inzh.-Fiz. Zh.*, **57**, No. 5, 861 (1989). Dep. at VINITI 22.06.99, No. V 89.
8. G. I. Isaev, L. M. Mirzoeva, F. Kh. Mamedov, and Sh. G. Mamedov, *Izv. Vyssh. Uchebn. Zaved., Énergetika*, No. 10, 101–104 (1990).
9. G. I. Isaev, G. K. Abdullaeva, I. T. Arabova, and F. Kh. Mamedov, *Teploénergetika*, No. 9, 70–73 (1991).
10. G. I. Isaev, I. T. Arabova, and F. Kh. Mamedov, *Izv. Vyssh. Uchebn. Zaved., Énergetika*, No. 9, 116–120 (1991).
11. G. I. Isaev, I. T. Arabova, and F. Kh. Mamedov, *Prom. Teplotekh.*, **17**, Nos. 1–3, 35–39 (1995).
12. G. I. Isaev, *Izv. Vyssh. Uchebn. Zaved., Neft' Gaz*, No. 2, 67–72 (1981).
13. G. I. Isaev, *Prom. Teplotekh.*, **12**, No. 6, 96–98 (1990).

14. G. I. Isaev, *Izv. Vyssh. Uchebn. Zaved., Neft' Gaz*, No. 2, 46–49 (1982).
15. G. I. Isaev, I. T. Arabova, and G. K. Abdullaeva, *Izv. Vyssh. Uchebn. Zaved., Neft' Gaz*, Nos. 1–2, 49–51 (1997).
16. T. A. Guseinov, G. I. Isaev, I. T. Arabova, and F. Kh. Mamedov, *Izv. Vyssh. Uchebn. Zaved., Neft' Gaz*, Nos. 3–4, 27–29 (1997).
17. Ch. M. Verdiev, *Heat Transfer in the Pulsation Regime at Supercritical Pressures of Aromatic Hydrocarbons*, Candidate's Dissertation in Technical Sciences, Baku (1992).
18. I. T. Arabova, *Heat Transfer in Motion of Liquid n-Heptane of Supercritical Pressures in a Tube*, Candidate's Dissertation in Technical Sciences, Baku (1993).