INTERRELATION OF TEMPERATURE OF COOLED SURFACE AND FREQUENCY OF NATURAL PRESSURE OSCILLATIONS IN TURBULENT HEAT TRANSFER

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An investigation of heat transfer in the surface boiling ($p < p_{cr}$) and pseudoboiling ($p > p_{cr}$) regimes has shown that it is related with the corresponding natural oscillations. An increase in their frequency prevents prevents a rise in the temperature of the cooled surface.

Under conditions of internal convection at subcritical pressures, liquid heat transfer goes over into the "improved" regime with the beginning of surface boiling. A plateau appears on the curve relating the temperature of the cooled surface with the heat flux. The same effect has been noted under certain conditions even at supercritical pressures in the surface pseudo-boiling regime.

The improvement in heat transfer in surface boiling is associated with the turbulence-generating effect of the vapor bubbles as they develop and condense. Many investigators have observed that surface boiling and pseudo-boiling are accompanied by a characteristic noise and whistle.

We have studied the amplitude-frequency characteristics of the sound associated with improved heat transfer and have found that for different liquids (diisopropylcyclohexane, n-heptane, ethyl alcohol, water, etc.) the characteristics of the vibrations are similar and constitute almost pure harmonics from 2000 to 30 000 Hz. The amplitudes and frequencies of the vibrations depend on the heat flux, the pressure, and the geometry of the heated part. The vibrations that develop in the "improved" heat transfer regime have a certain influence on it: the temperature of the cooled surface does not remain strictly speaking, constant.

Below, we present the results of heat-transfer experiments on a liquid hydrocarbon obtained in the process of refining oil; its fractions boil in the range from 435 to 545° K. The theoretical values of the critical parameters are: pressure 245 MN/m^2, temperature 675° K. As the working section we used a thin-walled tube of Cr18Ni10Ti steel 30 mm long and 1.6 mm inside diameter.

The tube was heated by passing an alternating current through it. The test liquid flowed through the tube at the required velocity and the established pressure. The object of the investigation was to determine the relationship between the temperature of the cooled surface and the vibration characteristics.

As the characteristic wall temperature we took the value at the center of the length of the test section. Preliminary investigations (the temperature was measured every 2 mm) confirmed the correctness of this choice; hydraulic and thermal stabilization at the heat fluxes corresponding to the improved heat transfer regime was complete at approximately 1/4 of the length of the working section. The temperature was measured with a clip-on iron-constantan thermocouple.

To record the characteristics of the pressure oscillations in the flow we used a JAN-100 two-channel piezoelectric pressure indicator ("Electronika," Hungary). A feature of this indicator is the high input capacitance, which makes it possible to record a signal proportional to the pressure and considerably facilitates calibration. The channel diameter of the indicator probe is 2.4 mm. The probe signal was fed into one channel of the indicator, while a harmonic signal from a ZG-10 audio-frequency oscillator was introduced into the other. To measure the frequency, the image of the probe signal on the screen was stopped and the identical harmonic selected by adjusting the frequency of the ZG-10. The amplitude was determined by directly measuring the image, the necessary calibration having been carried out in advance.

To reduce the possibility of secondary vibrations, the hydraulic transition from the working section to the probe channel was made at a cone angle at 60°. "Cold" pumping and operation outside of the region of improved heat transfer

did not reveal any vibrations, apart from those associated with the pump, whose amplitude did not exceed 0.1 MN/m^2. Thus, it can be stated that the measured frequency accurately corresponded to the frequency of the vibrations produced by the heat-transfer process.

However, the amplitude of the vibrations can only be approximately estimated from the readings of a probe located at the outlet from the working section. It is necessary to take into account the hydraulic expansion of the flow and the difference between the wave impedances of the two-phase liquid inside the working section and the one-phase medium outside it. For the case in question, calculations show that the amplitude of the vibrations inside the working section may be 30% higher than that registered by the transducer.

In our investigation, as shown below, the frequency and not the amplitude of the vibrations was the important factor.

During the tests we recorded the temperature of the cooled surface as a function of the heat flux. The curves in Fig. 1 show how the wall temperature, and the frequency and amplitude of the vibrations vary with the heat flux at a pressure of 4.41 MN/m^2 and a flow velocity w = 12.5 m/sec.

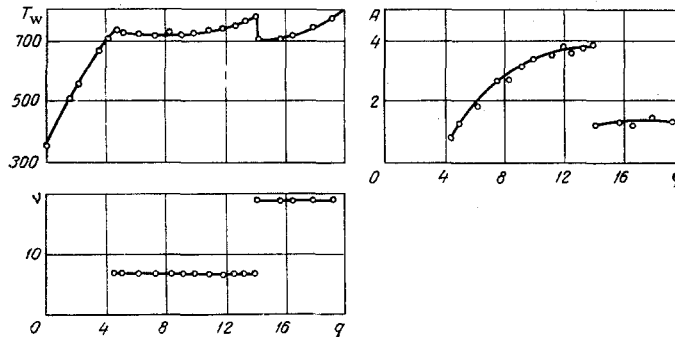Fig. 1. Temperature of cooled surface (T_w, °K), frequency (ν, kHz) and amplitude of vibrations (A, MN/m^2) as functions of the heat flux (q, MW/m^2) at a pressure of 4.41 MN/m^2 and a velocity of 12.5 m/sec.

It is clear that, as the heat flux increases, the temperature rises monotonically to the beginning of improved heat transfer (725° K), then smoothly goes over into a horizontal plateau. Pressure oscillations with a frequency of 7000 Hz appear. Their amplitude increases. The temperature, after first remaining constant, begins to increase. The frequency of the vibrations is constant. At a heat flux of 14 MW/m^2 there is an abrupt change in the parameters: the temperatures falls to the level of the horizontal plateau, the frequency increases to 19 000 Hz, and the amplitude is reduced by a factor of 3.

With subsequent increase in the heat flux the pattern is repeated: the temperature begins to increase, the frequency remains constant, and the amplitude increases.

It may be assumed that in the absence of a frequency jump the wall temperature would continue to rise. It is characteristic that at flow velocities less than 10 m/sec this is precisely what happens—the temperature increases until the tube loses its strength.

However, at velocities greater than 15 m/sec a second frequency jump to 31 000 Hz was frequently observed with a characteristic fall in wall temperature and vibration amplitude.

The parameters also display a time dependence. The variation of the wall temperature and the frequency and amplitude of the vibrations with time is shown in Fig. 2 at the heat flux of 17 MW/m^2 characteristic of the jump at a flow velocity of 18 m/sec. It is clear than an increase in frequency corresponds to a fall in wall temperature and vibration amplitude. Thus, the sudden increase in vibration frequency prevents an increase in wall temperature, apparently owing to the intensification of boundary layer turbulence.

The results of an investigation at subcritical pressure p = 1.9 MN/m^2 are shown in Fig. 3. Although the

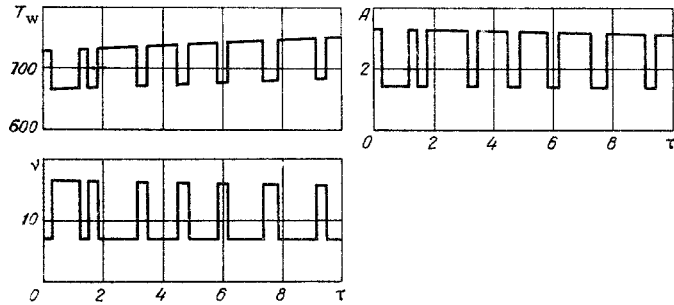Fig. 2. Variation of wall temperature and frequency and amplitude of the vibrations with time (τ, min) in the transition regime. Pressure 4.41 MN/m², velocity 18 m/sec.
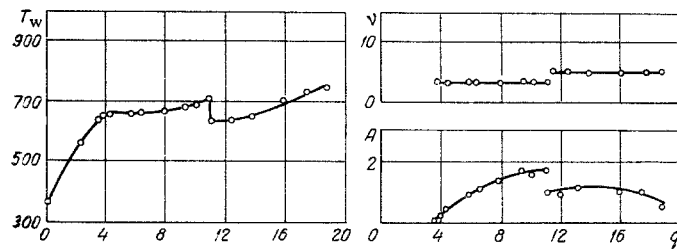

Fig. 3. Wall temperature and vibration frequency as a function of the heat flux at a pressure 1.9 Mn/m² and velocity 12.5 m/sec.

frequencies had values of 3200 and 5000 Hz, the nature of the variation of the parameters is similar to the data obtained at supercritical pressures, which may indicate the identicalness of the heat-transfer improvement mechanism.

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