7. V. I. Tolubinskii, Heat Exchange during Boiling [in Russian], Naukova Dumka, Kiev (1980).
8. S. J. D. Van Stralen, "The mechanism of nucleate boiling in pure liquids and in binary mixtures. Part III," Int. J. Heat Mass Transfer, 10, 1469-1484 (1967).
9. E. I. Nesis, "Mechanism of action of boiling centers," Inzh.-Fiz. Zh., 23, No. 1, 51-58 (1972).
10. L. N. Grigor'ev and A. G. Usmanov, "Heat transfer during the boiling of binary mixtures," Zh. Tekh. Fiz., 28, No. 2, 325-332 (1958).
11. V. V. Molyavin and L. N. Grigor'ev, "Number of centers of vaporization during the boiling of binary mixtures," Inzh.-Fiz. Zh., 17, No. 1, 160-163 (1969).
12. K. A. Akiev, "Effect of inertial fields on heat transfer during the boiling of liquids," in: Heat and Mass Transfer and the Thermophysical Properties of Substances [in Russian], ITF Sib. Otd. Akad. Nauk SSSR, Novosibirsk (1982), pp. 48-51.

HELIUM BOILING CRISIS WITH A STEPPED INCREASE IN HEATING CAPACITY

V. K. Andreev, V. I. Deev,
and A. N. Savin

UDC 536.248.2:546.291

Results are presented from a study of the effect of saturation pressure on the nonsteady critical heat flux during the boiling of liquid helium in a large volume.

Impulsive heat release occurs in superconducting systems [1], and may lead to return of the superconductors to their normal state if adequate cooling is not provided. In connection with this, it is interesting to study the cooling capacity of liquid helium in nonsteady thermal processes.

Several studies have been published [2-5] regarding nonsteady heat transfer during the boiling of helium under conditions of an abrupt increase in power or impulsive heat release. They have shown that when the thermal load increases sufficiently, sheet boiling begins not immediately but after a certain time interval. The nonsteady heat conduction regime in helium is replaced by nonsteady nucleate boiling, and it is only after this that there is a deterioration in heat transfer — connected with the formation of a stable vapor film on the heating surface. Thus, there is a certain time interval τ_{cr} within which the heat-transfer rate remains fairly high after an increase in thermal load.

The character and sequence of occurrence of the nonsteady thermal processes in helium are similar in the case of impulsive heat release. However, if the duration of the thermal pulses is less than τ_{cr} and the time interval between pulses is long enough so that the semiconductor cools to the initial temperature, then it becomes necessary to remove heat from the surface of the superconducting element without its substantial overheating. Here, under certain conditions the magnitude of the impulsive thermal effects may significantly exceed the critical level for pulses of long duration. In the case $\tau_{imp} > \tau_{cr}$, the occurrence of sheet boiling at high thermal loads is unavoidable, so it is of great practical interest to determine the maximum heat flux which when attained will still not lead to a deterioration in heat transfer.

Vapor formation on the heating surface occurs somewhat differently in the case of an abrupt increase in heating than in the case of a slow increase in thermal load [6]. Thus, the critical heat flux $q_{cr.st}$ determined in the quasisteady regime may not agree with the value $q_{cr.ntst}$ characterizing the transition to sheet boiling with a stepped increase in heating. For example, it has been established in studies of the nonsteady boiling of organic liquids that the heat-transfer crisis with an abrupt change in thermal load occurs at heat fluxes $q_{cr.ntst}$ which are less than $q_{cr.st}$. The difference between $q_{cr.ntst}$ and

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 48, No. 1, pp. 16-18, January, 1985. Original article submitted July 25, 1983.

 0022-0841/85/4801-0010$09.50

TABLE 1. Values of Critical Heat Fluxes $q_{cr.st}$ and $q_{cr.ntst}$ in the Boiling of Helium in a Large Volume

p, kPa	$q_{cr.st}$, W/m²	$q_{cr.ntst}$, W/m²	p, kPa	$q_{cr.st}$, W/m²	$q_{cr.ntst}$, W/m²
6,2	3260	3020	59,2	6810	6790
10,0	3880	3810	78,7	6220	6200
11,0	4210	3960	99,8	5690	5670
18,8	5000	4920	128,5	5420	5380
23,8	5690	5580	167,7	3760	3740
39,5	6520	6510	197,3	1800	1770

$q_{cr.st}$ is particularly large in the region of atmospheric and reduced pressures. With an increase in pressure, heat flux $q_{cr.ntst}$ approaches $q_{cr.st}$. In experiments with water in the pressure range 0.02-1 MPa, no significant differences were seen in the values of $q_{cr.ntst}$ and $q_{cr.st}$.

To determine the critical heat flux in the boiling of helium under conditions of a stepped increase in heating, we conducted special tests in the pressure range 6-200 kPa (p/p_{cr} = 0.03-0.87). The working section on which the study was performed was a strip of brass foil 0.05 mm thick, 4 mm wide, and 65 mm long. The foil was heated directly by the passage of an electric current through it. One of the surfaces of the foil (4 × 65 mm) was thermally insulated with a layer of ÉD-20 epoxy resin 3-4 mm thick, while the other surface was in contact with the liquid helium in the cryostat. The temperature of the working section was measured with a film-type germanium resistance thermometer made by the Institute of Semiconductors of the Academy of Sciences of the Ukrainian SSR. The thermometer has low inertia at helium temperatures (about $3 \cdot 10^{-5}$ sec). The thermometer was placed in the middle of the working section inside the resin layer, about 2 μm from the surface of the copper foil. The temperature of the helium bath was measured with a TSG-2 germanium resistance thermometer, while the pressure of the helium vapors was measured with a standard spring manometer.

The tests were conducted with the working section horizontal, the heated side facing up. We used the following method to study the helium boiling crisis. First, with a slow increase in the thermal load on the test element, we determined the steady-state critical heat flux $q_{cr.st}$. The transition from nucleate boiling to sheet boiling was determined from the abrupt change in the readings of the working-section thermometer. The electric power corresponding to $q_{cr.st}$ was prescribed in the next test by increasing the heat input from the zero level. Simultaneous recording of the heater current and wall temperature on chart paper by means of an N-117 oscillograph made it possible to clearly establish the moment of occurrence of the helium boiling crisis in the nonsteady thermal regime. A new increase in load was made after the heater was turned off and cooled to the ambient temperature. In subsequent tests the increase in electric power was successively reduced until the working-section thermometer ceased to record the onset of a boiling crisis. The lowest thermal load at which we still observed a transition to sheet boiling was taken as the nonsteady critical heat flux $q_{cr.ntst}$. Analysis of the oscillograms obtained in the tests showed that thorough heating of the working section occurred fairly rapidly after connection of the heater, and wall temperature changed negligibly over time immediately before the onset of the boiling crisis. Thus, we could ignore the amount of heat spent on heating the working section at the moment of the crisis compared to the heat flux in the liquid helium. Consequently, the critical heat flux was simply determined as

$$q_{cr.ntst} = Q/F.$$

The values of $q_{cr.st}$ and $q_{cr.ntst}$ obtained in the tests are shown in Table 1. It is apparent that in the investigated range of saturation pressures the critical heat flux during nonsteady boiling of helium is slightly less than $q_{cr.st}$. However, except for the lowest pressures ($p \sim 10$ kPa and below), the difference between $q_{cr.ntst}$ and $q_{cr.st}$ does not exceed the limits of the error of measurement (about 3%) of these quantities.

NOTATION

F, area of heating surface, m²; p, pressure, Pa; p_{cr}, critical pressure, Pa; Q, magnitude of jump in heat release, W; $q_{cr.st}$, steady critical heat flux, W/m²; $q_{cr.ntst}$, nonsteady critical heat flux, W/m^2; τ_{imp}, duration of thermal pulse, sec; τ_{cr}, interval of time from moment of increase in thermal load to onset of sheet boiling, sec.

LITERATURE CITED

1. M. G. Kremlev, "Heat transfer and problems of the stabilization of superconductors," in: Heat and Mass Transfer in the Boiling and Flow of Cryogenic Fluids [in Russian], ITMO im. A. V. Lykova Akad. Nauk Belorussian SSR, Minsk (1980), pp. 94-99.
2. J. Jackson, "Transient heat transfer and stability of superconducting composites," Cryogenics, 9, No. 2, 103-105 (1969).
3. O. Tsukamoto and S. Kobayashi, "Transient heat-transfer characteristics of liquid helium," J. Appl. Phys., 46, No. 3, 1359-1364 (1975).
4. W. G. Steward, "Transient helium heat transfer. Phase I — static coolant," Int. J. Heat Mass Transfer, 21, No. 7, 863-874 (1978).
5. C. Schmidt, "Transient heat transfer to liquid helium and temperature measurement with a response time in the microsecond region," Appl. Phys. Lett., 32, No. 12, 827-829 (1978).
6. V. I. Tolubinskii, Heat Exchange during Boiling [in Russian], Naukova Dumka, Kiev (1980).

FRICTION AND HEAT TRANSFER IN THE TURBULENT FLOW OF A COMPRESSIBLE GAS IN A PLANE CHANNEL

Yu. I. Shvets, I. E. Virozub,
V. F. Vishnyak, N. M. Kondak,
V. N. Panchenko, and G. A. Frolov

UDC 536.24:532.54

Results are given of calculating the local friction and heat-transfer characteristics for the case of gas cooling. The calculations are compared with experiment.

At present, the problem of calculating the resistance and heat transfer in the flow of liquid and compressible gas with variable thermophysical properties through channels is attracting great interest; see [1-5], etc. The so-called stabilized profile is often used as initial velocity distribution here. For compressible-gas flow, this method, like the division of the flow into initial (stabilization section) and basic (stabilized section) sections over the length of the channel, is arbitrary.

In the present work, the results of numerical integration of the system of equations in the boundary-layer approximation, describing steady turbulent flow of compressible gas in the inlet section of a plane-parallel channel, are given. The hypothesis of hydrodynamic stabilization is not used here.

Introducing the dimensionless quantities

$$\bar{x} = \frac{x}{h\,\mathrm{Re}_\mathrm{I}},\quad \bar{y} = \frac{y}{h},\quad \bar{u} = \frac{u}{u_\mathrm{I}},\quad \bar{v} = \frac{v}{u_\mathrm{I}}\mathrm{Re}_\mathrm{I},\quad \Theta = \frac{T_0}{T_{0\mathrm{I}}},$$

$$\bar{p} = \frac{p_\mathrm{I} - p}{\rho_\mathrm{I} u_\mathrm{I}^2},\quad \bar{\rho} = \frac{\rho}{\rho_\mathrm{I}},\quad \bar{\mu} = \frac{\mu}{\mu_\mathrm{I}},\quad \xi_\mathrm{I} = \frac{u_\mathrm{I}}{\sqrt{2c_p T_{0\mathrm{I}}}},$$

$$\mathrm{Re}_\mathrm{I} = \frac{\rho_\mathrm{I} u_\mathrm{I} h}{\mu_\mathrm{I}},$$

the equations of motion, energy, continuity, and constancy of flow rate take the form

$$\rho\left(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right) = \frac{dp}{dx} + \frac{\partial}{\partial y}\left(\mu_\mathrm{e}\frac{\partial u}{\partial y}\right), \tag{1}$$

Institute of Engineering Thermophysics, Academy of Sciences of the Ukrainian SSR, Kiev.

Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 48, No. 1, pp. 19-23, January, 1985. Original article submitted October 10, 1983.