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BOILING OF NITROGEN AT VARIOUS PRESSURES WITH NONSTATIONARY HEAT INPUT

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Liquid-nitrogen boiling times have been measured at 0.1, 1.3, and 2 MPa by means of a piezoelectric sensor; there is a relationship to the homogeneous nucleation temperature.

The discovery of high-temperature superconductivity has raised interest in research on heat transfer in liquid nitrogen. We have measured the boiling times t_A for liquid nitrogen on step heat input, which simulates the transition to the resistive state in a current-carrying superconductor film on a substrate, where we examined the effects of pressures up to 2 MPa.

The apparatus, including the heater and the boiling recorder, has been described [1]. There was also a pressure-measurement system containing a high-pressure cell made of copper and a Sapfir pressure sensor, together with a thermometer. The cell was placed in liquid nitrogen at atmospheric pressure, i.e., all the measurements were made at 77.4 K. Figure 1 shows the results, where the solid lines correspond to the calculation described in [1]. A step-heated liquid in contact with a fast heater boils in accordance with

$$q\sqrt{t_A} = A\Delta T_*, \tag{1}$$

in which

$$A = \frac{\sqrt{\pi}}{2}\left(\sqrt{(\lambda C\rho)_\ell} + \sqrt{(\lambda C\rho)_s}\right);$$

where ρ is density, C is specific heat, λ is thermal conductivity, and ΔT_* is the limiting attainable superheating for a given liquid at the corresponding pressure. The subscripts ℓ and s relate to the liquid and substrate. The temperature is taken as the average of T_0 = 77.4 K and the value T_* corresponding to the pressure in the cell, the limiting attainable temperature, which has been calculated for example in [2].

The pressure was limited to 2 MPa, although the critical pressure for nitrogen is $P_{cr} \approx 3$ MPa, because of the physically obvious reduction in the sensor signal on boiling as the pressure increases, i.e., as the critical point is approached. That reduction can be estimated from the [3] model: explosive growth of a vapor bubble produces an amplitude in the pressure wave $\Delta p \sim (\rho_\ell - \rho_V)(dR/dt)^2$, in which R is radius and ρ_V the vapor density. The growth rate is

$$\frac{dR}{dt} \sim \frac{q\sqrt{(\lambda C\rho)_\ell}}{A\rho_V\ L},$$

in which L is the latent heat of evaporation. The numerical values give $\Delta p_{0.1}/\Delta p_2$ as 300, while the ratio of the signal amplitudes at 0.1 and 2 MPa was 100, i.e., the values agree as to order of magnitude.

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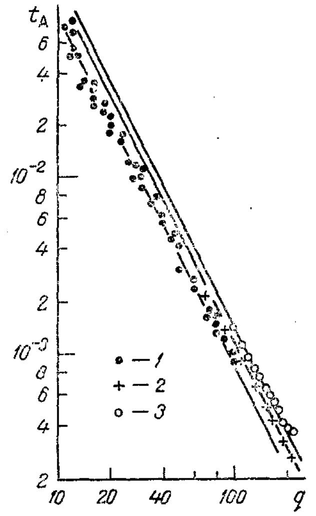

Fig. 1. Nitrogen boiling times t_A in sec in relation to heat flux density q at the heater in 10^4 W/m^2 at pressures in Mpa of: 1) 0.1; 2) 1.3; 3) 2.

TABLE 1. Limiting Superheating Temperatures

Pressure, MPa	$q\sqrt{t_A}$, W·sec$^{1/2}$·cm^{-2}	T_{*e}, K	T_{*c}, K
0,1	2,86	108,5±0,7	111
1,31	3,37	115,8±1,1	116
2,0	3,69	120,1±1,2	119

Table 1 gives the limiting attainable superheating T_{*e} from (1) via the measured t_A and the value calculated, T_{*c}, from homogeneous nucleation theory.

The conclusions are as follows:

1. To estimate the boiling time with a fast film heater, one can use (1) with the constants corresponding to the average of T_0 and T_* for the corresponding pressure, where the estimation accuracy is evident from Fig. 1 (Table 1 gives the standard errors).

2. Raising the pressure to 2 MPa increases t_A by a factor of 1.7, which can be used to improve the stability and reliability in the corresponding devices.

NOTATION

Δp, pressure step on boiling; $\pi = 3.14...$i $\Delta p_{0.1}$; Δp_2, pressure steps at pressures in cell of 0.1 and 2 MPa correspondingly; t_A, boiling delay from start of heating to appearance of sensor signal; q, heat flux density at heater; T_0 and T_*, bath temperature and limiting superheating.

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