объединенный
институт
ядерных
исследований
дубна

E8-88-361

Yu.P.Filippov, V.M.Miklayev, I.A.Sergeyev

TRANSIENT HEAT TRANSFER INTO SUPERFLUID HELIUM UNDER CONFINED CONDITIONS

Presented at the 12th International Cryogenic Engineering Conference, July 12-15, 1988, Southampton, UK

1988

INTRODUCTION

A variety of physical installations use superfluid helium as coolant. For such systems the so-called confined conditions are typical when the cooled surface is in close contact with restricted volume of liquid. Though the analysis of thermal stability limits as well as the optimization of cooling systems require exact information about various aspects of heat transfer into HeII, the dynamics of thermal processes at solid-HeII interface has not been studied in full till recently. Present report deals with some results of the experimental investigation of transient heat transfer into HeII restricted to annular channel.

EXPERIMENTAL SYSTEM

The structure of experimental specimen is as followes: a carbon film resistor (less than 1 μm thick, 54 mm long) serving both as an extremely fast response heater and high-sensitive thermometer, is deposited on a substrate – a ceramic hollow cylinder (11.5 mm ed, 80 mm long). When the sample is coaxially put inside a thin-walled stainless steel tube an annular channel with the internal surface heating is created, i.e. confined conditions are obtained. The specimen is suspended in a pool of saturated liquid helium (depth of submersion is about 10 cm).

Heater loading and thermometer resistance measuring are provided by an electronic apparatus complex. The voltage drops across the carbon film and standard resistor are measured at controlled intervals by two 12-bit 30-μs ADCs. The heater is loaded with electric pulse, the released power being time-stabilized. All the results we report are for square-top power pulses (6.4 s duration, about 20 μs leading edge time). The obtained data are plotted as $\Delta T(t)_q$ curves, where function ΔT is the superheating ($\Delta T = T_s - T_b$, where T_s is the solid surface temperature and T_b the bulk fluid one), variable t is the time from the pulse beginning, parameter Q is the heat pulse power. A microcomputer data acquisition system processed

and stored the results. The details of experimental arrangement have been published elsewhere [1,2]. Time strobes are generated to an accuracy of 1 μm. The annuli gap width d metering is in error by 0.02 mm. Uncertainties of measurements of ΔT and Q are estimated to be: superheating – about 10 mK at $T_s \le 5$ K and 0.05% all over the remaining range; power – 1-4%, where the larger values correspond to smaller Q-values.

Tests cover the following parameters variations:
- power from 0.05 to 20 W (heat flux 25-10000 W/m^2);
- annuli gap width from 0.40 to 3.20 mm, and special runs under pool conditions (i.e. without confinement);
- bath temperature from 1.41 to 2.15 K;
- two specimen orientations – vertical/horizontal;
- two configurations – both channel outlets open/one outlet is pluged (bottom in the vertical case).

RESULTS AND DISCUSSION

The typical results are plotted in Fig.1. The following modes of transient heat transfer can be selected:

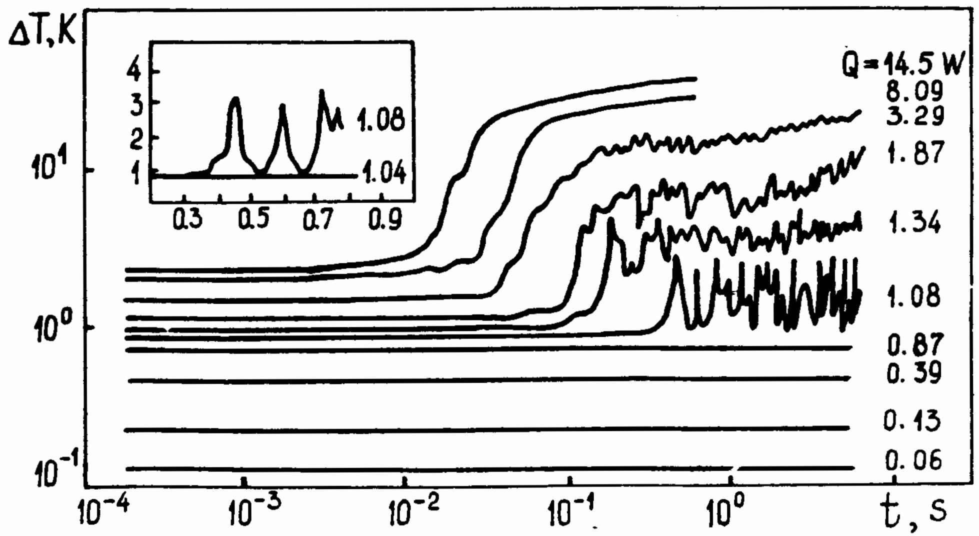

Fig.1. Superheating response elicited by step power pulse (horizontal orientation, d=0.40 mm, T_b=1.82 K).

- Steady state high-intensive first mode ($\Delta T(t)_q$ curves with parameters Q below Q_c = 1.06 W), controlled by the Kapitza resistance regime at solid-HeII interface and laminar regime of heat transfer in HeII. It should be noted, that times to reach such regimes as well as heat transfer coefficients agree well with data of other authors [3,4]. Only such mode is observed under pool conditions.

- Metastable high-intensive second mode (straight-line parts of curves at $Q > Q_c$), controlled by the same regimes as the first mode.

- Slightly transient low-intensive third mode (non-straight-line parts of curves at $Q > Q_f$ =3 W), stipulated by the transition to film boiling. There is a large (of two orders of magnitude) discrepancy between the obtained and published [5] times of film boiling onset.

- High transient fourth mode (wavy parts of curves at $Q_c < Q < Q_f$), controlled by the development of superfluid turbulence state followed by the change of hydrodynamical and thermodynamical helium states (metastable HeII → metastable HeI [6] e.g.). At the same time the rival processes: the propagation of turbulent fronts, removal of appeared phases, etc. are in action. If the pulse power is large enough to create the stable vapor-covered zone ($Q > Q_f$), then the "accelerated" film boiling takes place. In the opposite case ($Q_c < Q < Q_f$) there is no burnout origin, and $\Delta T(t)_q$ function represents a sequence of peaks (see insert on Fig.1). Peaks characteristics: their number, frequency, amplitude, width, etc.,vary signifucantly with every experimental parameter [2].

According to the above interpretation of the forth regime the Q_c, T_c and t_c values are selected to characterise the transient heat transfer. In this context the power Q_c corresponds to the critical heat flux, the instant t_c of the first peak beginning correponds to the vortecity generation time, and T_c is the heater temperature at the point of turbulization. The connection between the vortecity generation time and heat pulse power is approximated by power relation

$$t_c = A \cdot Q^{-3/2}, \tag{1}$$

where the coefficient A varies with bath temperature, channel size, etc. It should be noted, that the structure of eq. (1), the shape of the $A(T_b)$ function [2], as well as the magnitudes of t_c and A are similar to the results obtained [7] for one-dimensional channels.

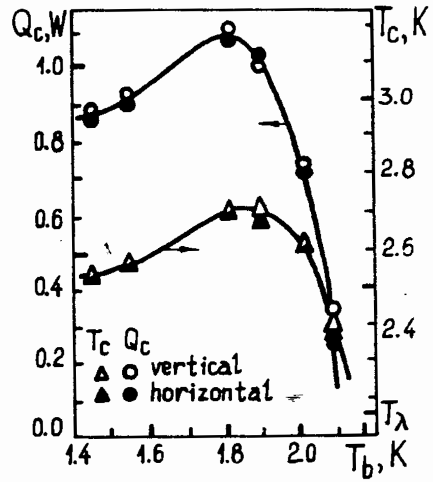

Fig.2. Bath temperature dependence (d = 0.40 mm).

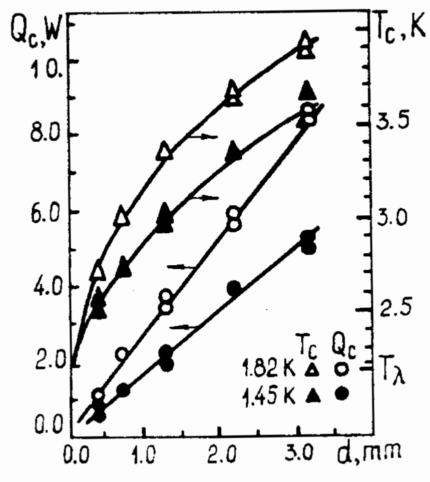

Fig.3. Annuli width dependence (both orientations).

Figure 2 shows the temperature dependence $Q_c(T_b)$ to have an unimodal shape characteristic for the power threshold parameters of heat transfer processes. Such dependence can be easily obtained through the two-fluid dissipative equations. On the contrary, the similar shape for the $T_c(T_b)$ dependence is unexpected.

The gap width dependences $Q_c(d)$ and $T_c(d)$ are plotted in Fig.3. It can be seen, that Q_c is a linear function of d. This fact, to all appearances, results from the combination of two factors: the d^2-dependence of axial component of heat flux, and the d^{-1}-dependence [8] of critical heat flux. There seems to exist no obvious explanation for rigorous influence of annuli width on T_c value. As to the orientation, there is no detectable influence of it upon the Q_c and T_c results, e.g. see Fig.2, with the exception of the $T_b \to T_\lambda$ case (when the phase separation in HeII volume under gravity takes place).

The presence of a plug at a channel outlet results in the reduction of Q_c value by a factor of two approximately, and also in the deminution of T_c magnitude on a few tenths of Kelvin. Thus, such configuration is to some extent analogous to a channel with the same annuli size, equal heat load per length unit, and two times as large in the axial direction.

CONCLUSIONS

There are both qualitative and quantitative differences between the regimes of transient heat transfer into HeII under pool and under confined conditions, stipulated by superfluid turbulence development in the latter case. Vortecity generation time is proportional to the -3/2 power of heat pulse. Critical pulse power as well as solid surface temperature at turbulization point vary unimodally with bath temperature and monotonically with gap width (the former dependence is linear).

REFERENCES

1. Miklayev V.M. et al. In: Proc. 13th Int. Conf. High Energy Accelerators, Aug. 1986, Novosibirsk. Nauka Publ., Novosibirsk, 1987, v.2, pp.53-58 (in Russian).
2. Miklayev V.M., Sergeyev I.A., Filipov Yu.P. JINR Rapid Comm., No.5(25)-87,Dubna, 1987, pp.31-38.
3. Katerberg J.A., Anderson A.C. - J. Low Temp. Phys., 1981, v.42, pp.165-176.
4. Haben R.L., Frederking T.H.K. - Adv.Cryog.Engng., 1975, v.20, pp.383-388.
5. Van Sciver S.M., Lee R.L. ibid., 1980, v.25, pp.363-371.
6. Nishigaki K., Saji Y. - Phys.Rev. B, 1986, v.33, pp.1657-1662.
7. Vinen W.F. - Proc.Roy.Soc.Ser.A, 1957, v.240, pp.128-143.
8. Tough J.T. Superfluid Turbulence. In: Progress in Low Temperature Physics, North-Holl.Publ.,Amsterdam, 1982, v.8, pp.133-219.

Received by Publishing Department
on May 24, 1988.

Филиппов Ю.П., Микляев В.М., Сергеев И.А.

E8-88-361

Нестационарная теплопередача к сверхтекучему гелию в стесненных условиях

Было предпринято исследование нестационарных тепловых процессов на границе твердое тело - HeII при подаче ступенчатого импульса тепловой нагрузки. Особое внимание было уделено изучению влияния геометрии экспериментального образца на динамику теплопередачи. При наличии стесненных условий обнаружен резкий срыв высокоэффективных режимов теплопередачи, вызываемый развитием состояния сверхтекучей турбулентности, причем зарегистрировано сопровождающее изменение температуры. Выделены некоторые характерные параметры, установлены их зависимости от экспериментальных условий.

Работа выполнена в Общеинститутском научно-методическом отделении ОИЯИ.

Препринт Объединенного института ядерных исследований. Дубна 1988

Filippov Yu.P., Miklayev V.M., Sergeyev I.A.

E8-88-361

Transient Heat Transfer into Superfluid Helium under Confined Conditions

Transient thermal processes at solid - HeII interface under step pulse heat load input are brought into exploration. Particular attention is given to the influence of geometry of experimental specimen upon the heat transfer dynamics. Dramatic breakdown of fine heat transfer modes caused by development of superfluid turbulence under confined conditions is revealed, and accompanying temperature excursions are traced. Certain character parameters are selected, their dependences on experimental conditions being established.

The investigation has been performed at the Scientifical-Methodical Division of High Energy Physics, JINR.

Preprint of the Joint Institute for Nuclear Research. Dubna 1988