CONTOUR OF LIQUID HYDROGEN NATURAL CIRCULATION IN THE UNIVERSAL NEUTRON SOURCE AT WWR-M REACTOR

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At present many research nuclear reactors are equipped with cold and ultracold neutron sources. Usually, these sources are chambers filled with some moderator and installed near a reactor core in the area of high thermal neutron flux and high radiation heating. Liquid hydrogen, deuterium or their mixture are used as the most effective moderators. The main task is to remove the high absorbed radiation heat from hydrogen so as to maintain the hydrogen in a liquid state at lower boiling temperature. The widely spread systems are "boiling". In these systems boiled away hydrogen gets from a chamber up to a condenser where it is condensed on the refrigerated surface and pours down to a chamber. An existence of boiled vapor in a chamber reduces efficiency of the source and limits allowed radiation heating.

The problem how to remove this heat is suggested to be solved by means of the method of natural circulation of subcooled hydrogen along the locked contour (vertical thermosiphon). This method can be compared favourably with those used before as it allows to maintain hydrogen in a subcooled state. The scheme of a natural circulation contour is shown in fig.1. Subcooling of hydrogen increases neutron intensity gain factor [1].

The condition of stationary hydrogen circulation along a contour is governed by equilibrium between buoyant force and friction force [2]:

$$\Delta\rho\, g h = \xi \frac{\rho V^2}{2} \frac{L}{d}, \tag{1}$$

$$\xi = \frac{0.316}{\mathrm{Re}^{0.25}}, \tag{2}$$

where $\Delta\rho$ is density difference between warm and cold fluid, g is gravitational acceleration, h is height of the contour, V is the velocity of hydrogen movement, L/d is ratio of the total contour length and the diameter of the pipe, ξ is friction coefficient for the turbulent flow.

If the height of the contour is large ($L \approx 2h$) the losses of pressure because of local resistance to liquid flow can be ignored and regime of circulation is independent of the height of contour. The mass flow rate of hydrogen in the contour depends on the thermal power absorbed in the hydrogen, the specific thermal capacity of liquid hydrogen and heating-up range.

Using the equation (1), (2) and carrying out an approximation of the temperature dependencies for density, viscosity and thermal capacity one gets the dependence established temperature difference (ΔT^{H2}) of warm and cold liquid with thermal power (Q) and equivalent diameter (d) of the contour pipe:

$$\Delta T^{H2} = 1.7 \frac{Q^{0.636}\,(W)}{T_m^{H2}\,(K)\, d^{1.73}\,(cm)}, \tag{3}$$

where T_m^{H2} is mean temperature of H_2. For the main temperature of hydrogen one can write, using equation for the mean temperature thrust (see fig.2):

$$T_m^{H2} = T_1^{He} + \frac{\Delta T^{He}}{1 - e^{-\beta}} + \frac{\Delta T^{H2}\,(1 + e^{-\beta})}{2(1 - e^{-\beta})}, \tag{4}$$

where $\beta = \dfrac{\Delta T^{He} + \Delta T^{H2}}{\Delta t}$, Δt is the mean temperature thrust. The exponential terms determine effectiveness of heat exchange only at low heat power. The final results of calculation are shown in fig.2 — dependence of hydrogen temperatures in warm and cold arms of the contour. Experimental data are also marked in fig.2.

Limited resources of the locked natural circulation contour with heat rejection from moderator to heat exchanger were analyzed. Correlation between limited heat power and minimum diameter of the contour pipe from equations (3) and (4) have been reported and are shown in fig.3 for the different mass flow rates.

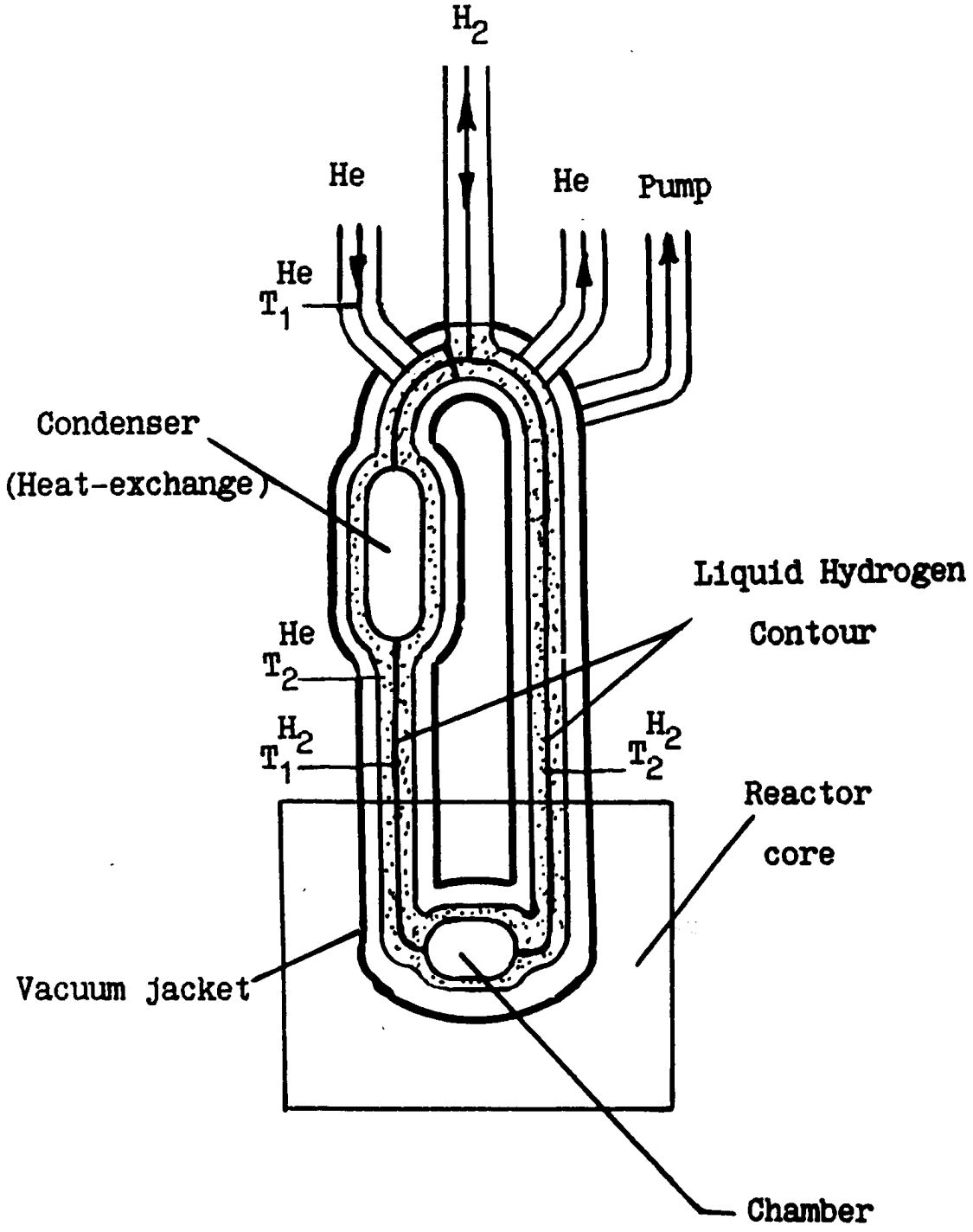

Fig.1. Scheme of subcooled liquid hydrogen thermosyphon

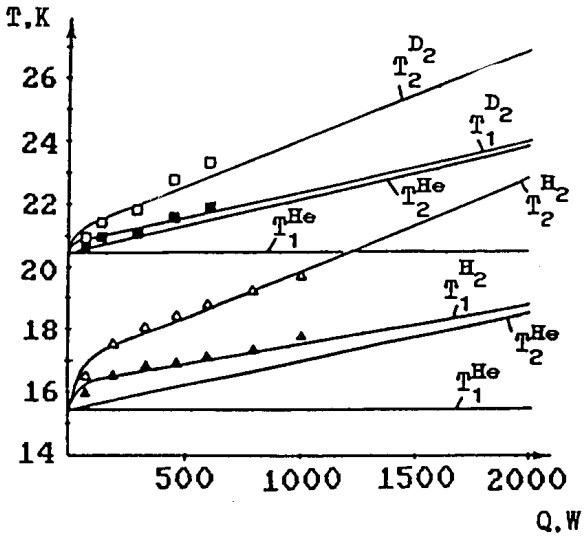

Fig.2. Plot of temperatures versus heating power

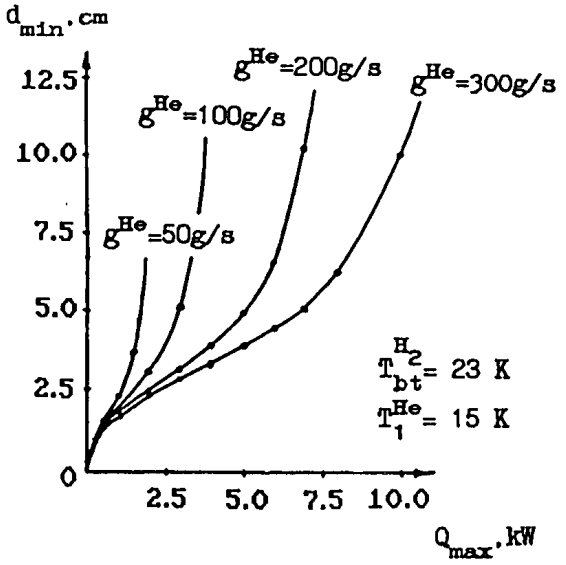

Fig.3. Dependence of pipe diameter of heating and on flow rate

$$d_{\min} = \frac{2\,Q_{\max}^{0.37}}{\left[T_{bt}^{H2} + T_1^{He} + \frac{Q_{\max}}{C_p^{He}\,g^{He}}\right]^{0.42}\left[T_{bt}^{H2} - T_1^{He} - \frac{Q_{\max}}{C_p^{He}\,g^{He}}\right]^{0.58}} \qquad (5)$$

This figure gives practical recommendation for the choice of a helium refrigerator according to flow rate, for the choice of pipe diameter of a liquid hydrogen contour according to radiation heating. The method developed and the experience obtained allow us to make high effective constructions.

References

1. Altarev I.S. et al. //JETP Lett., 1986. V.44. P.344.

2. Doose C., Tholen A. //Kerntechnick. 1971. T.13. S.525.