LOW-TEMPERATURE HEAT PIPES WITH SEPARATE CHANNELS FOR VAPOR AND LIQUID

Yu. F. Gerasimov, Yu. F. Maidanik,
G. T. Shchegolev, G. A. Filippov,
L. G. Starikov, V. M. Kiseev,
and Yu. E. Dolgirev

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The design of a heat pipe with separate channels for vapor and liquid, ensuring high heat flux densities for any orientation in the gravitational field, is discussed.

Existing designs of heat pipes with separate channels [1] present the same high hydraulic resistance to the fluid as ordinary heat pipes.

An increase in the length of the heat pipe, especially for work in the gravitational field, where the evaporator is above the condenser, leads to a considerable reduction of the heat flux density.

The case where heat is transferred in the direction of the gravitational field is a special one — in addition to the usual frictional hydraulic resistance, there is the loss incurred on overcoming the hydrostatic pressure of the liquid column. It is impossible to reduce this loss in existing designs of heat pipes.

Hence, the optimum diameter of the capillary-porous channels of heat pipes transferring heat over large distances in the direction of the gravitational field is very small (of the order of a few microns or fractions of a micron), and the pumping power of the wick is very low.

The main method of increasing the heat-transferring properties of long heat pipes (50 cm or more) is reduction of the frictional resistance of the liquid without altering the difference of capillary pressures corresponding to the optimum pore diameter in the evaporator as, for instance, is the case in arterial heat pipes [2]. The possibility of using such heat pipes at negative angles of inclination, however, is very limited [3]. At negative angles of inclination an increase in the pumping power of the wick and, hence, in the heat flux density can be achieved by reduction of the path of the working fluid through the capillary-porous material, i.e., reduction of the length of the wick and separation of the channels for vapor and liquid.

We present (Fig. 1) a design for a very long heat pipe capable of operating at any angle in the gravitational field. There is no wick in the heat flow section, and a capillary-porous packing is present only in the evaporator and condenser, or only in the evaporator.

All the parts of the body of the heat pipe are made of 0.3 mm thick stainless steel. The packing 2, 100 mm long and 25 mm in diameter, consists of fine-pored nickel and fits tightly in the evaporator casing. The open porosity of this packing is 62%. In the evaporation zone, close to the heating surface, the evaporator has 16 vapor channels 2.5 mm in diameter (section A—A). There is a compensation cavity 7 in the packing on the liquid-feed side.

The diameter of the vapor channel 5 varies: In the region of the evaporator it is 10 mm, and over the rest of the length it is 5 mm.

The diameter of the liquid channel 6 is 3 mm. The condenser 3 is 80 mm long and has an outer diameter of 20 mm. The packing 4 of the condenser consists of several layers of nickel gauze with mesh size 0.125 mm.

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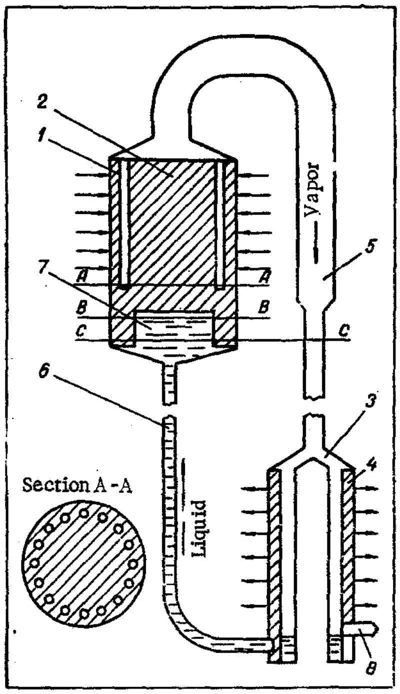

Fig. 1

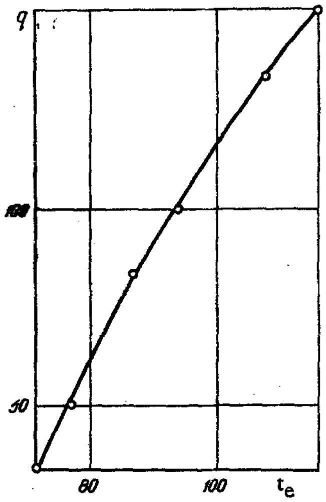

Fig. 2

Fig. 1. Diagram of heat pipe: 1) evaporator; 2) evaporator wick; 3) condenser; 4) condenser wick; 5) vapor channel; 6) liquid channel; 7) compensation cavity; 8) connecting branch.

Fig. 2. Plot of heat flux q, W/cm^2, against evaporator temperature t_e, °C.

The condenser has a connecting branch 8 for evacuation of the tube, filling it with the working fluid, and for final sealing-off. The total length of the tube (the distance between opposite ends of the evaporator and condenser) is 120 cm. The heat pipe is filled with the working fluid to the level C — C. Thus, when the pipe is not in operation the wick in the evaporator is always in contact with the working fluid and is saturated with it.

When the evaporator is heated the vapor pressure drives the liquid from the lower part of the vapor channel and condenser into the compensation cavity. The volume of this cavity must be not less than the total volume of the part of the vapor channel and condenser which becomes free of working fluid under nominal load.

The condensate becomes overheated as it moves through the liquid channel. The most dangerous spot for boiling of the liquid is the compensation cavity, where the encroachment into the metastable region is greatest.

If the temperature in the compensation cavity is above the permissible level, the feed of liquid to the evaporator wick may be interrupted, and the tube will cease to operate. This undesirable effect can be prevented by additional cooling of the working fluid after condensation, an increase in the permeability of the evaporator wick, and a reduction of its thermal conductivity. If the heat pipe operates only at negative angles of inclination there is no need for a wick in the condenser.

Figure 2 shows a plot of the axial heat flux density in a vertical water heat pipe against the evaporator temperature t_e, for the case where the temperature of the condenser coolant is 35-40°C. The average cross section of the pipe was used in the determination of the heat flux density.

The power transferred by the heat pipe was determined from the amount of heat taken from the condenser (Fig. 3). The loss in the heat flow path was ignored.

The advantages of a heat pipe of this design are:

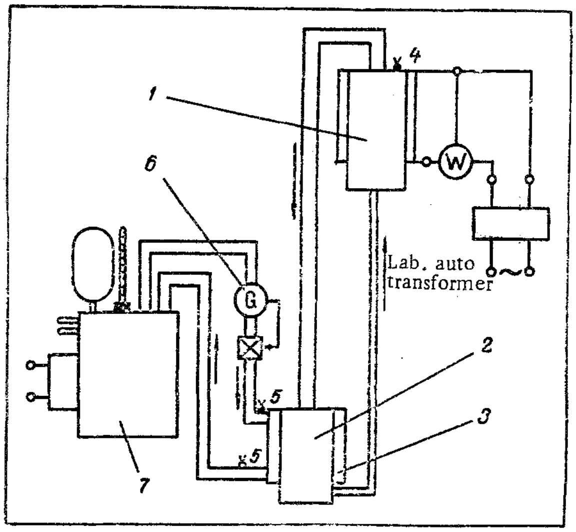

Fig. 3. Test setup for heat pipe: 1) evaporator; 2) condenser; 3) cooling jacket; 4) copper–Constantan thermocouple; 5) differential thermocouples; 6) flowmeter with flow regulator; 7) thermostat for cooling liquid.

1) there is no danger of separation of the liquid column from the evaporator wick;

2) the length (height) of the heat pipe can be increased, other conditions being kept the same, by an increase in the degree of useful overheating of the working fluid;

3) the size of the wick and the weight of the heat pipe can be reduced;

4) the vapor does not react with the liquid anywhere in the heat flow section;

5) fabrication of wicks is simple, and they can easily be fitted in the heat pipe;

6) the pipe can be flexible (in the form of a coil), and the transmission of vibrations from one end to the other can be reduced;

7) the heat pipe can have any desired configuration;

8) the vapor and liquid channels can be constructed separately in assembly of the pipe;

9) heating of the condensate by the vapor can be completely eliminated and, if necessary, the liquid can be further cooled after condensation;

10) it is very easy to investigate the operation of the heat pipe (measurement of temperatures, liquid flow, pressure drops, independent investigations of the operation of the evaporator and condenser, observation of the operation of the vapor and liquid channels by constructing them of transparent materials, and so on);

11) the design of the heat pipe allows parallel operation of several evaporators on a common condenser or one evaporator on several condensers.

Investigations showed that the heat pipe can operate under vibration and still work after heavy impacts.

Pipes of this design more than 2 m long have been constructed and operate effectively in a horizontal position and at negative angles of inclination. Heat pipes of this design can be used to cool electronic equipment, primarily semiconductor components.

LITERATURE CITED

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