DEVELOPMENT OF HEAT REMOVING SYSTEMS ON BASE OF HEAT PIPES WITH POWDER CAPILLARY WICK

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Abstract

Heat pipes are assuming increasingly more and more importance as an efficient heat removal system in industrial equipment and processes where large amount of heat flux is involved. Different applications require different types of heat pipes. Nowadays powder capillary wicks are widely used in the great field of heat pipe applications. Therefore it is very important to recognize what of mentioned types is appropriate in definite conditions. This paper is the review of heat pipe with metal powder wicks applications in heat removing systems.

KEYWORDS

heat removing, heat pipe, powder capillary wick.

INTRODUCTION

The effective heat transfer and maintenance of thermal modes of various systems and equipment is an urgent problem of modern engineering. Within the latest 30 years heat pipes are used sufficiently as base components of heat removing systems. The principal scheme of operation of a heat pipe is shown in Fig. 1. The functioning principle of heat pipe is based on a closed evaporation/condensation cycle of a heat agent inside the heat pipe; that enables to transfer large heat flows along the heat pipe axis with little temperature drop between the evaporation zone and condensation zone. The heat flow transferred from the heat source to the evaporator of the heat pipe prompts evaporation of the heat agent from a capillary structure into a vapor channel. The vapor flow under the pressure gradient is transferred to the condensation zone via the vapor channel and is condensed there due to heat rejection from the heat pipe housing by natural or forced convection, radiation or heat conductance. The condensed phase returns to the evaporator, gravity counteracting, via the porous capillary structure. The capillary structure provides, besides liquid heat agent transfer, high heat transfer coefficient on the inside evaporator wall (low heat resistance of the evaporator) and eliminates temperature pulsation in it.

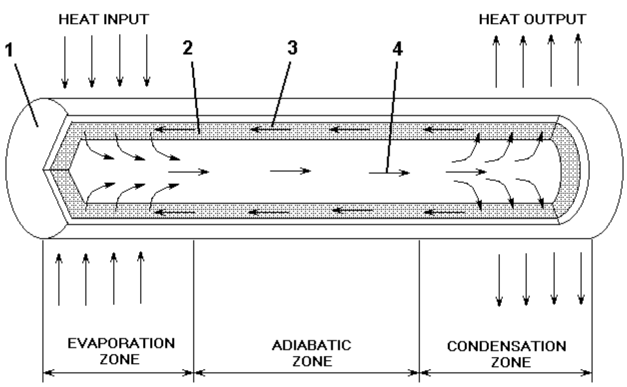

Fig. 1. Scheme of heat pipe operation: 1 – casing, 2 – capillary structure, 3 – working liquid, 4 – vapor

The main advantages of heat pipe are:
- unprecedented high heat conduction – 2–3 orders higher than that of an aluminum or copper;
- small size and low weight;
- ensured capability of stable operation at any disposition;
- perfect ability to keep heat transfer agent in the capillary structure at random dynamic load;
- high reliability and long service life (up to 10–15 years);
- rather simple production technology;
- easy for production automation;
- low cost.

The unique physical properties of heat pipes allow to design and produce perfect structural members for air cooling systems used for different industrial objects, i. e.: power semiconductor devices, separate units and modules of radio and electronic equipment, cabinets with numerical programmed control, electric motors.

Heat pipe are indispensable in production of recuperative heat exchangers – waste heat utilizers. The application of heat pipes in heat exchangers enables:
- to increase production and economical efficiency;
- to simplify the device structure;
- to diminish weight-dimensional characteristics;
- to minimize expenditures for service and maintenance;
- to increase the device reliability.

Heat pipes can be successfully used not only in radio-, electrotechnical- and power industries, but in engineering, metallurgy, light, food and chemical industries, in construction, transport, agriculture and medicine for heat transfer and heat setting of different installations.

HEAT SINKS FOR COOLING POWER SEMICONDUCTOR DEVICES

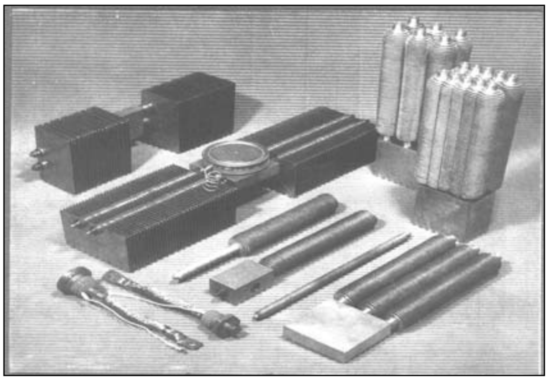

Fig. 2. Heat sinks on the base of heat pipes

Heat sinks on the base of heat pipes with powder capillary structure (Fig. 2) are intended to be used for natural and forced convection cooling powder semiconductor devices of 40–80 mm diameter and power load 320–630 A. The heat pipe heat thinks can be also used for cooling and heat setting of transistors and modules in radio electronics with heat losses 120–360 W.

High equivalent heat conduction, small dimension and weight of the unified heat pipes enables to use them for developing heat sinks with 20–40 % less weight-dimensional characteristics as compared to conventional cast-en-block rolled heat sinks. The heat sinks are intended for operation under environment temperature range from – 60 °C up to 45 °C, contact surface heating limit is up to 190 °C.

The application of the heat sink enables:
- to increase heat load for powder semiconductor assembles in electrical converting devices;
- to diminish weight-dimensional characteristics and to develop converters of simpler design;
- to unify the electrical converters design;
- to lower maintenance-service expenses, to increase the device reliability

The heat pipe heat sinks are intended also to be used for forced air cooling of powder semiconductor devices (tablet- or pin-type) of 30–80 mm diameter and powder load 320–2000 A.

MINIATURE HEAT PIPES

The problem of thermal control of electronic elements having the tendency of miniaturization and corresponding increase of specific heat energy evolving is especially urgent. For example, metal oxide semiconductor controlled thyristors can dissipate up to 300 W/cm^2 [1]. In complete evaluation of the qualities of one or another cooling system important parameters except for heat transfer characteristics are also: mass, size, simplicity of positioning and cost. From this point of view miniature heat pipes of conventional type (Fig. 3) have indisputable advantage before other cooling systems. Use of miniature heat pipes with cross size limited by meaning of 3–4 mm for cooling elements of telecommunication systems and PC components were begun 15 years ago [2]. The miniature heat pipes are very efficient devices for the achievement of high local heat removal rate and uniform temperatures in electronic components. However small area of capillary structure cross section causes also small heat transport capacity, especially at heat transport distance more than 200 mm. Therefore development of miniature heat pipes with high transport capacity is the urgent practical task.

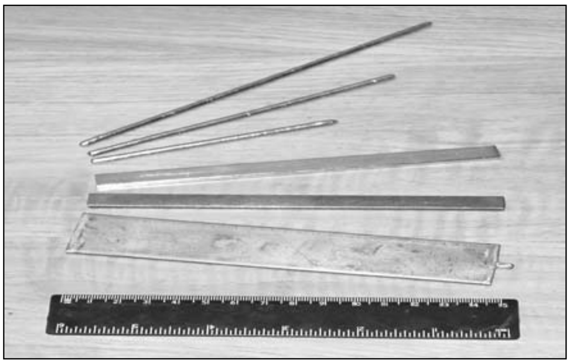

Fig. 3. Miniature heat pipes

ARTERIAL MINIATURE HEAT PIPES

For solution of this task a design of the miniature heat pipe with an arterial powder capillary structure was developed. The design of the arterial miniature heat pipe is presented in Fig. 4.

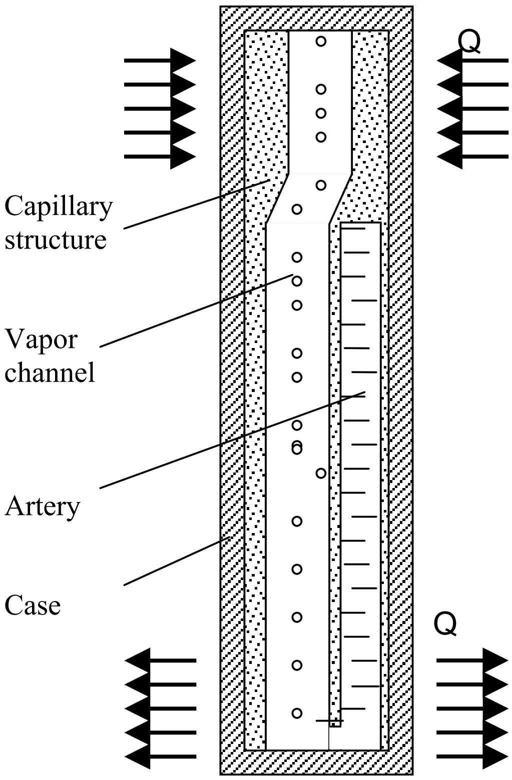

Fig. 4. Scheme of longitudinal section of arterial miniature heat pipe

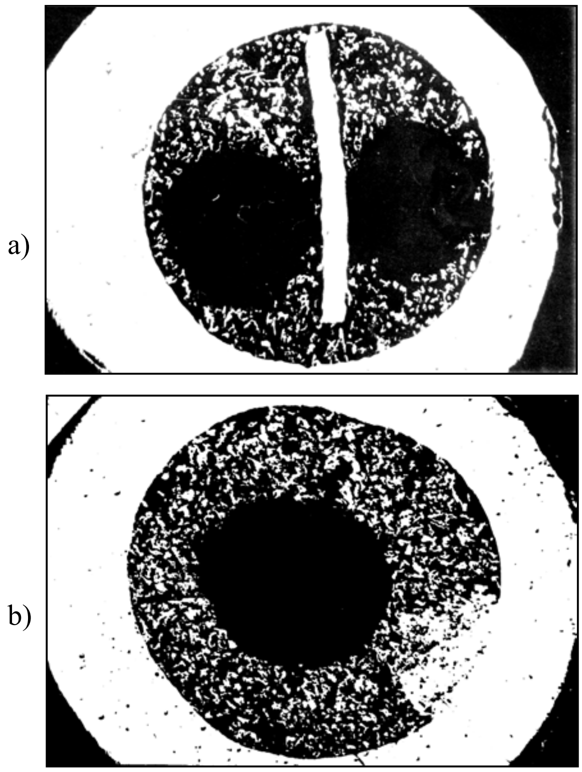

Fig. 5. Photograph of cross-section of arterial miniature heat pipe in transport zone (a) and in evaporation zone (b)

The basic feature of the design is presence in the capillary structure of a thin (diameter less than 1 mm) artery, in which condensate is delivered to evaporation zone under action of vapor pressure. To avoid the formation in the artery of vapor bubbles the artery doesn't pass through evaporation zone, and ends up some mms before it. Fig. 5 illustrates a variant of real device of powder arterial capillary structure. The outside diameter of the copper case is 3 mm, thickness of a wall is 0.5 mm. For reliable separation of artery and vapor channel in condensation and adiabatic zones the copper plate with thickness of 0.2 mm is used.

In order to check the serviceability of described miniature heat pipe design two heat pipes "copper-water" was made and tested. Design parameters of heat pipes are presented in Table 1.

Table 1. Design parameters of heat pipes

Parameters	Heat pipe 1 (hp 1)	Heat pipe 2 (hp 2)
Outside diameter of pipe, mm	3	4
Inside diameter of pipe, mm	2	3
Total length, mm	200	300
Length of evaporator, mm	20	20
Length of condenser, mm	50	50
Diameter of vapor channel, mm	1.2	1.8
Diameter of artery, mm	0.6	1
Average pore diameter, μm	20	20

Results of experimental investigation of heat pipe heat transfer capacity in comparison with results of calculation are given in Fig. 6. Also here the results of calculation [3] of maximal heat transfer capacity of conventional heat pipes having the same geometrical sizes are given.

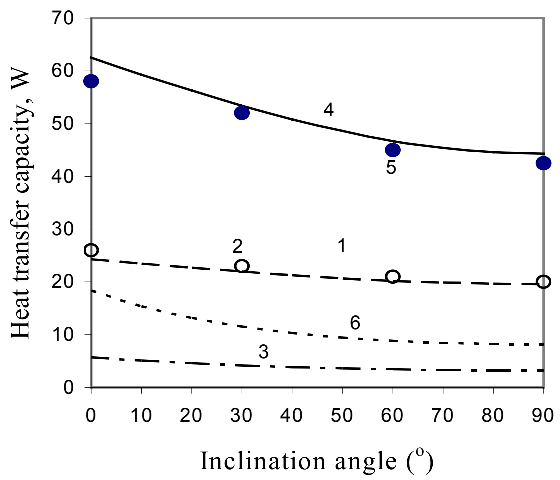

Fig. 6. Maximum heat transfer capacity of miniature heat pipes as function of inclination angle: 1 – calculation, 2 – experiment for hp 1, 3 – calculation for conventional hp Ø 3 mm, 4 – calculation, 5 – experiment for hp 2, 6 – calculation for conventional hp Ø 4 mm

THERMAL RESISTANT UNDERSPINNERET COOLER

Underspinneret coolers (USCs) are used in production process of fiberglass factories for cooling glass fibers going out from spinnerets. USC consists of a copper case with unions for cooling water flow and a set of soldered to the case parallel located heat removal lamellae with the sizes of about 60×13×1.5 mm. Temperature of the bottom surface of a platinum container with the liquid glass mass makes about 1200 ^{o}C, and the distance between this hot surface and the lamellae doesn't surpass 8 mm. The influence of high temperature causes heating the lamellae up to temperature of about 700 °C. This factor in combination with influence of an aggressive atmosphere of acids vapor causes corrosion of the lamellae. A result is complete failure of USC within a month.

Thermal resistant USC operating with use an evaporation-condensation cycle by a principle of a heat pipe have been developed (Fig. 7).

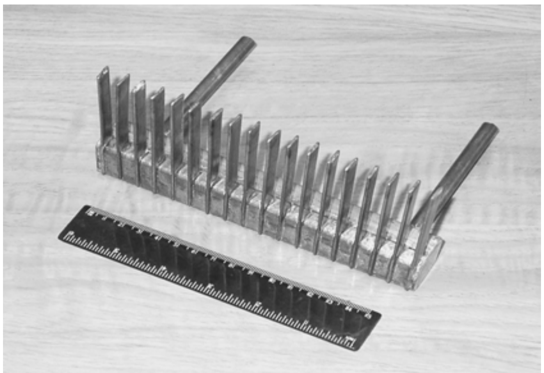

Fig. 7. Photograph of underspinneret cooler

The outside case (a copper tube with the closed end faces) has unions for cooling water flow. The copper tube with the closed end faces is located inside the case. Copper lamellae pass through the case and are soldered in the inside tube. The lamellae are hollow (wall thickness makes 0.5 mm), closed at outside end face and open into the inside tube. On the inside surface of lamellae walls there is a porous layer with thickness of about 0.1 mm consisting of sintered copper powder (Fig. 8). The internal spaces both of lamellae and inside tube connected between themselves are isolated hermetically from environment and filled with water distillate. Thus, in the USC design is used principle of heat pipe with hollow lamellae as an evaporator and inside tube as a condenser.

The photograph of cross-section of the lamella wall with the capillary structure is presented in Fig. 9.

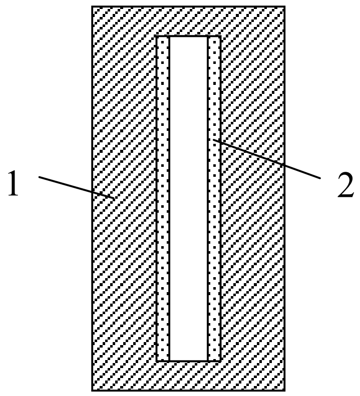

Fig. 8. Drawing of lamella cross-section: 1 – case, 2 – capillary structure

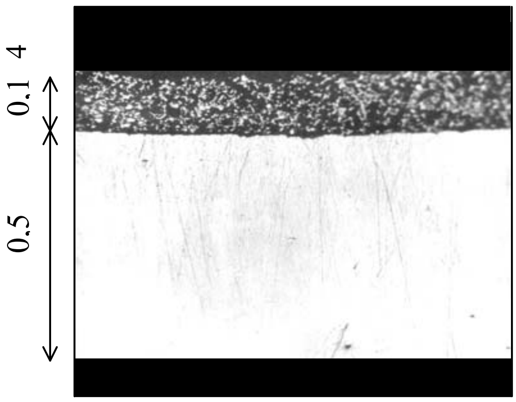

Fig. 9. Photograph of cross-section of lamella wall with the capillary structure

LOOP HEAT PIPES AND EVAPORATORS

Loop heat pipes are highly efficient heat-transfer devices. The first stages of loop heat pipes development were connected with the problems of space application. But with decreasing costs of these devices their application is efficient in many other spheres of engineering when a heat load with a high density is concentrated on a relatively small surface. So, loop heat pipes can be successfully used for cooling elements in power electronics, radioelectronic equipment, laser engineering, modular blocks of computers, nuclear power equipment.

As a rule all tested in presence cooling systems based on miniature loop heat pipe use evaporators (diameter about 6 mm) of the same design that loop heat pipe of lager size (with inverted meniscus). It means that thermal resistance of such cooling systems maintains quite large. However, relatively small sizes of PC components allow avoiding the inverted meniscus principle, organization in loop heat pipe evaporator of longitudinal motion of liquid and evaporation by the scheme of conventional heat pipe (with noninverted meniscus). By this way it is possible to use materials with high heat conductivity such as copper for evaporator case and capillary structure. It leads to essential decreasing of evaporator thermal resistance and cooling system price. Miniature loop heat pipe is imagined in Fig.10.

Another branch of our activity is production of evaporators of loop heat pipes with inverted meniscus. As a result of researches of liquid phase sintering process of binary powder materials on nickel and titanium base the technology of obtain of evaporators capillary structures immediately in evaporator case were developed. Produced evaporators are able to transfer heat load from 10 to 6,000 Wt. Their imaginations are given in Fig. 11.

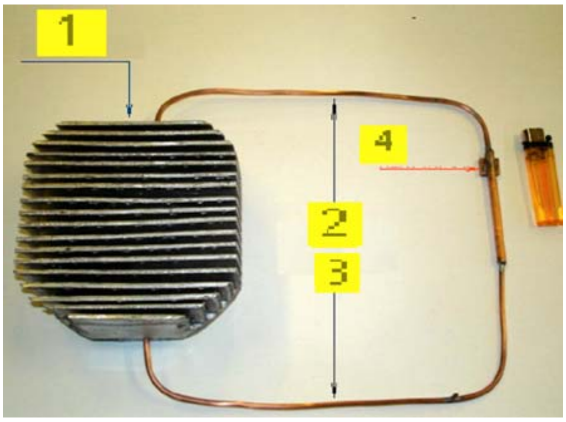

Fig. 10. Loop heat pipe: 1 – sink, 2 – vapor line, 3 – liquid line, 4 – heated surface

Fig. 11. Evaporators of loop heat pipes

TRANSFORMER COOLING SYSTEM

The case of electric distribution transformer as a rule have a jalousie for natural or forced air

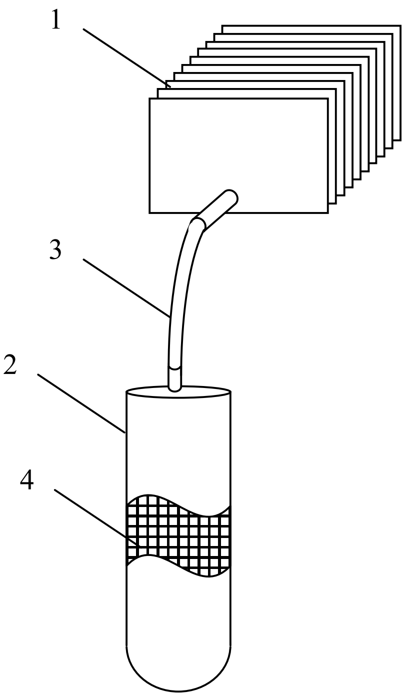

Fig. 12. Element of cooling system: 1 – condenser with radiator,2 – evaporator, 3 – hose, 4 – porous insert

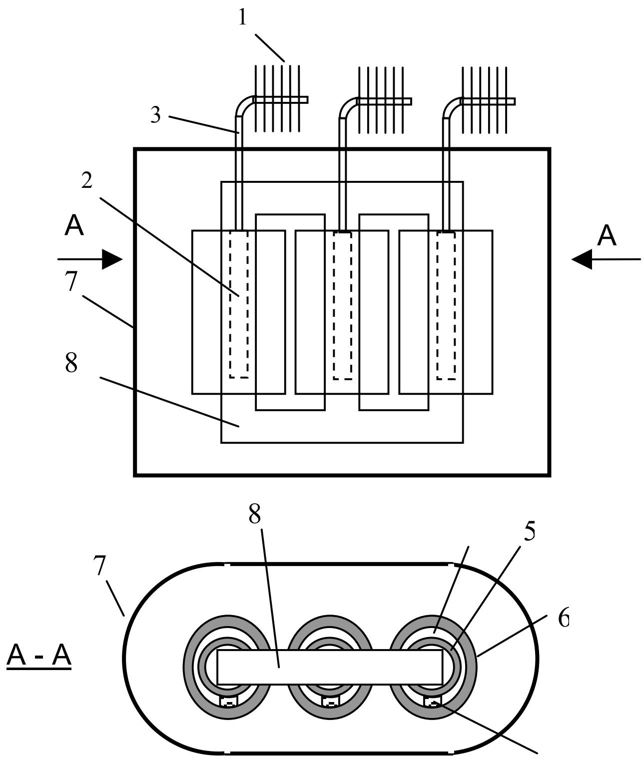

Fig. 13. Cooling system: 1 - condenser with radiator, 2 – evaporator, 3 – hose, 4 – gap, 5 – primary winding, 6 – secondary winding, 7 – case, 8 – magnetic core

cooling. This allows dust, water to penetrate inside and consequently confines the area of dry transformer applications. Case capsulation cancels mentioned problem but it requires heat removing from the transformer windings. It may be done with heat pipe based cooling systems. In Fig. 12 the heat pipe – element of transformer cooling system and in Fig. 13 sketch of heat pipe allocation in transformer are shown.

The heat pipe includes radiator-bearing condenser, evaporator made from elastic material, flexible hose connecting evaporator and condenser. There is a flat powder porous retaining insert within evaporator. The heat pipe is filled partially with liquid heat carrier. At inactive status the atmosphere pressure drives the elastic material of evaporator into the porous insert and replaces liquid into connecting hose and condenser. Only part of liquid keeps in evaporator, namely in pores of retaining insert. The evaporator thereby is flat.

At operating mode of transformer liquid in retaining insert comes to a boil. As vapor pressure within evaporator coves to higher than atmospheric one, elastic material is bowed out. The hard contact between evaporator and both windings is formed. The intensive heat exchange between transformer windings and liquid heat carrier in evaporator by means of heat transfer through elastic material is realized. Under heating liquid heat carrier poured out from hose and condenser boils strongly.

Vapor bubbles drives along hose into condenser where they are condensed realizing heat. The condensate under gravitation flows down in evaporator enclosing cycle of evaporation-condensation.

Fig. 14 shows the results of experimental investigations of transformer windings temperature with and without cooling system while start up. Heat pipe application allows essentially decrease the temperature of transformer windings.

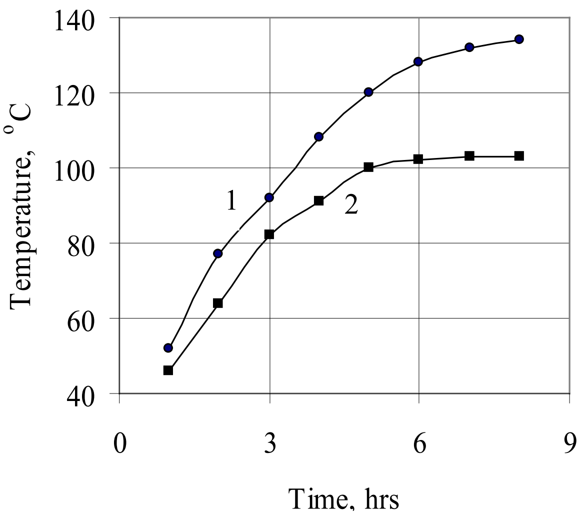

Fig. 14. Dynamic of transformer heating:
1 – without cooling, 2 – with cooling

CONCLUSION

Heat pipes with powder capillary wick have great variety of applications in different types of cooling systems. It is important that meanwhile technique developing new kinds of application are required and realized. In these conditions using of powder capillary wicks seems reasonable for satisfying heat removing requirements.

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