Experimental study of heat transfer in a heat pipe

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Heat pipes are a promising cooling system due to the fact of high efficiency and non-availability of moving parts such as pumps. The experimental investigation of heat transfer in a flat heat pipe has been carried out. The temperature field on the heat pipe has been evaluated using an infrared camera and K-type thermocouples. The IR-camera data and K-type thermocouple data have been compared. The linear dependence of the power supplied to the evaporator on the temperature difference between the evaporator and the condenser is shown.

1. Introduction
One of the most important research topics in our days, which will remain urgent for a long time, is the problem of efficient heat transfer. The use of heat pipes is a promising direction in the fields of solar energy, geothermal energy, aerospace industry, as well as cooling electronic components due to the high thermal conductivity.

Heat pipes, as an invention, were created relatively recently, several decades ago, but despite this, they gained quite a lot of popularity. So, for example, when creating an electronic device, be it a personal computer, laptop, or mobile phone, one of the most important engineering tasks is the development of the cooling system for this device. Currently, to solve the problem of cooling microelectronics, heat pipes are widely used. Simplicity, long service life and the absence of moving parts, allows this type of device to serve humanity for decades.

Heat pipes are used in the space industry for cooling aircraft components, in atomic energy for thermal stabilization of nuclear reactor elements, and in everyday life for cooling microprocessors [1]. These applications of heat pipes can be expanded and complimented, but it can be argued that the practical application of heat pipes in industry and in everyday life will only increase [2].

The overview of heat pipe studies is presented in [3]. For such a short period of time, extensive tests and studies were carried out, and theoretical models were constructed describing the operation of heat pipes. The efficiency of the heat pipe was investigated depending on the wall and wick materials used, as well as the working fluid. The analysis of the compatibility of materials and working fluids is made, the design is improved. Optimal parameters and materials have been developed for specific temperature ranges and long service life. Due to the urgency of the problem, an increase in the number of publications on this topic is noticeable in the literature. Some authors attempt to summarize the available data and build a theoretical model that fully describes the physical processes inside a heat pipe.

The term "heat pipe" was proposed in the patent by Grover G.M. on behalf of the United States Atomic Energy Commission in 1963. This patent includes a theoretical analysis of the ongoing thermal processes. Under the leadership of Grover, a series of research and development was carried
out to create heat pipes. The first article on these studies was published in [4]. Grover's patent was not the first on this kind of device. Earlier, a similar development was proposed by an employee of General Motors Corporation, Gogler in 1942. The documents stated the following purpose of the invention: "... ensuring the absorption of heat, or in other words, the evaporation of a liquid at a point above the condensation area or the heat removal zone, without additional costs for raising the liquid from the level of the condenser". Later, the properties of such devices were evaluated, and in the future, scientists continued to study heat pipes. In the laboratory of Atomic Energy in Harwell (UK), researchers have been working on sodium heat pipes. This work was aimed at the use of heat pipes in nuclear power. Such studies were conducted under the direction of Nei and Busse at the Joint Nuclear Research Center in Ispra (Italy), which started in 1965. This laboratory was one of the most active in the study of heat pipes. In 1969 the first article devoted to the review of heat pipes in the USSR was published [5].

The heat pipe was first tested on an artificial Earth satellite in 1967 (case - stainless steel, working fluid - water, electrical heating), and in 1968 - used for the first time for thermoregulation of the Geos - B satellite (two heat pipes, case - aluminum alloy, wick - aluminum mesh, working fluid - freon- 11; used for temperature control of the equipment on board the satellite). Later, the practical application of heat pipes in the industry, from aviation, radio electronics to household appliances and medicine, was significantly expanded. This is due to the widespread use of fuel or heat consuming devices with multi-stage energy conversion processes. Commercial production of heat pipes began with RCA, from 1964. The company used the following materials to produce heat pipes: glass, copper, nickel, stainless steel, molybdenum. The following fluids were used as working fluids: water, cesium, sodium, lithium, and bismuth.

2. Experimental setup

In the present work, an experimental study of heat transfer in a flat heat pipe has been carried out. Heat pipe length 220 mm long with a porous filling was selected for the study. The cross section of the pipe is shown in Fig. 1. The thickness of the copper wall of the heat pipe is 0.33 mm. Next is a layer of porous filler (copper powder). The thickness of this layer is 1.4 mm and 0.9 mm along the long and short sides of the heat pipe, respectively. In the center of the heat pipe, there is a gas chamber with characteristic dimensions of 4.8 mm and 0.84 mm along the long and short sides of the heat pipe, respectively.

![Fig. 1. Heat pipe cross-section.](image)

The experimental setup is shown in Fig. 2. A heater is wound on the evaporator and is connected to a TTi QPX 1200L power supply. The condenser is cooled by a liquid heat exchanger into which water enters from the LOIP FT-211-25 thermostat. The condenser temperature was kept constant at 20°C.
Temperature is measured by thermocouples in the area of the evaporator, condenser and isothermal part. For accurate calculation of temperatures, 6 K-type thermocouples were used, one for each in the part of the evaporator and one for the condenser, and four for the isothermal part. The temperature field on the heat pipe was investigated using an infrared camera Titanium HD 570M.

![Experimental setup diagram](image1)

**Fig. 2.** Schematic diagram of the experimental setup.

### 3. Experimental results

The heat exchange of a heat pipe under various heat flows has been experimentally investigated. Figure 3 shows a comparison of data obtained from thermocouples with an infrared camera. It is seen that in the area of the evaporator and condenser, the temperatures are different.

![Temperature field graph](image2)

**Fig. 3.** Temperature field along the heat pipe at P = 20 W, measured using an IR camera and K-type thermocouples.
This is explained by the fact that in the area of the evaporator the infrared camera measures the temperature of the heater, and in the area of the condenser, it measures the temperature of the heat exchanger installed on the pipe. Thermocouples always show the temperature of the heat pipe itself. It is also seen that the temperature along the heat pipe is constant and slightly lower than the temperature in the area of the evaporator. Figure 4 shows the dependence of the power supplied to the evaporator on the temperature difference between the evaporator and the condenser. It can be seen that the power increases monotonically with increasing temperature differences.

![Graph showing the dependence of power supplied to the evaporator on temperature difference between evaporator and condenser.](image)

**Fig. 4.** The dependence of the power supplied to the evaporator on the temperature difference between the evaporator and the condenser.

**4. Conclusion**

In this work, an experimental study of heat transfer in a heat pipe with a porous filler was carried out using two independent methods, namely, by means of an IR scanner and K-type thermocouples. An almost linear dependence of the heat transfer capacity for a heat pipe with a porous filler has been established.

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