Some Properties of Heat Pipes with Magnetic Fluid as a Workload

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Abstract. Heat pipes have a unique place for electronic devices cooling. One possible working substance may be also the magnetic fluid. Some basic properties of magnetic fluids are discussed first. The aim of the work was to evaluate some properties of magnetic fluids as the workload of the heat pipes. Furthermore some new possibilities in the design of the heat pipes themselves filled with water and with magnetic fluid were laboratory tested. The results are graphically presented in an appropriate manner and photographically documented.

Keywords

heat pipe, magnetic fluids, thermal conductivity

1. Introduction

Heat pipes are used for highly efficient heat transport in pre-determined direction which is given by the physical shape of the heat pipe. The basic part of the heat pipe is an outer casing and workload, which is selected with respect to the range of working transmitted temperatures, which can be in a very wide range of Kelvin degree. Heat pipes are also divided into gravity that transfers heat mainly in the vertical direction and the capillary, where the heat transfer is less position dependent.

2. Theoretical Part

The heat pipe ensures high intensity heat transfer, which has a relatively limited transport control. In principle, the flow interruption of workload is usually, for example mechanically or by restricting activities of condensing part of heat pipe.

In this context the use of magnetic fluids and their properties as workload is offered. Magnetic fluids are suspensions of very fine ferromagnetic particles in the carrier liquid. These particles have an approximately spherical shape and a diameter in the nanometer range, generally 3 to 15 nm. Particles are mostly made of iron oxyde, such as Fe₃O₄ and exhibit super-paramagnetic properties, which mean that the permeability is greater than one. For this reason, the magnetic fluids are responding to an external magnetic field.

If the fluid is not affect with the magnetic field, the magnetic moments of the particles are randomly oriented and liquid outwardly appears nonmagnetic. Chemical and mechanical properties of the magnetic fluid are determined by the carrier liquid, while the magnetic properties are determined by particles and their concentration.

Typical magnetic fluid contains 5% (by volume) hard magnetic materials, 10% of a surfactant that modifies the surface adhesion and prevents direct contact of the individual particles and has anti-coagulation function and 85% (by volume) carrier liquid. The carrier liquid can be various, in our case is used water based magnetic fluid. Working temperature of the magnetic fluid is generally from -125 °C to 200 °C.
The magnetic field significantly changes some physical properties of magnetic liquids, for example in the growing field the viscosity increases. Due to the surfactant magnetic fluid remains partially liquid even in a strong magnetic field.

Magnetic fluids are colloidal solutions that are obtained synthetically. Magnetic fluids do not exist in the nature.

The magnetic force \( F \) applied on a spherical particle in an inhomogeneous magnetic field is equal to

\[
F = V \cdot \mu_0 \cdot M \cdot \nabla \mathbf{H} \quad [N]
\]

\( V \) – volume of the particle \([m^3]\]
\( \mu_0 \) – permeability of vacuum \([4\pi \times 10^{-7} \text{N} \cdot \text{Am}^{-2}]\)
\( M \) – relative magnetization between the particle and the liquid \([\text{Am}^{-2}]\)
\( \nabla \mathbf{H} \) – gradient of magnetic field intensity \([\text{Am}^{-2}]\)

Transferred thermal energy is determined by the geometry of the heat pipe and by the workload. In the case of using a magnetic fluid as the workload the influence to heat transfer is caused by the superposition of two effects:

a) The magnetic field pulls magnetic fluid from the evaporator and for the thermal transmission is less magnetic fluid available

b) Magnetic fluid creates at the place of magnetic field a closure which prevents the reverse flow of workload

These two events will cause growth of temperature difference between the evaporator and the condenser.

3. Experimental Part I.

The influence of cyclically present and absent an external magnetic field on the heat transfer in the heat pipe, during uninterrupted heating was examined. The copper heat pipe dimensions 500x8 mm was used, workload magnetic fluid Ferrotec EMG705 thinned with de-ionized water 1: 1. The pressure in the heat pipe was reduced to 30kPa using vacuum pump. Distance temperature sensors (thermocouples) 250 mm, a magnetic field of 0.5T perpendicular to the longitudinal axis of the heat pipe has been realized by two NdFeB permanent magnets and located 100 mm from the evaporator. Heating the pipe through an electric coil, power 10W, see Fig. 1.

The number of cycles was 20 and immediately followed. The curves of thermal conductivity do not differ from each other and the course of one cycle is shown in Fig. 2. The temperature difference between the evaporator and condenser of heat pipe is on the vertical axis.

Fig. 2. The temperature difference between the evaporator and the condenser depending on time

The graph shows that the return to the heat pipe normal function after removal of the external magnetic field is much faster than the interruption of thermal conductivity.

In the next part, the influence of periodic changes of the heating of the heat pipe to its functionality was examined. The same heat pipe as in the previous experiment was used. Evaporator of the heat pipe was periodically heated and cooled, the number of cycles was 20. The heat transfer was measured at the beginning and at the end of experiment. The measurement results did not differ from each other, the effect of cyclic temperature changes was not reported.

4. Experimental part II.

An experiment with the placement of iron cuttings (steel wool) inside the heat pipe was performed.

First the iron cuttings were magnetized outside of the heat pipe by a magnetic field of about 0.3T using NdFeB magnet. Subsequently, the magnetic flux density of this sample after the removal from the magnet was measured and it proved to be insignificantly small.

A glass tube of length 500 mm and of diameter 8 mm filled with de-ionised water with a volume of 2 ml was used. The pressure in the tube was lowered to 30kPa. Heating of the evaporator section of the tube was made using water bath at 85°C. Cuttings were placed in the middle of the tube and it showed that their presence has no influence to the functionality of the heat pipe. See Fig. 3.
Furthermore, the heat pipe was filled with 2.5 ml MK705 magnetic fluid thinned 1:1 de-ionized water. Pressure was reduced to 30kPa, liquid temperature decreased to 15 °C during pressure reducing. The function of heat transport was successfully tested, including workload capture in the place where iron cuttings were located. See Fig. 5.

The external magnetic field of 0.45T size was located to the place of capture (with metal cuttings). Under the assumptions its effect on heat transfer was not observed, water is diamagnetic. See Fig. 4.

Further, in about half of length of glass heat pipe was inserted metal grid see Fig. 6.
The magnet was attached to the place where was about 4 cm long iron grid inside the heat pipe. Interrupt function was observed, but certainly not better than without grid. **Iron grid benefit seems to be none.** See Fig. 7.

**Chart description:**
- Time 0-3 minutes: magnet attached
- Time 3-5 minutes: magnet removed
- Iron grid is placed 4cm above winding insulation
- Power input is 15W

**Curve 1:** coil and magnet with grid
**Curve 2:** condenser and magnet with grid
**Curve 3:** coil and magnet without grid
**Curve 4:** condenser and magnet without grid

**5. Conclusion**

The article describes the examination of the influence the working temperature’s cyclic periodic changes and the external magnetic field’s cyclic periodic changes on the function of the heat pipe filled with the magnetic fluid. After performing a given number of cycles, no effect on the thermal conductivity of the heat pipe was observed. Further is described the situation after the inserting the iron grid into the heat pipe. In case of using a magnetic fluid as the workload the positive influence on the heat flow interruption was not confirmed. On the contrary, the function of heat pipe was slightly restricted.

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**References**


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