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Visualization of heat transport in heat pipes using thermocamera

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Abstract Heat pipes, as passive elements show a high level of reliability when taking heat away and they can take away heat flows having a significantly higher density than systems with forced convection. A heat pipe is a hermetically closed duct, filled with working fluid. Transport of heat in heat pipes is procured by the change of state of the working fluid from liquid state to steam and vice versa and depends on the hydrodynamic and heat processes in the pipe. This study have been focused on observing the impact these processes have on the heat process, the transport of heat within the heat pipe with the help of thermovision. The experiment is oriented at scanning the changes in the surface temperatures of the basic structural types of capillary heat pipes in vertical position.

Keywords: Thermovision; Heat pipe

1 Introduction

The heat pipe is a hermetically closed pipe which is filled with working substance. By heating the evaporation section of the pipe the working substance starts to evaporate and flows through to the opposite side of the pipe. Here the vapour condenses and in the form of liquid flows down the walls of the pipe as a result of gravity or it is transported back to the evaporation section of the pipe through the capillary system. The transport

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of latent heat procured in this way significantly increases the effectiveness of transporting heat compared to transporting heat by the standard pipe. Heat flow transported by the heat pipe depends on the material of the pipe, working substance and their mutual compatibility. In case of the wick heat pipes the maximal possible transport of heat flow depends also on the capillary system, however mainly it depends on the hydrodynamic and thermal processes taking place during operation of heat pipe.

During operation of the heat pipe a phase change from liquid state to gas state and vice versa occurs. This paper is focused on observing the hydrodynamic and thermal processes which take place inside the pipe and affect the overall transport of heat through the heat pipe. Thermography is one of the ways with which it is possible to monitor these processes. Thermography is a method which allows us to observe these processes using the infrared sensor which measures surface temperature without contact of objects and consecutively digitally shows the temperature fields of the objects. The operation of the thermovision camera is based on this principle. Using thermovision camera the surface temperatures of the wick heat pipes related to time were scanned. Such method of monitoring heat pipe surface temperatures can be used to verify and test their correct functioning.

2 Experimental set-up

2.1 Used materials

The main construction material of heat pipes is usually metal with good thermal conductivity. In our case to make the heat pipe a cooper tube was used. Another important part of the wick heat pipes is the capillary system. The capillary system transports the working fluid in liquid state from the condensation section to the evaporation section. The choice of the capillary system for the wick heat pipes depends on many factors and only a few of these factors are related to the properties of the working fluid. The working fluid must have good thermal stability in relation to the specific working temperature and pressure. The most important requirements for working fluids are the following: compatibility with the capillary system and with the material of the pipe, high thermal stability, high state of heat, high thermal conductivity, low viscosity of the liquid and vapour phase, high surface tension, acceptable freezing point.

2.2 Test pipes

For the monitoring of heat transport dynamics the heat pipes with a sintered capillary structure were chosen which were manufactured of the Department of Mechanical Engineering of the University of Žilina. For the experiments three various capillary structures were made by sintering copper powders with granularity of 100 μm, 63 μm and 50 μm, applying the copper powder to the inner wall of the copper pipe (see Fig. 1).

Figure 1. Sintered structures.

Capillary structure of heat pipes made from cooper powder was sintered in the high thermal electric oven used in powder metallurgy. By this method a 1.5 mm thick coat of sintered capillary structure was created. Distilled water and 96% ethanol were used as working mediums in the considered heat pipes. The overall length of the heat pipes is 0.45 m, Fig. 2.

Experiment was realized in a special laboratory at our department. Before scanning, the surface of heat pipes was painted with white matt colour for better results of visualization. A sketch of the experimental stand for visualization of the heat pipe by thermocamera is shown in Fig. 3.

Figure 2. Water heat pipes with sintered capillary structure.

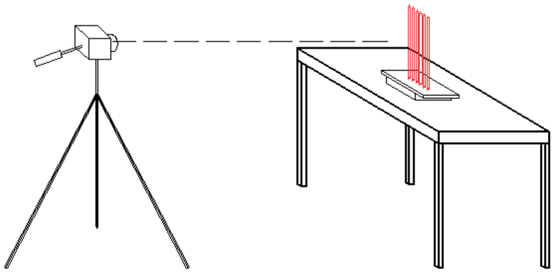

Figure 3. Schema of visualization of heat pipes by thermo camera.

3 Results from experiments and its analysis

Scanning surface temperature of heat pipes by thermovision camera was determined in case of operating heat pipes at the start and revealed their ability to transfer heat. Experiment was realized on six types of wick heat pipes. On the thermovision photographs are wick heat pipes with powder capillary structure. First three types on the right side are filled with water and the last three types of heat pipes are filled with ethanol as a working fluid. The first one on the right side is a heat pipe with capillary structure made from 50 μm copper powder, second and third ones from 63 μm and 100 μm copper powder, respectively. The next three heat pipes have the same wick structure as a first one and are placed in the same rank. For each experiment all six heat pipes were placed in to the thermal isolated container with water and then water was constantly heated form 20 °C to 90 °C.

On the obtained multicolour photographs from thermocamera there is clearly seen the increase of temperatures on the surface of the pipes from 24 °C to 85 °C during the heating time. In Figs. 4 and 5 one can see the increase of temperature along the length of the pipe no. 3 and a bit slower increase of temperature of pipes no. 5 and no. 6.

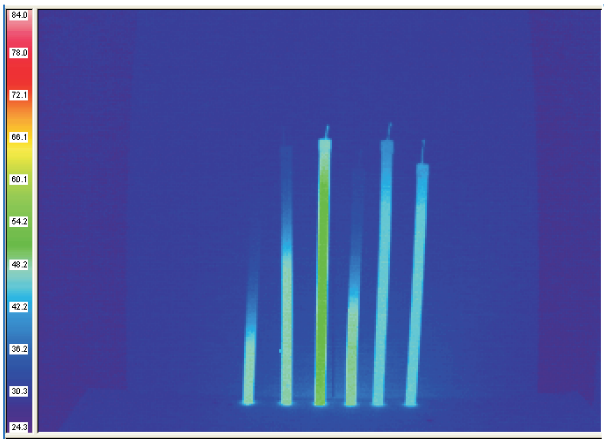

Figure 4. Development of surface temperature of heat pipe at heating time 7:16 min.

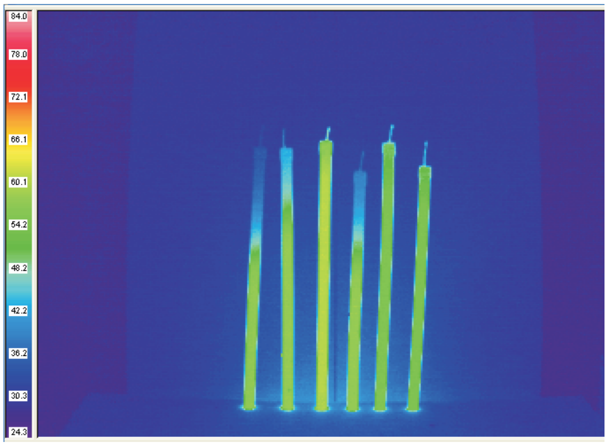

Figure 5. Development of surface temperature of heat pipe at heating time 9:50 min.

A slower dynamics of the increase of temperatures along the length of pipes no. 1, no. 2 and no. 4 at eleventh minute from the start of heating can be seen, as presented in Figs. 6, 7 and 8. It is interesting, in this case, that the pipes no. 1, 2 and 4 achieve higher temperatures in the evaporation and adiabatic sections than pipes no. 5 and no. 6. This may be caused by the fact that the capillary forces on the interface of the liquid and vapour phase in the condensate section of the pipe are not big enough to overcome the pressure losses caused by friction.

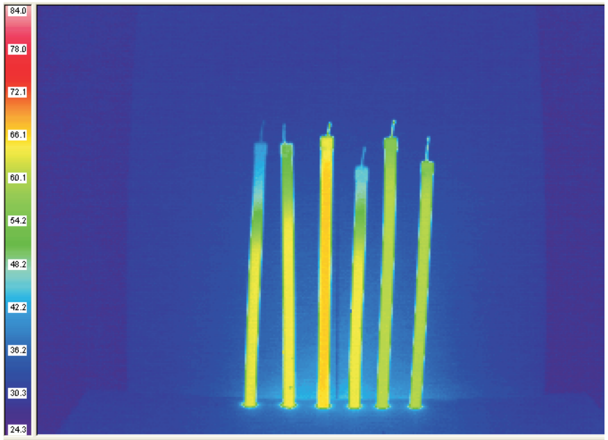

Figure 6. Development of surface temperature of heat pipe at heating time 11:04 min.

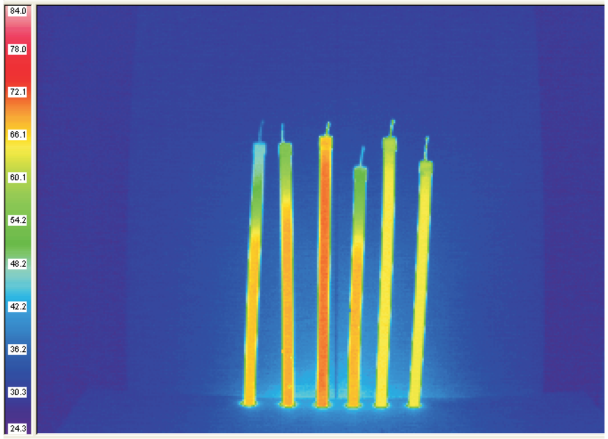

Figure 7. Development of surface temperature of heat pipe at heating time 11:58 min.

In Fig. 9 heat pipes at fifteenth minute from the start of heating are presented, when the temperature of the heat source obtained 90 °C. Almost every heat pipe in this time achieves linear temperature along the length and are single-coloured appertaining to temperature of 85 °C. This is a sign of correct operation of heat pipe because in order to facilitate a correct operation of heat pipes there must be a maximal temperature difference of 5 °C assured between evaporator and condensator. In case of heat pipes no. 1 and 4 temperatures in evaporator and condesator are not equal. This may be caused by geometry of capillary structure or partly by construction of used heat pipes.

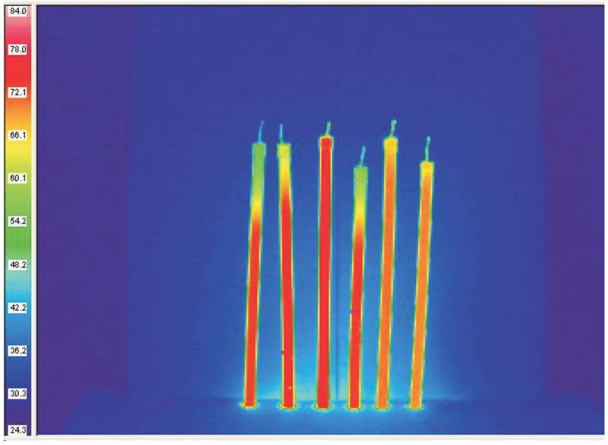

Figure 8. Development of surface temperature of heat pipe at heating time 12:56 min.

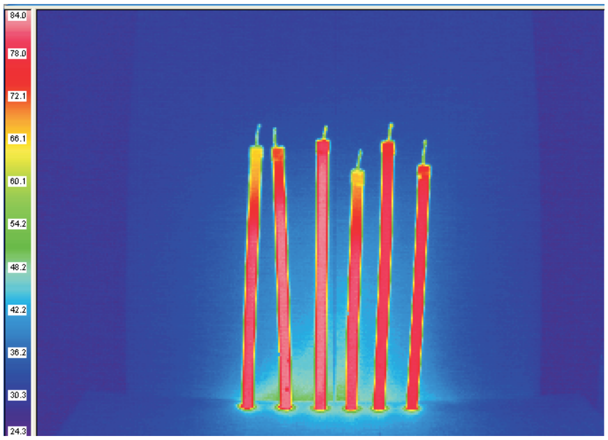

Figure 9. Development of surface temperature of heat pipe at heating time 15:11 min.

4 Conclusions

The experiment reveals that the most influencial factors on performance of the heat pipe are mainly geometric parameters of the capillary structures and thermophysical properties of the working fluid. The effect of these factors on the dynamics of the heat transfer by heat pipes can be easily identified by thermovision scanning surface temperatures of the heat pipes. Photographs from the thermovision camera showed the different behaviour of the monitored heat pipes, resulting from their various capillary structures and working fluid. The fastest start of operation on was monitored in heat pipe with capillary structure made from copper powder with the size of grains 100 μm. The slowest start was observed in case of heat pipes with capillary structure made from copper powder with the size of grains 50 μm. Even though all tested structures of heat pipes with both working fluids created eventually a balanced distribution of temperatures along the length after sufficiently long time. The result of experiment is that the performance of heat pipe is depending on the pace of operation development.

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