Thermal Imaging Heat Flux Transferred Working Fluid in Heat Pipes by Infrared Camera

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Abstract The main topics of article are heat pipes construction, thermal visualization of working fluid dynamics and research results interpretation. The work deals about investigate influence of working fluid and capillary structure on heat transport ability of wick heat pipe and heat flux transport by working fluid in loop heat pipe from evaporator to condenser evolution. The results of the work give us how the hydrodynamic and thermal processes which take place inside the heat pipes affect on the overall heat transport by heat pipe at start-up and during operation.
Keywords: Thermal Imaging, Heat Pipe, Heat Flux

1 Introduction

Infrared thermography is one of the most important sensing technologies applied to the detection and monitoring of manufacturing and production equipment. Until recently this sophisticated technology was prohibitively expensive, being driven primarily by military applications; over the last few years, however, the technology has improved and it has been introduced to high volume commercial and professional applications by innovative companies. This has brought the price down to a level which is opening up a host of new applications to use infrared thermography. One of new infrared thermograpy applications is thermal imaging heat flux transferred working fluid in heat pipes to verify and test heat pipe operation [1].
Heat pipe is device which is more and more used to heat transport industry branch, such as industries using thermal processes, heat transfer processes or in power electronics cooling, because use to heat transport latent heat contained in vapour at working fluid vaporization and thus significantly increases the heat pipe thermal conductivity.
The most cases of incorrect operation heat pipes is due to, carelessness in filling and sealing the heat pipe, wrong choice working fluid amount or the formation of non-condensable gas arising on account materials and working fluid incompatibility or impurities in the working fluid and materials of the heat pipe. These aspects affect the transferred heat flux which is reflected in the increase of the temperature difference between the evaporator and condenser part of the heat pipe. Scanning the surface temperature of the heat pipe during operation by infrared camera can be monitored transferred heat flux of the working fluid and thus determine whether the heat pipe working correctly [2].

2 Experiments

In this section are described experiments of thermal imaging heat flux transferred working fluid in various types' heat pipes by infrared camera. The experiments deals about influence of working fluid and capillary structure on heat transport ability of wick heat pipe, distribution of heat flux by working fluid and evolution of free convection from heat pipe condenser to the surrounding in loop thermosyphon and loop heat pipe.

2.1 Influence of working fluid and capillary structure on heat transport ability of wick heat pipe

The capillary system is important part of the wick heat pipe. The capillary system transports the working substance in liquid state from the condensate section to the evaporation section and basically limits the heat output transported by the heat pipe. The selection of the capillary system for the heat pipe depends on many factors and only a few of these factors are related to the properties of the working fluid. The working fluid has to have good thermal stability in relation to the specific working temperature and pressure. The most important requirements which the working fluid must have 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 vapor phase, high surface pressure, acceptable freezing or congealment point [3, 4].

2.1.1 Analysis influence of capillary structure on heat transport ability of wick heat pipe

This experiment was realized with heat pipes with sintered capillary structure made from copper powder with granularity of 100 µm, 63 µm and 50 µm. By scanning the surface temperature with the infrared camera the onset of the functioning and the ability to heat transfer of six various wick heat pipes was monitored. On the figures are heat pipes with sintered capillary structure of copper powder 50 µm, 63 µm and 100 µm. The first three heat pipes are filled with water and second three heat pipes are field with ethanol. The heat source for all types' heat pipes was the thermal water bath with adjustable temperatures from 20 °C to 90 °C [5].

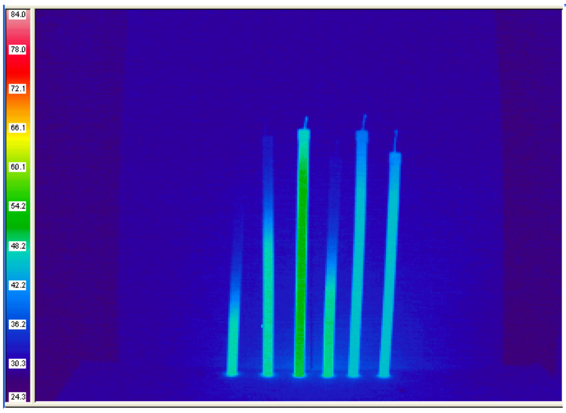


Fig. 1 Surface temperature development of heat pipes at time 7 min from heating start

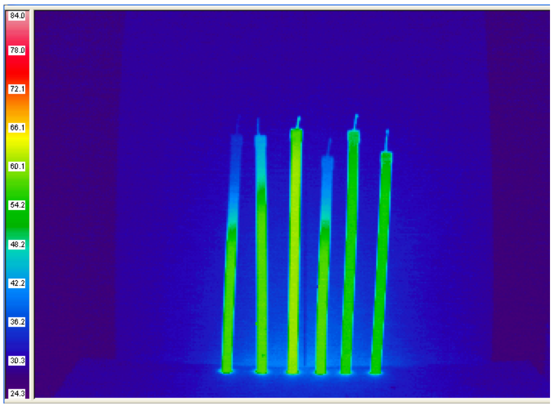


Fig. 2 Surface temperature development of heat pipes at time 10 min from heating start

On the figures is clearly to see the increase of temperature on the heat pipes surface from 24 °C to 85 °C, based on the color distinction. On the first two figures is seen the temperature increase along the whole length of the heat pipe no. 3 and a little bit slower temperature increase of the heat pipes no. 5 and 6.

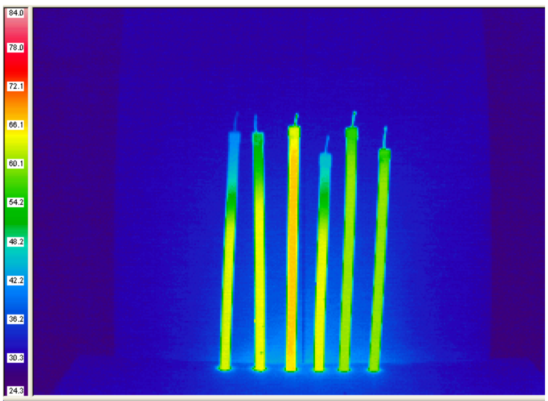


Fig. 3 Surface temperature development of heat pipes at time 11 min from heating start

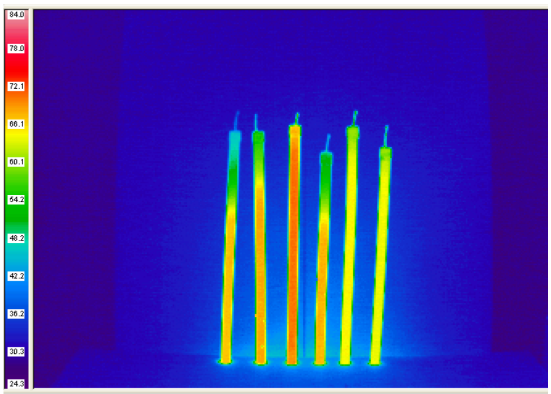


Fig. 4 Surface temperature development of heat pipes at time 12 min from heating start

On the next figure is seen slower equalization of temperature along the whole length of the heat pipes no. 1, 2 and 4, but compared to heat pipes no. 5 and 6 achieve higher temperature in the evaporation and adiabatic section. This may be caused by the fact that the capillary forces on the interface of the liquid and vapor phase in the condensation section are not enough strong to overcome the pressure losses caused by friction.

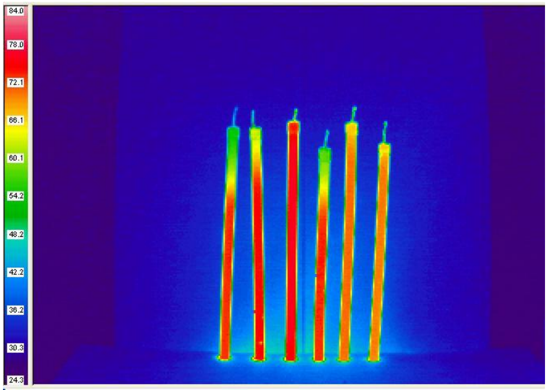


Fig. 5 Surface temperature development of heat pipes at time 13 min from heating start

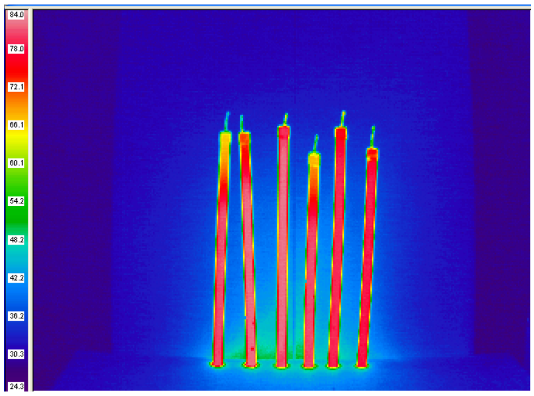
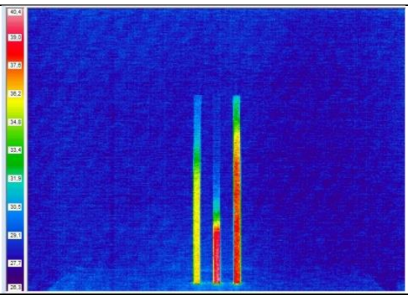
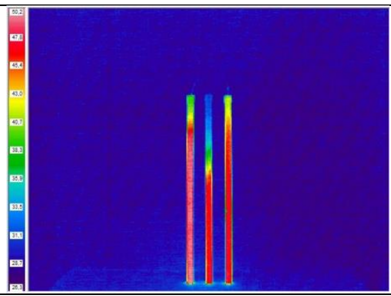
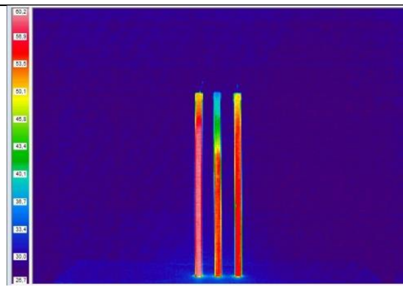
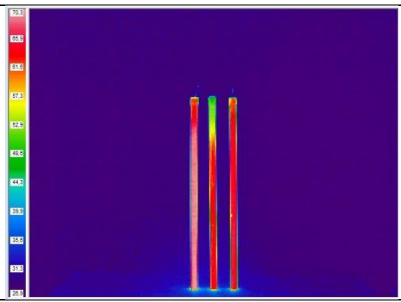
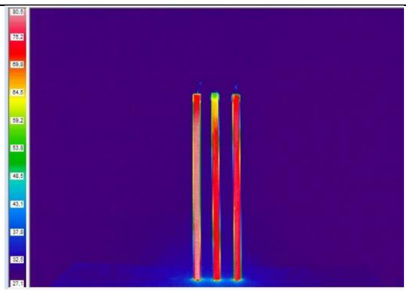
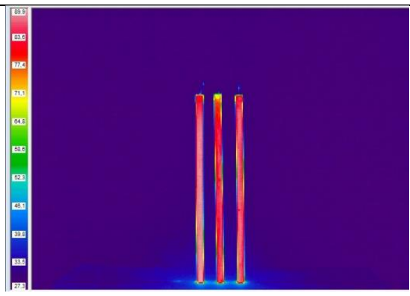


Fig. 6 Surface temperature development of heat pipes at time 15 min from heating start

2.1.2 Analysis influence of working fluid on heat transport ability of wick heat pipe

This experiment was realized with heat pipes with mesh screen capillary structure with mesh 200. Thermovision photos in table 1 show the heat transport dynamics of heat pipes with working fluids of ethanol, water and acetone at the same condition of working temperature from 40 to 90 °C [6].

Table 1 Thermovision visualization of mesh screen wick heat pipes with working fluids ethanol, water and acetone.

		
Working temperature 40 °C	Working temperature 50 °C	Working temperature 60 °C
		
Working temperature 70 °C	Working temperature 80 °C	Working temperature 90 °C

On the thermovission photos scanned by infrared camera is clearly see increase of temperature on the surface of the heat pipes depending on the heat source temperature. Multicolor scales on the left side of the photos determine scanned surface temperature. Blue and green colors are low temperatures, yellow and red colors are high temperatures equivalent to heat source temperature. Heat pipe visualization by infrared camera imagine thermal and hydrodinamical phenomenon inside the heat pipe. Coloring of the scanning surface plane displays speed of the working fluid vapor flow and volume of the mass flow transfer from evaporation to the condensation section of the heat pipe. On the photos 1, 2, 3, 4 and 5 where heat source temperature increase from 40 to 80 °C is to see on heat pipe no. 1filled with ethanol and no. 3 filled with acetone better and faster heat transport reaction than on heat pipe no. 2 filled with water. The slower reaction of the water heat pipe at startup cause different thermophysical properties of the water than acetone and ethanol. On the last photo at working conditions 90 °C every three heat pipes achieve uniform temperature along the length and have a single color. This experiment achieve that acetone and ethanol heat pipe operate at lower temperature better than water heat pipe but at higher temperature water heat pipe operate as well as acetone and ethanol heat pipe. Results of scanning surface temperature of the heat pipes by thermovision camera are show how does work heat pipes on the startup, how it does influence their heat transfer ability and if operate correct.

2.2 Heat flux transport by working fluid in loop heat pipe

This experiment was realized with loop heat pipe with sintered capillary structure made from copper powder with granularity of 50 µm. The condenser of LHP was created from finned pipe, so that heat loaded to the evaporator was dissipate to the surrounding by natural convection. The working fluid in loop heat pipe is acetone (50 % of LHP volume). On the figures 7 to 12 are shown thermal images of the loop heat pipe loaded by heat 60 W. On the figures is seen heat flux distribution by working fluid at the time.

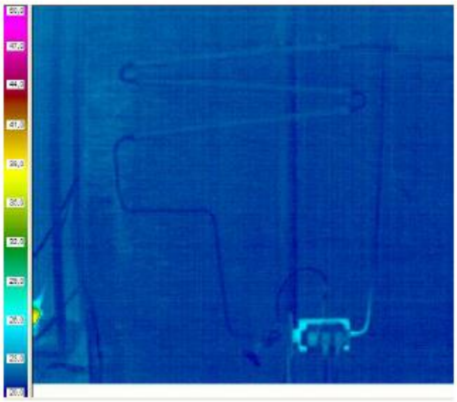


Fig. 7 Surface temperature develop of loop heat pipe at time 2 min from heating start

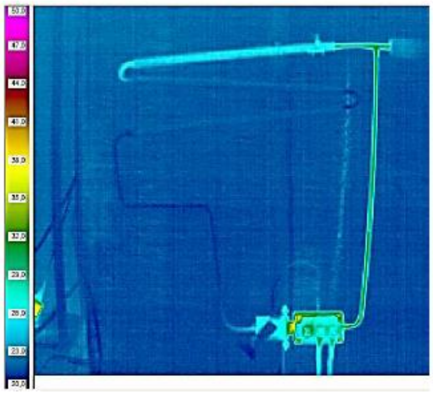


Fig. 8 Surface temperature develop of loop heat pipe at time 8 min from heating start

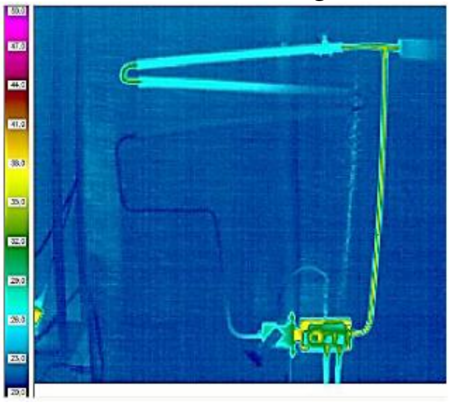


Fig. 9 Surface temperature develop of loop heat pipe at time 12 min from heating start

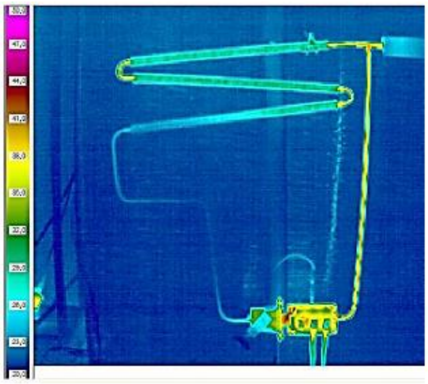


Fig. 10 Surface temperature develop of loop heat pipe at time 24 min from heating start

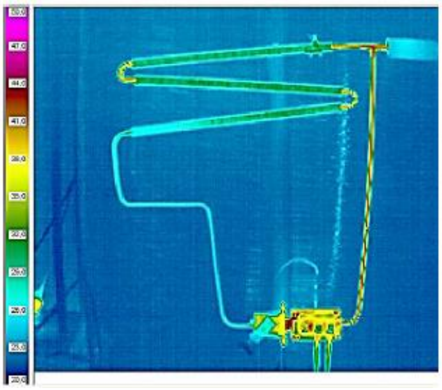


Fig. 11 Surface temperature develop of loop heat pipe at time 32 min from heating start

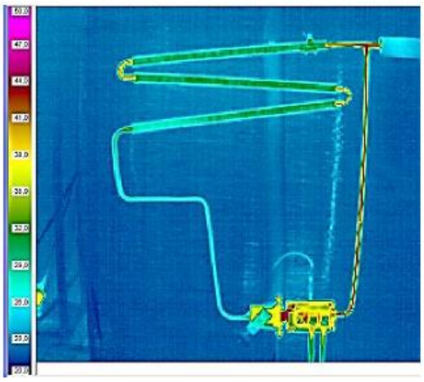


Fig. 12 Surface temperature develop of loop heat pipe at time 52 min from heating start

On the first four thermal images is seen startup of loop heat pipe, where is the heat flux gradually transferred by working fluid from evaporator to the condenser part. On the last two thermal images is see fully operated loop heat pipe without no temperature changes at time. There is seen different temperature between vapor line (on the right) and condenser line (on the left), too. The vapor line is hotter than the condensation line. It means that the vapors of the working fluid transfer all heat flux from evaporator (on the bottom) to the condenser (on the top). There vapor of the working fluid heat sink to the surrounding, condense to liquid and working fluid is return back to the evaporator.

3 Conclusions

These experiments show that the factors, which are influencing on performance of wick heat pipe, are mainly the geometric parameters of the capillary structures and the thermo physical 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 temperature of the heat pipes. Photos scanned by infrared camera show different behavior of the heat pipes, which is caused by various working fluids or capillary structures.
The influence of the working fluid on the heat transport ability of the heat pipe show that the heat pipe filled with acetone has fasted startup, heat pipe with ethanol has slower startup and heat pipe with water has the slowest startup. Even though that the water heat pipe has slowest start, at higher working temperature achieve uniform temperature along the length as well as acetone and ethanol heat pipes and this means that all heat pipes operate correctly.
The influence of the capillary structure on the heat transport ability of the heat pipe show that the heat pipes with capillary structure made from copper powder with grain size 100 µm has fasted startup and heat pipes with capillary structure made from copper powder with grain size 50 µm has slowest startup. Even thought all tested heat pipes achieve after longer time uniform temperature along the length, what means that all heat pipes operate correctly.
Thermal imaging of the loop heat pipe shows that the loop heat pipe loaded by heat 60 W has stabilized evaporator and condenser temperature after 30 minutes from startup. Its operation was in equilibrium state without any temperature changes on evaporator and condenser part at time and this means that operate correctly.

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