EPJ Web of Conferences 92, 02053 (2015)
DOI: 10.1051/epjconf/20159202053

Visualization of working fluid flow in gravity assisted heat pipe

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Abstract. Heat pipe is device working with phase changes of working fluid inside hermetically closed pipe at specific pressure. The phase changes of working fluid from fluid to vapor and vice versa help heat pipe to transport high heat flux. The article deal about construction and processes casing in heat pipe during operation. Experiment visualization of working fluid flow is performed with glass heat pipe filed with ethanol. The visualization of working fluid flow explains the phenomena as working fluid boiling, nucleation of bubbles, vapor flow, vapor condensation on the wall, vapor and condensate flow interaction, flow down condensate film thickness on the wall, occurred during the heat pipe operation.

1 Introduction

The thermosyphon (gravity assisted heat pipe) is shown in figure 1. The bottom is a heating (evaporation) section, the middle an adiabatic section, and the upper part a condensation section.
A small quantity of liquid is placed in a tube from which the air is then evacuated and the tube sealed.

The lower end of the pipe is heated, this causing that the vapour flows from the bottom to the condensation section where it is cooled and condensed into liquid. Then the liquid flows downwards along the wall as a very thin film. However, liquid plugs may form at high heat input. This entire cycle repeats in heat pipe again and again.

The Thermosyphon works on both conduction and convection mechanism. The heat from the heat source is transferred to the thermosyphons through conduction and inside thermosyphon heat convection occurs [1].
Since the latent heat of evaporation is large, considerable quantities of heat can be transported with a very small temperature difference from end to end. Thus, the structure will also have a high effective thermal conductance.

One limitation of the basic thermosyphon is that in order for the condensate to be returned to the evaporator region by gravitational force, the evaporation section must be situated at the lowest point [2].

The amount of heat that can be transported by these systems is normally several orders of magnitude greater than pure conduction through a solid metal [3].

A thermosyphon needs only a temperature difference to transfer large amount of heat, and are widely used in various areas of industry, such as chemical engineering, thermal engineering or thermal management systems with limited space applications and other heat recovery systems.

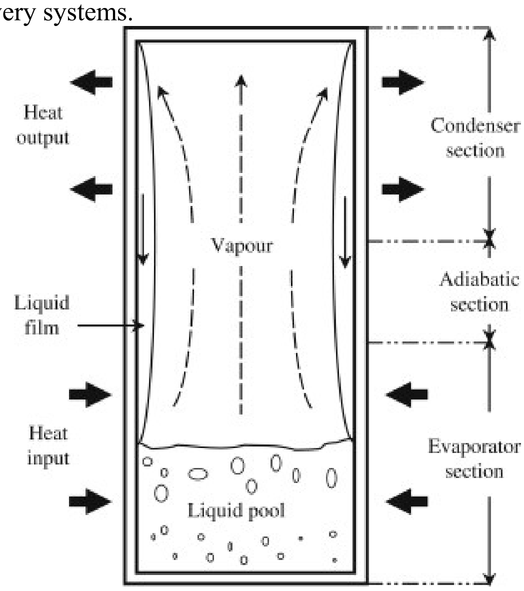

Figure 1. Working principle of the Thermosyphon [4].

2 Flow regimes in heat pipe

In heat pipe occurs two-phase flow regime. The two-phase regime is simplest case of multiphase, which means simultaneously flow of several phases. In case of heat pipe it is liquid-vapour phase.

The subject of two-phase flow has become increasingly important in a wide variety of engineering systems including heat pipes for their optimum design and safe operations. It is, however, by no means limited to today's modern industrial technology, and multiphase phenomena which require better understanding.

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Two-phase flows obey all of the basic laws of fluid mechanics. The equations are merely more complicated or more numerous than those of single-phase flows. The techniques for analyzing a 1 D flows fall in to several classes which can conveniently be arranged in ascending order of sophistication, depending on the amount of information which is needed to describe the flow.

Perhaps the first step in rendering this problem of flow regime in heat pipe is to break it up into various regimes, which are each governed by certain dominant geometrical or dynamical parameters. Part of the definition of the flow regime is a description of the morphological arrangement of the components, or flow pattern. An example of the complexity of two-phase flows is depicted in figure 2. That shows a sequence of flow patterns taking place in an evaporator of heat pipe as more and more liquid is getting converted to vapour. Complexity of the problem arises in different parts of the evaporator that requires different methods of analysis, and the problem of how one regime develops from another has to be considered too [5].

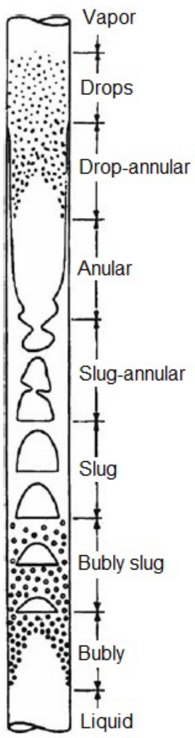

Figure 2. Two-phase flow schema [5].

Many presentations of flow pattern and flow regime were mapped out by numerous authors for given apparatus and specific components. For examples Inoue [6] deal with heated surface temperature fluctuation and flow pattern. On the other side Liu [4] pointed out thickness of liquid film in heat pipe.

The flow inside a heat pipe is more complex than the Nusselt model [7]. This can be demonstrated by examining a more realistic description of a liquid film in a heat pipe as in figure 3.

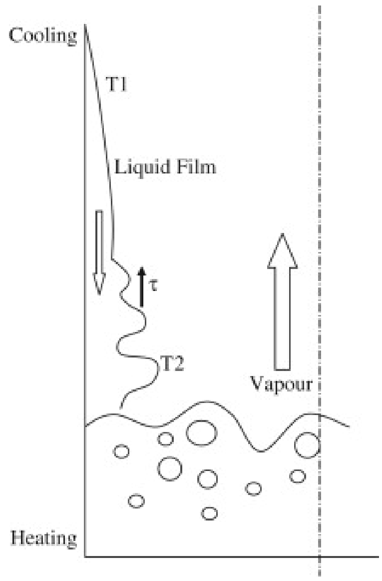

Figure 3. Liquid film in heat pipe [4].

First, a temperature gradient ∇T exists, i.e. $T_2 > T_1$, a thermocapillary force T_T , expressed by equation (2), occurs due to the surface tension $\nabla\sigma$, thus increasing the film thickness [8]

$$T_T = \nabla\sigma = (\partial\sigma / \partial T). \qquad (1)$$

Second, the counter-current flow of the vapour exerts a shear force T_s on the film surface

$$T_s = f\,(u_v + u_l), \qquad (2)$$

where u_v and u_l are vapour and liquid velocities m s^{-1} respectively. This shear may deter the downward flow of the film, resulting in a thicker film.

Last, under certain conditions, waves tend to appear on the film surface, causing thickness fluctuations above the average thickness δ_{avg}, which can be modelled by a sinusoidal function:

$$\delta = \delta_{avg} + f\,(sin\,(L_c)). \qquad (3)$$

3 Experiment

Visualization of the flow regime in heat pipe was performed with gravity assisted heat pipe made from glass. The parameters of the heat pipe are inner diameter 10 mm, outer diameter 12 mm and total length 150 mm. The working fluid of heat pipe was ethanol. The heat pipe was putted in to hot water bath with temperature 90 °C and two-phase flow regime of working fluid was scanned by HD video camera. The visualization of the working fluid flow in heat pipes can be helpful in solution or CFD simulation of the flow dynamics or heat and mass transfer of the heat pipes [9, 10].

Figure 4. Two-phase flow visualization.

4 Results

The pictures in the figure 5 and 6 show two-phase flow of the working fluid in gravity assisted heat pipe at the time 28 – 31 second from start-up. On the pictures in the figure 5 is shown one cycle since the vapour phase is occurring in heat pipe, over the condensate layer crating on the heat pipe top and condensate flowing down from condenser to the evaporator till the start of the second cycle when is in heat pipe again only vapour phase.

On the first picture is shown the vapour phase in heat pipe. On the second picture is shown creating of the condensate layer of the working fluid on the top section of the heat pipe and interaction vapour and liquid phase in the middle. On the third picture the uprising vapour condense below the condensate layer, because the condensate layer chocked the heat pipe. The part of the condensed vapour was added to the condensate layer and part drop down the wall to the bottom of heat pipe. At the same time the vapour are generated in evaporator part of heat pipe and is seen vapour flow off the drop of condensate on the bottom. On the fourth picture the vapour upraise to the top of heat pipe. On the fifth and sixth picture is shown the breaking through the condensate layer by vapour on the top. All collected condensate drop down the pipe wall. On the fifth picture is shown a thin film of the flowing down condensate on the top and vapour flow off the drop of condensate on the bottom. On the sixth picture is shown a thin film of the flowing down condensate on the bottom. On the seventh picture is shown vapour phase along the all pipe. All liquid phase is down in evaporator and part of the liquid phase condensed under the top of the pipe. In the figure 6 are pictures which show second cycle of the evaporation and condensation of the working fluid in heat pipe. On the first picture is shown vapour phase uprising in heat pipe. In the middle heat pipe it is seen a small nebulosity.

On the second picture is shown condensate layer in the middle. On the third picture the collected condensate is pressed up by vapour on the top. On the fourth and fifth picture is shown the part of the condensate is pressed to the top of heat pipe and part of the condensate is flow down to the evaporator. On the sixth picture is seen that the all condensate collected in the condenser flow down to evaporator.

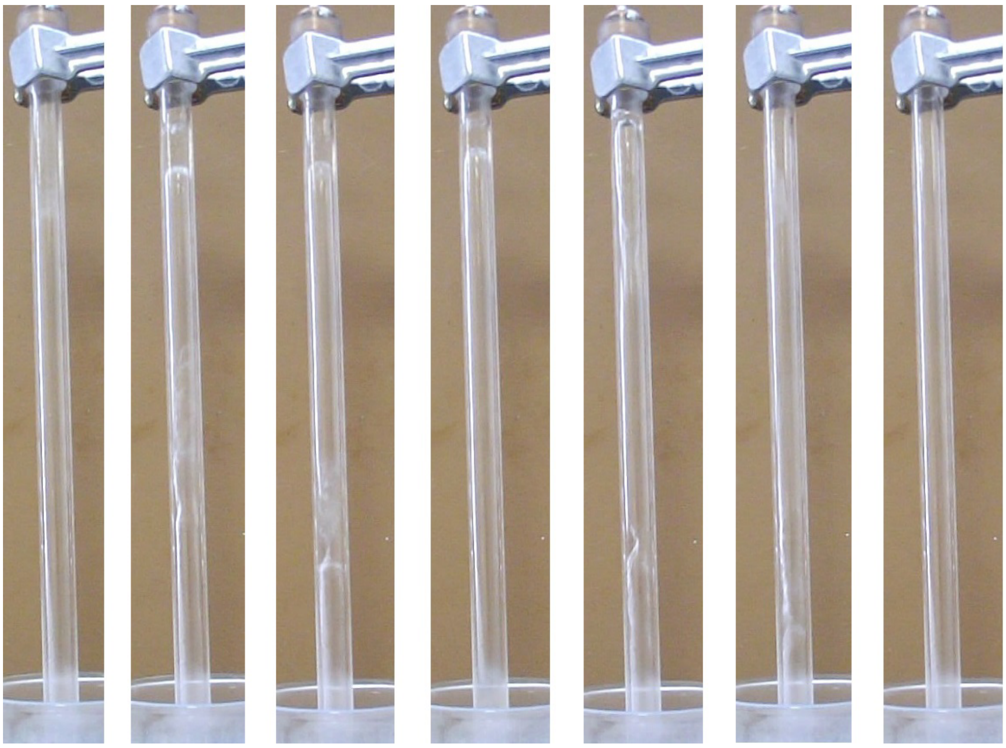

Figure 5. First cycle of the evaporation and condensation.

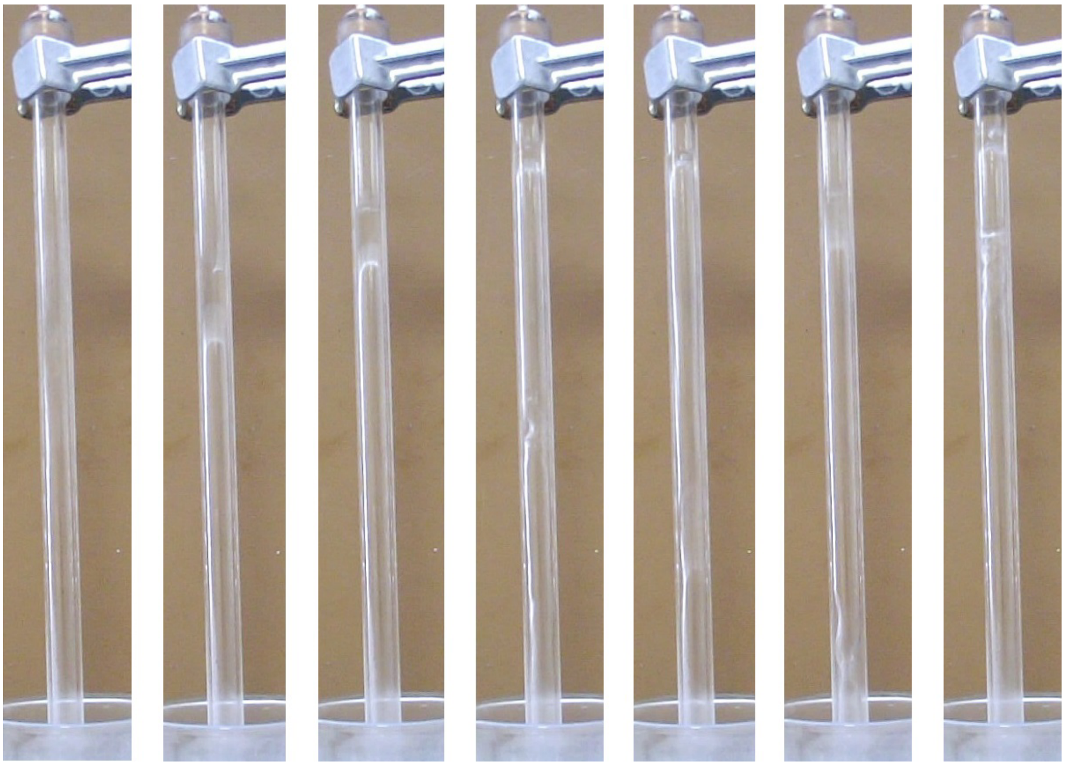

Figure 6. Second cycle of the evaporation and condensation.

On the bottom is seen interaction vapour and liquid phase. On the top is collected next condensate layer. On the last seventh picture is shown a start of the new cycle. There is seen two condensate layers on the top of heat pipe the first upper layer is created from all collected condensate from previous picture and the second lower layer is created from next vapour phase flowed up.

5 Conclusions

The results from experiment bring near what is occurring inside the heat pipe during its operation. On the pictures was seen evaporation and condensation of the working fluid in same time. This experiment is just the start of the work which we would realize in the future. From reason of the better visualization it will be used to scanning flow regime high speed camera in future. In future work will be performed pictures of the flow regime various working fluids and various diameters of heat pipes.

Acknowledgment

This paper was written within the solution of the projects KEGA 064 ŽU-4/2012 and Moderné vzdelávanie pre vedomostnú spoločnosť/Projekt je spolufinancovaný zo zdrojov EÚ. **Podpora kvality vzdelávania a rozvoj ľudských zdrojov v oblasti technického výskumu a vývoja v priestore modernej vedomostnej spoločnosti, ITMS 26110230117.**

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