

An optical method for measuring the thickness of a falling condensate in gravity assisted heat pipe

Martin Kasanický^{1,a}, Richard Lenhard¹, Katarína Kaduchová¹ and Milan Malcho¹

¹University of Žilina, Faculty of Mechanical Engineering, Department of Power Engineering, Univerzitná 1, 010 26 Žilina, Slovakia

Abstract. A large number of variables is the main problem of designing systems which uses heat pipes, whether it is a traditional - gravity, or advanced - capillary, pulsating, advanced heat pipes. This article is a methodology for measuring the thickness of the falling condensate in gravitational heat pipes, with using the optical triangulation method, and the evaluation of risks associated with this method.

1 Introduction

CFD simulations of gravity assisted heat pipes (GAHP) or thermosyphon are nowadays common practice. However, the current CFD models are not robust and flexible enough to capture a wide range of conditions occurring within the heat pipe. For this reason it is necessary to pay more attention to adapting these models in order to capture larger number of functional states within GAHP.

2 Theoretical background of the draft

Nowadays there are many approaches to calculate the heat pipes properties. One of these approaches is the calculation of GAHP heat performance parameters is based on knowledge of the falling condensate thickness. According to [1], the average value of Nusselt Reynolds number in the laminar flow region can be stated as

$$Nu = \frac{\alpha_L}{\lambda_L} = \left[\frac{\eta_L^2}{\rho_L \cdot (\rho_L - \rho_V) \cdot g} \right]^{\frac{1}{3}} = \quad (1)$$

$$= \frac{4}{3} \cdot \frac{(\delta^*)^3}{x^*} + \frac{2 \cdot (\delta^*)^2 \cdot \tau_\delta^*}{x^*},$$

$$Re_\delta = \frac{4}{3} \cdot (\delta^*)^3 + 2 \cdot (\delta^*)^2 \cdot \tau_\delta^*, \quad (2)$$

where α_L is the heat transfer coefficient of the liquid phase, λ_L is thermal conductivity of the liquid phase, η_L dynamic viscosity of the liquid phase, ρ_L and

^a Corresponding author: martin.kasanicky@fstroj.uniza.sk

ρ_V density of liquid and vapour phase respectively and g is the gravity acceleration. Another – dimensionless variables are expressed as follows

$$\delta^* = \frac{\delta}{L_F}, \quad (3)$$

$$x^* = \left(\frac{x}{L_F} \right) \cdot \frac{4 \cdot c_{pL} \cdot \Delta T}{Pr_L \cdot l_V}, \quad (4)$$

$$\tau_\delta^* = \frac{\tau_\delta}{(\rho_L - \rho_V) \cdot g}, \quad (5)$$

where δ is the falling condensate thickness, x is the coordinate in direction of the flow (by common configuration it is vertical downwards direction), c_{pL} is the constant pressure specific heat of the liquid phase, ΔT is the temperature difference between wall and liquid, Pr_L is the Prandtl number of liquid phase, l_V is heat of evaporation, τ_δ is the interfacial shear stress between liquid and vapour phase and

$$L_F = \left[\frac{\eta_L^2}{\rho_L \cdot (\rho_L - \rho_V) \cdot g} \right]^{\frac{1}{3}}. \quad (6)$$

With combination of equations 3,4 and 5 we can get equation criteria equation

$$x^* = (\delta^*)^4 \frac{4}{3} \cdot (\delta^*)^3 \cdot \tau_\delta^*. \quad (7)$$

The last formula is an expression of one variable through the second and, therefore, it is necessary to solve

the system of equations iteratively. It should be noted, however, that the knowledge of the thickness of the condensate, the system of equation can be solved with a single variable (is also relative, since all material constants are a function of its temperature, which varies with the thickness of the condensate in the y direction, but for the purpose of further assume, it can be considered as a constant.). The above equations are valid for laminar flow regime of falling condensate. For turbulent flow it can be also used a wide range of correlations that can be found in the referenced literature.

3 Optical triangulation method

The method is based on this method is to light the walls of the tube and at the same time the layer of condensate running down the laser beam and the reflection from the two capture facility using a CCD camera, as shown the layout in figure 1.

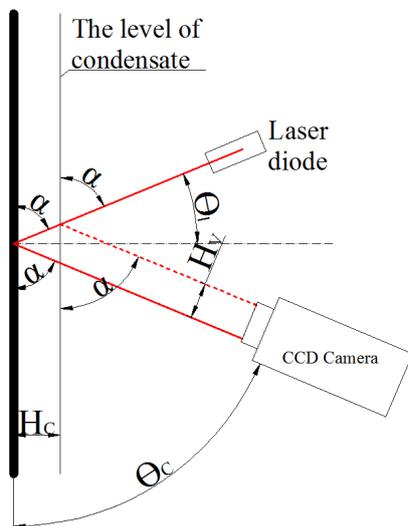


Figure 1. The principle of optical triangulation

Based on the layout, the condensate thickness equation can be determined as

$$H_C = \frac{H_V \cdot G_X}{\cos(\Theta_C)} \cdot \left[\frac{1}{1 + \text{tg}(\Theta_C) \cdot \text{tg}(\Theta_C)} \right], \quad (7)$$

where H_C is condensate thickness, H_V is the distance shown at CCD camera, G_X is the optic magnification, Θ_C is angle which make camera with the drenched wall and Θ_L the angle which make laser beam with the wall

Optical principle of the method was tested on glass-plate, in which water has sprayed



Figure 2. Experimental device to test the applicability of the method

On the basis of this experiment it was evaluated the optimal color of the laser beam recorded by CCD camera is in the green part of the light spectrum. The experiment also showed that the distilled water at ambient temperature (20 °C) is not an appropriate medium for the thickness measurement by using this method, because the glass surface does not form a continuous film. This deficiency may be removed by heating the water to a higher temperature because the increased temperature decreases surface tension value. When using ethanol system worked properly.

The accuracy of this method is not known yet, so that the first thing after building the device (in next heading) is setting it.

4 Design of the device for condensate thickness measurement

The suggested device will be constructed according to the scheme in figure 3. and figure 4.

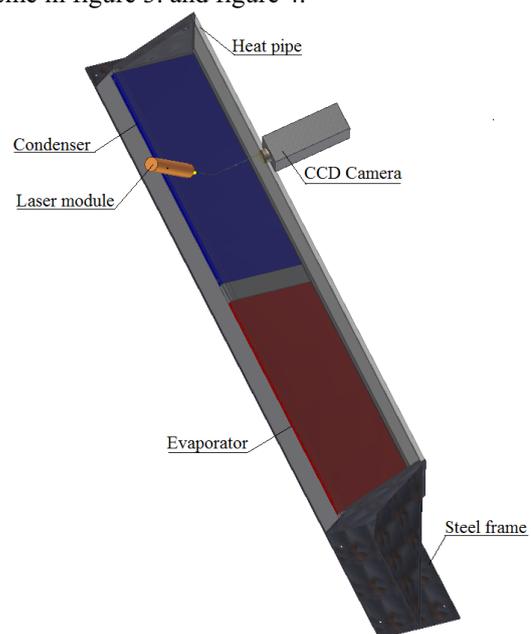


Figure 3. Schematic of measuring the thickness of the condensate in GAHP

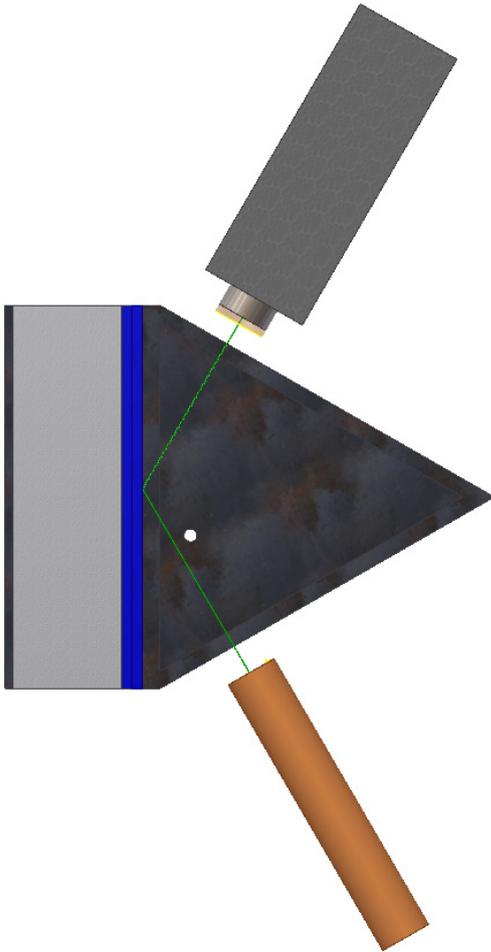


Figure 4. Detail of the device

The basis of the device is a glass construction with a hollow triangular prism, which will work as GAHP. The glass structure is inserted in a steel frame, which is attached by screws to the wall. Anticipated working liquids in heat pipe will be distilled water and ethanol. Triangular cross-section construction is designed by means of the elimination of refraction passing through a glass wall, or on the side of the laser beam emitted from the diode, or reflections on the side of the CCD camera. Principle of operation of GAHP will be driven by using two heat exchangers. One will work as a heater (evaporator) and the other as a cooler (condenser). The two heat exchangers are coequal. ... The heat exchanger is shown in figure 5.

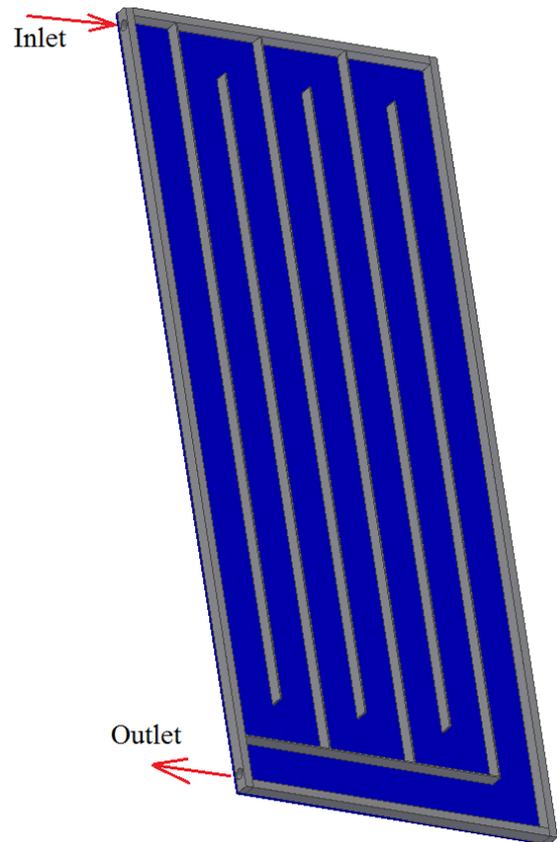


Figure 5. Used heat exchanger

The heat exchanger is divided by seven barriers vertically. Draft of its construction is justified in [2]. The vertical flow direction was designed because of a more even distribution of temperatures on the surface of the heat exchanger.

Each exchanger is individually connected to the circulation thermostat Julabo and heat transfer fluid is distilled water. In each independent circuit will be used PT100 temperature sensors at the inlet and the outlet of the heat exchanger and also has a flow meter, in order to use a colorimetric method to express performance at separate heat exchangers, as well as the actual power delivered by the heat pipe.

The pressure and the amount of charge in the heat pipe will be accomplished by gradual evaporation of the working fluid of the heat pipe. The entire device will be thoroughly insulated using extruded polystyrene. The polystyrene plates for the other two glass surfaces are still in addition, supported by two permanent magnets in order to be able to move them vertically and with them move the laser module and a CCD camera in the vertical direction (the horizontal direction as well as, to obtain the biggest possible picture on heat pipe main wall). On these polystyrene plates will be, from the outside, in addition placed heating infra-foil to prevent condensation on these glass surfaces. Such condensation would be impossible to measure the thickness of the condensing optical triangulation method

5 Overview of measured values

Besides thermal performance on both exchangers it will be possible to measure and record the temperature of the wall in contact exchanger and glass wall (heated and cooled wall of GAHP) using PT100 thermal sensors, internal temperature in the GAHP by using stainless steel sump, pressure in the system and of course and thickness of condensate using optical triangulation method. On the basis of the measurements it will be possible to obtain a broader picture of the processes taking place inside the heat pipes.

Acknowledgement

This work is supported by the financial assistance of the project KEGA-064ŽU-4/2012 - Use of heat pipes for cooling and heating technology and



Agentúra
Ministerstva školstva, vedy, výskumu a športu SR
pre štrukturálne fondy EÚ



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**

References

1. A. Faghri, Y. Zhang, *Transport phenomena in multiphase systems*, (2006)
2. M. Kasanický, M. Malcho, Conference of departments of fluids mechanics and thermomechanics, **33**, 33-36, (2014)
3. R. Lenhard, M. Malcho, Math. and comp. modelling, **57**, 111-125, (2013)
4. K. Sulovcova, J. Jandačka. *Komunikacie* **15**, 44-47 (2013)
5. M. Malcho, J. Jandačka, M. Vantúch, A. Kapjor, S. Gavlas, *Komunikacie* **14**, 18-22 (2012)
6. P. Nemeč, A. Čaja, R. Lenhard, *Arch. of Thermodyn.* **31**, 125-132 (2010)
7. R. Lenhard, Power control and optimization proceedings **4**, 32-36 (2010)
8. P. Dančová, P. Sitek, & T. Vít, *EPJ Web of Conferences* **67**, (2014).
9. A. Petrenko, J. Soukup, *AIP Conference Proceedings* **1608**, 191-196, (2014).
10. S. Giroud-Garapon, G. Heid, G. Lavergne, O. Simonin, *Proceedings of PSFVIP* **4**, 1-6 (2003)
11. Ch. Tzotzi, N. Andritsos, *Int. Journal of Multiphase Flow* **54**, 43-54 (2013)
12. A. Alizadehdakhel, M. Rahimi, A. A. Alsairafi, *Int. Comm. Int. Heat and Mass Tra.* **37**, 312-318 (2010)