# Study of different process parameters and optimization methods of heat pipe: A Review

**Ashish Arora[1], Prof. R.C Gupta[2]**

[1]Research Scholar, Fourth Semester, M.E. (Heat Power Engineering)
[2]Associate Professor, Department of Mechanical Engineering
Jabalpur Engineering College, Gokalpur, Jabalpur(M.P.)- 482011, India

***Abstract*: In this paper, the characteristics and working principles of the heat pipes are introduced and the current researches in the field are described from the viewpoint of experimental tests, theoretical analyses as well as practical applications. Besides, it is found that the state-of-the-art experimental investigations on the heat pipes are mainly focused on the flow visualization and the applications of nano fluids and other functional fluids. The purpose of this review is to evaluate current heat pipe systems for heat recovery and renewable applications utility. Basic features and limitations are outlined and theoretical comparisons are drawn with respect to the operating temperature profiles for the reviewed industrial systems. Working fluids are compared on the basis of the figure of merit for the range of temperatures. A brief discussion on the heat pipe is mention in this paper.**

***Keywords*: Heat pipe, Nano fluids, Thermal performance, Fluid concentration, Methods**

## 1. Introduction

A heat pipe is essentially a conserved slender tube containing a wick structure lined on the inner surface and a small amount of fluid such as water at the saturated state. It is composed of three sections: the evaporator section at one end, where heat is absorbed and the fluid is vaporized; a condenser section at the other end, where the vapor is condensed and heat is rejected. The operation of a heat pipe is easily understood by using a cylindrical geometry. The schematic diagram and working operation of a heat pipe as shown in figure 1 and figure 2 respectively. Heat pipes can be of any size or shape. The components of a heat pipe are a sealed container (pipe wall and end caps), a wick structure, and a small amount of working fluid in equilibrium with its own vapor. Different types of working fluids, such as water, acetone, methanol, ammonia, or sodium can be used in heat pipes based on the required operating temperature. The length of a heat pipe is divided into three parts: the evaporator section, adiabatic (transport) section, and condenser section.

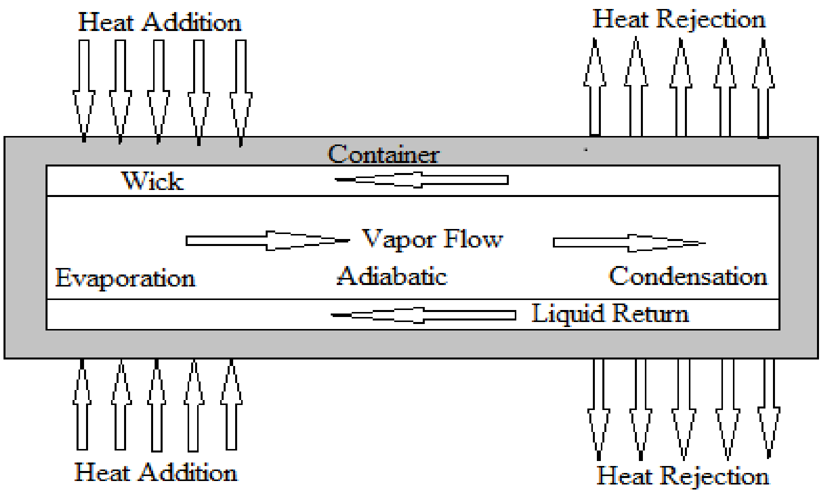


Fig 1: Schematic diagram of heat pipe

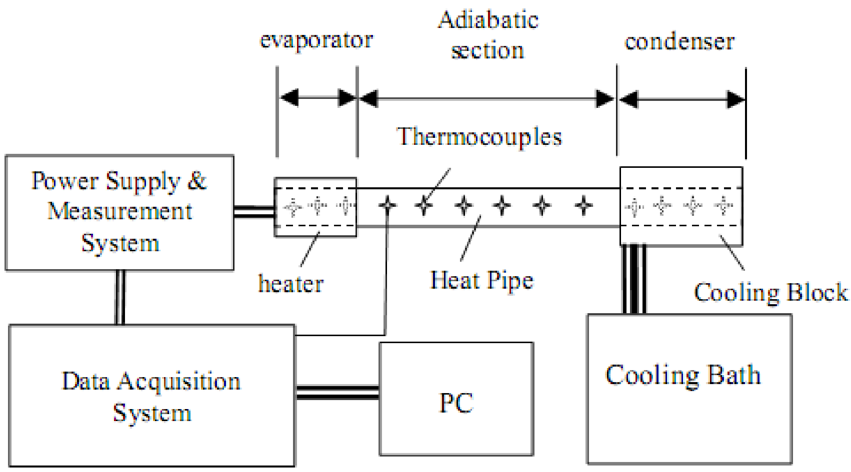


Fig 2: Working mechanism of heat pipe

Recent experimental studies are mainly focused on the enhanced heat transfer performance, the start-up procedure and the stable operating status of the pulsating heat pipes (PHPs). There are many interacting factors regarding to the heat transfer capabilities of a PHP, among which the charge ratio, heating method, working fluids properties, and scale effects of tube diameter have dominating impacts on the heat transfer performance, compared to the number of turns, shapes of intersection, length of evaporation and condensation section. The heat flux and overall thermal resistance are two characteristic quantities for the measurement of the thermal performances for a PHP. Many of the researcher have perform the optimization of different process parameters of heat pipe which is mention in the below section.

## 2. Existing research effort

From decade's researcher are working of the heat transfer devises, different devises like heat exchanger, heat pipe and other were optimized and modified to enhance the heat transfer rate of that device. Researchers are working on heat pipe to increase the heat transfer rate. Many of the parameters on which heat transfer depends where optimized, some of the research work is in the field of heat pipe is mention here

1. **Singh et.al (2017)[1]** In this research work here it develop a method to improve the performance of heat pipe by using the wettability gradient at the inner core surface of heat pipe. Through analysis it was found out the effect of wettability gradients on micro heat pipes performance using a quasi-one-dimensional mathematical model and measure the accounts for axially varying Solid–liquid contact angle. For analysis, here in this work they considers micro heat pipes with different wettability schemes methodologies, such as uniform, step-variation, and linear variation in the contact angle. Their different model methodologies predictions show that increment in wettability of the evaporator surface and reducing the wettability of the condenser surface of micro heat pipes can lead to an increase in the heat transfer capacity of micro heat pipes by over 35%.

2. **Qu et.al (2017)[2]** during the analysis they considered MEMS-based micro heat pipes, as a novel heat pipe technology. Through analysis it is found that MEMS base micro heat pipe is a promising choice for thermal management applications in microelectronic circuits packaging, concentrating photovoltaic cells, infrared detectors, laser diodes, etc. Here in this work it presents a comprehensive investigation of the current developments and advances that were happened in different types of MEMS-based micro heat pipes for increasing heat transfer and emerging polymer flexible heat pipes, starting from a brief introduction of basic concept, structure characteristics, and advantages over conventional heat pipes. The manufacturing and packaging methodology of MEMS-based micro heat pipes are summarized and compared.

3. **Aly et.al (2017)[3]** here in this work it find out the thermal performance of helically-micro-grooved heat pipe in which water-based alumina Nano fluid is used as a working fluid. Here in this work it analyzed the effects of the inclination angle that is (0°C, 30°C, 60°C, and 90°C), filling ratio (20, 40, 60 and 80%) and heat input (45,65 W) on heat transfer characteristics of the heat pipe using different working fluid either distilled water or water-based alumina nano fluid with the volume concentration of $Al_2O_3$ nanoparticles of 3.0% are experimentally investigated. Through analysis they found that the thermal performance of the heat pipe increases with use of nano fluid compared to DW. Through analysis they also found that both parameters that is inclination angle and filling ratio significantly affect the thermal performance of the heat pipe. They perform experimental analysis to investigate the thermal performance of helically-micro-grooved heat pipe working with $Al_2O_3$ nano fluid at different inclination angles and filling ratios.

4. **Shahed et.al (2017)[4]** here in this work researcher used the heat pipe in electronic devices to maintain the temperature at optimum level so that the life span of electronic devises can increases. The heat pipes have been widely used in various hand held mobile electronic devices such as smart phones, tablet PCs and digital cameras. With the development and requirement of

technology these devices have different user friendly features and applications; which require very high clock speeds of the processor. In general, a high multifunctional processor generates high amount of heat during the working time and to maintain the performance of their processor it is necessary to maintain their temperature. However, it is a challenging task to achieve proper cooling of such electronic devices mentioned above because of their confined spaces and concentrated heat sources. Regarding this challenge, it introduced an ultra-thin heat pipe; this heat pipe consists of a special fibre wick structure named as "Centre Fibre Wick" which can provide sufficient vapour space on both sides of the wick structure.

5. **Zhou et.al (2016)[5]** here in this work researchers used a miniature loop heat pipe and employing a 1.2 mm thick flat evaporator and a vapour line, liquid line and condenser with a 1.0 mm thickness. For circulating the working fluid and providing the driving force they used miniature loop heat pipe employs with an internal wick structure which is fabricated of sintered fine copper mesh. And a secondary wick inside the liquid line to promote the flow of condensed working fluid back to the evaporator. Analysis was carried out under natural air convection at an ambient temperature of 24 ± 1°C. The proposed miniature loop heat pipe demonstrated stable start-up behavior at a low heat load of 2W in the horizontal orientation with an evaporator temperature of 43.9°C and efficiently dissipates a maximum heat load of 12 W without dry-out occurring.

6. **Paiva et.al (2015) [6]** here in this study, a theoretical thermal study of a wire-plate mini heat pipe is presented. The wire plates are considered grooved type heat pipes. Two models are used: a hydrodynamic model taken from literature and a thermal model, developed in the present paper. The influence of vapor channel hydraulic diameter and evaporator length are determined by the hydrodynamic model, which takes into account the geometry of the liquid layer in the groove. For the thermal model, for both evaporator and condenser, the liquid film cross section area is divided into three regions, represented by three resistances in parallel. The hydrodynamic model allowed for the precise determination of the working fluid volume to be charged in the mini heat pipe.

7. **Shewale et.al (2014) [7]** here in this work researcher used the heat pipe to cool electronic devices. They used it as an important tool to extract excess amount of heat generated inside the electronic equipment to maintain their reliability. The main focus of this research work to mainly review different applications of heat pipe in electronic system. Minimizing the size of electronic devices put more load on chips and increasing processing speed, decreases the heat transfer surface area and generates very high heat fluxes resulting in large temperature rise in electronics devices. Therefore, in order to maintain the temperature, an effective cooling heat pipe is a better option because of its high efficiency and reliability. The review investigates the different applications of heat pipe in electronic system cooling. In the current time heat pipes are one of the available technologies to maintain or draw excess amount of heat from high density electronic cooling problem due to their high thermal conductivity, reliability and low weight. Based on literatures, it has been found that different types of heat pipes are used for cooling electronic devices.

8. **Hung et.al (2014) [8]** in this study, they investigate the effect of nano fluid on heat transfer enhancement in heat pipe. Here in this work they used $Al_2O_3$/water nano fluid, which was produced with the help of direct-synthesis method using a cationic chitosan dispersant. Here in this work $Al_2O_3$/water nano fluid served as the base fluid with three different concentrations that are 0.5, 1.0 and 3.0 wt. % in heat pipes. The heat pipe used in this work was a straight copper tube with an outer diameter of 9.52 mm and different lengths of 0.3 m, 0.45 m and 0.6 m. During this work they showed a discussion on the effects of the charged volume ratio of the working fluid (20%, 40%, 60% and 80%), tilt angle (10°C, 40°C, 70°C and 90°C), heat pipe length, heating power (20 W, 30 W and 40 W), and weight fraction of nanoparticles on the overall thermal conductivity of the heat pipe to evaluate the thermal performance.

9. **Chang et.al (2014) [9]** In this research work, they incorporate solid wall conduction heat transfer concept, together with the continuity, momentum, and energy equations of the liquid and vapor phases and develop the new mathematical model based on different law of conservation to yield the heat and fluid flow behavior and different characteristics of micro heat pipes. Here in this work they provide a comprehensive and insightful analysis on the effects of different working fluid and solid wall on the thermal performance of micro heat pipes. The characteristics and performance of different types of working fluid and solid wall are elucidated. A well-defined exposition of the circulation effectiveness of the working fluid is proposed and the operation regime map for different types of working fluid is conceived for the identification of the optimal operating conditions. A mathematical model of heat and fluid flow in micro heat pipe is developed to scrutinize, primarily, the effects of working fluid and solid wall on the thermal performance of the device.

10. **Yousefi et.al (2013) [10]** here they perform the experimental study to analyze the flow behavior of heat transfer from CPU through heat pipe, they examining the effects of inclination angle of pipe and nano fluids on heat transfer. It is shown that one-degree inclination angle of pipe has a significant effect on the cooling process, inclination directly influences the operation of the evaporator, with the inclination the performance of heat pipe increases. The effect is mainly due to the capillary effect and boiling limits of the heat pipe. The results demonstrate that for a given CPU temperature, there is a threshold angle at which the thermal resistance of the heat pipe increases dramatically.

11. **Liu et.al (2013) [11]** in this analysis of transient fluid flow and heat transfer in a triangular micro heat pipes has been conducted to study the thermal response characteristics. By introducing the system identification theory, the quantitative evaluation of the micro heat pipes transient thermal performance is comprehended. The results indicate that the evaporation and condensation processes are both extended into the adiabatic section. During the start-up process, the capillary radius along axial direction of micro heat pipes decreases drastically while the liquid velocity increases quickly at the early transient stage and an approximately linear

decrease in wall temperature arises along the axial direction. A numerical simulations is conducted to investigate the thermal response of a triangular shaped micro heat pipe based a developed transient model.

12. **Moraveji et.al (2012) [12]** in this research, author assuming the effect of using aluminum oxide nano fluid (pure water mixed with Al2O3 nanoparticle with 35 nm diameter) on the thermal efficiency enhancement of a heat pipe on the different operating state was investigated. The heat pipe was made of a straight copper tube with an outer diameter and length of 8 and 190 mm and a 1 mm wick-thickness sintered circular heat pipe. In the heat pipe tube, there is a 90° curve between the evaporator and condenser sections. The tested concentration levels of nano fluid are 0%, 1% and 3%wt. The more $Al_2O_3$ nanoparticles were dispersed in the working fluid, the performance of heat pipe were enhanced.

13. **Hung et.al (2012) [13]** In this research work, the progressive evaporation and condensation processes in a micro heat pipe, with which high heat fluxes at the liquid–vapor interface are associated, render it a device of high thermal conductance. By coupling the phase-change interfacial resistance model with a mathematical model based on first principles for fluid flow and heat transfer, the axial temperature variations of the liquid and vapor phases as well as those of other field variables are characterized and analyzed. The findings provide a well-defined exposition of the validity of uniform-temperature assumption for the liquid and vapor phases in the analysis of micro heat pipes. This analysis focuses on the heat transfer associated with phase-change processes at the interfacial region between the saturated liquid and saturated vapor inside a micro heat pipe.

14. **Vasiliev et.al (2008) [14]** in this work researcher try to give brief information regarding the evolution of heat pipe , they mention the introduction of heat pipe that was near about 40 years ago with first heat pipe definition and prediction of most simple cases. At the time micro and miniature heat pipes have received considerable attention. The interest stems from the possibility of achieving the extremely high heat fluxes near 1000 W/cm$^2$, needed for future generation electronics cooling application. Now at the computer age some changes of basic equations are performed, more powerful predicting methods are available with increasing awareness of the complexity of heat pipes and new heat pipe generations. But even today heat pipes are still not completely understood and solution strategies still contain significant simplifications.

15. **Boukhanouf et.al (2006) [15]** here in this work researcher perform the experimental analysis and determining the thermal performance of a flat plate type heat pipe with the help of infra-red thermal imaging camera. Here researcher's used Steady state and transient temperature distribution of the evaporator surface of the flat plate type heat pipe were measured using a single heat source with varied heat flux inputs. For performance comparison, the experimental measurements were also carried out on an identical flat plate heat pipe with a defect and on a solid copper block of similar dimensions. It was shown that temperature excursion on the surface of the fully functioning flat plate heat pipe is less than 3°C for operating temperatures up to 90°C and heat flux inputs ranging from 4 to 40 W/cm$^2$.

16. **Li et.al (2006) [16]** In this research work, here is the second of a two-part investigation, designed to systematically identify and investigate the parameters affecting the evaporation from and boiling within, thin capillary wicking structures with a range of volumetric porosities and mesh sizes. The experimental studies were investigated under steady-state conditions at atmospheric pressure. Part I of the investigation described the wicking fabrication process and experimental test facility, and focused on the effects of the capillary wick thickness. The minimum value of these three menisci determined the maximum capillary pressure generated through the capillary wick. The free liquid-vapor interface, due to local condensation and the pressure difference, instead of departing from the heated wall.

17. **Moon et.al (2002) [17]** in this study, author analyses the miniature heat pipe with woven wire wick was used for cooling a notebook PC. The cross-sectional area of the pipe is reduced by about 30% of the original, when the diameter of the miniature heat pipe is pressed from 4 to 2 mm for packaging in a notebook PC. In the present study, a test of the miniature heat pipe has been performed in order to review the thermal performance by varying pressed thickness, total length of miniature heat pipe, wall thickness, heat flux and inclination angle. New wick types were considered for overcoming low heat transfer limits, which occur when the miniature heat pipe is pressed to a thin plate.

18. **Ha et.al (1998) [18]** in this research work the original analytical model for predicting the maximum heat transport capacity in micro heat pipes, as developed by Cotter, has been re-evaluated in light of the currently available experimental data. As is the case for most models, the original model assumed a fixed evaporator region and while it yields trends that are consistent with the experimental results, it significantly over predicts the maximum heat transport capacity. In an effort to provide a more accurate predictive tool, a semi-empirical correlation has been developed.

19. **Babin et.al (1990) [19]** In this research work a combined experimental and analytical investigation was conducted to identify and understand better the phenomena that govern the performance limitations and operating characteristics of micro heat pipes which is so small that the mean curvature of the vapor liquid interface is comparable in magnitude to the reciprocal of the hydraulic radius of the flow channel. The analytical portion of the investigation began with the development of a steady-state model in which the effects of the extremely small characteristic dimensions on the conventional steady-state heat pipe modeling techniques were examined.

Some of the parameter and different methods used of the optimization of heat pipe is mention in the table 1.

**Table 1: The existing research work and different process parameters**

| S.no. | Authors Name | Input Parameters | Types | Output Parameter | Analysis Type |
|---|---|---|---|---|---|
| 1. | Manjinder Singh et.al (2017) | Temperature, Axial position | Micro heat pipes using wettability gradient | Maximum heat Transfer, Pressure | Numerical Analysis |
| 2. | Jian Qu et.al (2017) | Temperature | MEMS-based micro heat pipes | Saturated pressure | Experimental Analysis |
| 3. | Wael I.A. Aly et.al (2017) | Length, Heat Transfer | Helically- micro grooved heat pipe | Temperature, Heat transfer coefficient | Experimental Analysis |
| 4. | Ahamed Mohammad Shahed et.al (2017) | Thickness of heat pipe, heat pipe width | Ultra-thin heat pipe | Heat transfer coefficient, Effective thermal conductivity, Temperature | Experimental and theoretical Analysis |
| 5. | Guohui Zhou et.al (2016) | Time, Heat load | Ultra-thin miniature loop heat pipe | Temperature | Experimental Analysis |
| 6. | K.V. Paiva et.al (2015) | Axial position | Wire plate micro heat pipe | Meniscus radius, Pressure, Liquid velocity, Vapour velocity | Experimental Analysis |
| 7. | Sapana P. Shewale et.al (2014) | Heat flux | Heat pipe with Nano Fluid | Thermal Efficiency | Experimental Analysis |
| 8. | Yi-Hsuan Hung et.al (2014) | Heating power | Heat pipe using Alumina Nano fluid | Thermal conduction | Experimental Analysis |
| 9. | Fun Liang Chang et.al (2014) | Temperature | Micro heat pipe with fluid & solid wall | Heat transport property, surface tension, dynamic viscosity | Numerical Analysis |
| 10. | T. Yousefi et.al (2013) | Inclination angle, Temperature | Heat pipe with inclination angle | Evaporator Temperature, Time, Thermal Resistance | Experimental Analysis |
| 11. | Xiangdong Liu et.al (2013) | Time | Micro heat pipes | Temperature | Theoretical Analysis |
| 12. | Mostafa Keshavarz Moraveji et.al (2012) | Length, Rate of Heat transfer | Heat pipe using Nano fluid | Temperature, Thermal Resistance | Experimental Analysis |
| 13. | Yew Mun Hung et.al (2012) | Contact Angle, Meniscus radius | Water filled micro heat pipe | Heat transport Capacity, Liquid Velocity | Numerical Analysis |
| 14. | L.L. Vasiliev et.al (2008) | Tilt of heat pipe Inclination | Micro & Miniature Heat pipes | Maximum Heat transfer | Numerical Analysis |
| 15. | R. Boukhanouf et.al (2006) | Time, Spreading Resistance | Flat plate Heat pipe | Temperature, Heat flux | Experimental Analysis |
| 16. | Chen Li et.al (2006) | Heat flux, Temperature | Thin capillary wick pipe | Heat transfer coefficient, Heat flux | Experimental Analysis |
| 17. | Seok Hwan Moon et.al (2002) | Inclination angle, Thermal resistance | Miniature heat pipe | Heat transfer rate, Heat transfer limit, Thermal resistance | Experimental Analysis |
| 18. | J. M. Ha et.al (1998) | Operating temperature | Micro heat pipes | Input power, Heat flux | Experimental Analysis |
| 19. | B. R. Babin et.al (1990) | Operating temperature, Evaporator temperature | Micro heat pipes | Heat transfer, Pressure, Thermal conduction | Experimental Analysis |

## 2. Conclusion

This study reviewed some of the general heat pipe systems used in building and ground applications including heat recovery and renewable energy methodologies in order to determine the typical heat pipe arrangements along with their working temperature range for use in the respective.

The investigation revealed that heat pipes incorporated with sorption phenomenon display greater heat transfer capacity and tubular heat pipes have the highest working range on average with the maximum operating temperature from all reviewed systems being 453 K for the tubular heat pipe arrangement respectively. In general, it has been shown that heat pipe simulations must include conjugate heat transfer with the wall, wick and vapor, since these affect both the transient and steady-state operating conditions. More fundamental works are needed to better understand the physical phenomena of heat pipes and loop heat pipes.

Generally, it was also seen from study that from past few decades heat pipes were used in electronic devices. Based on literature, it was found that micro and miniature heat pipes are used for cooling compact electronic devices. Nano fluid {[3], [8], [10], [12]} employed as working medium had shown higher thermal performance and reliability of such devices.

## REFERENCE


[1] Manjinder Singh, Sasidhar Kondaraju, Supreet Singh Bahga, Enhancement of thermal performance of micro heat pipes using wettability gradients, International Journal of Heat and Mass Transfer 104 (2017) 400–408.

[2] Jian Qu, Huiying Wu, Ping Cheng, Qian Wang, Qin Sun, Recent advances in MEMS-based micro heat pipes, International Journal of Heat and Mass Transfer 110 (2017) 294–313.

[3] Wael I.A. Aly, Moustafa A. Elbalshouny, H.M. Abd El-Hameed, M. Fatouh, Thermal performance evaluation of a helically-micro-grooved heat pipe working with water and aqueous Al2O3 nanofluid at different inclination angle and filling ratio, Applied Thermal Engineering 110 (2017) 1294–1304.

[4] Ahamed Mohammad Shahed, Yuji Saito and Makoto Takahashi, High Performance Ultra-Thin Heat Pipe Cooling Module for Mobile Hand Held Electronic Devices, Thermal Technology Business Unit, 2 FAI new Product Development Division, Fujikura Technical Review, 2017.

[5] Guohui Zhou, Ji Li, Lucang Lv, An ultra-thin miniature loop heat pipe cooler for mobile electronics, Applied Thermal Engineering 109 (2016) 514–523.

[6] K.V. Paiva, M.B.H. Mantelli, Theoretical thermal study of wire-plate mini heat pipes, International Journal of Heat and Mass Transfer 83 (2015) 146–163.

[7] Sapana P. Shewale, S. K. Sahu, Sandesh S. Chougule, A. T. Pise, A Review of Heat Pipe with Nanofluid for Electronic Cooling, IEEE - International Conference on Advances in Engineering and Technology-(ICAET 2014).

[8] Fun Liang Chang, Yew Mun Hung, The coupled effects of working fluid and solid wall on thermal performance of micro heat pipes, International Journal of Heat and Mass Transfer 73 (2014) 76–87.

[9] T. Yousefi, S.A. Mousavi, B. Farahbakhsh, M.Z. Saghir, Experimental investigation on the performance of CPU coolers: Effect of heat pipe inclination angle and the use of nano fluids, Microelectronics Reliability 53 (2013) 1954–1961.

[10] Xiangdong Liu, Yongping Chen, Transient thermal performance analysis of micro heat pipes, Applied Thermal Engineering 58 (2013) 585-593.

[11] Yew Mun Hung, Kek-Kiong Tio, Thermal Analysis of a Water-Filled Micro Heat Pipe With Phase-Change Interfacial Resistance, Journal of Heat Transfer NOVEMBER 2012, Vol. 134 / 112901-1.

[12] Mostafa Keshavarz Moraveji, Sina Razvarz, Experimental investigation of aluminum oxide nanofluid on heat pipe thermal performance, International Communications in Heat and Mass Transfer 39 (2012) 1444–1448.

[13] Yi-Hsuan Hung, Tun-Ping Teng, Bo-Gu Lin, Evaluation of the thermal performance of heat pipe using alumina nanofluids, Experimental Thermal and Fluid Science 44 (2013) 504–511.

[14] L.L. Vasiliev, Micro and miniature heat pipes – Electronic component coolers, Applied Thermal Engineering 28 (2008) 266–273.

[15] R. Boukhanouf, A. Haddad, M.T. North, C. Buffone, Experimental investigation of a flat plate heat pipe performance using IR thermal imaging camera, Applied Thermal Engineering 26 (2006) 2148–2156.

[16] Chen Li, G. P. Peterson, Evaporation/Boiling in Thin Capillary Wicks-II, Effects of Volumetric Porosity and Mesh Size, 1320 / Vol. 128, DECEMBER 2006.

[17] Seok Hwan Moon, Gunn Hwang, Ho Gyeong Yun, Tae Goo Choy, Young II Kang, Improving thermal performance of miniature heat pipe for notebook PC cooling, Microelectronics Reliability 42 (2002) 135–140.

[18] J. M. Ha, G. P. Peterson, the Heat Transport Capacity of Micro Heat Pipes, 1064 / Vol. 120, NOVEMBER 1998.

[19] B. R. Babin, G. P. Peterson, D. Wu, Steady-State Modeling and Testing of a Micro Heat Pipe, Journal of Heat Transfer AUGUST 1990, Vol. 112 / 595.