ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 3, September 2013

On the Vapor Chamber with Jet Liquid Impingement Cooling System for CPU Cooling

Paisarn Naphon
Thermo-Fluids and Heat Transfer Enhancement Lab. (TFHT),
Department of Mechanical Engineering, Faculty of Engineering, Srinakharinwirot University,
63 Rangsit-Nakhornnayok Rd., Ongkharak, Nakhorn-Nayok, 26120, THAILAND

Abstract:-An experimental investigation on the application of vapor chamber with jet liquid impingement cooling system for cooling computer processing is investigated. The tests are performed with the vapor chamber with de-ionized water 20% fill ratio as working fluid. It was found that average CPU temperatures obtained from the vapor chamber with jet liquid impingement cooling system are 19.4%, 15.96% lower than those from the copper plate with liquid cooling technique for no load and 90% operating loads, respectively. This technique gives CPU temperature 14.55%, 5.05% lower than the vapor chamber with air cooling technique for no load and 90% operating loads, respectively. In addition, as compare with the vapor chamber with conventional flow liquid cooling technique, the CPU temperature decrease 6.38%, 2.67% for no load and 90% operating loads, respectively. The results of this study are of technological importance for the efficient design of thermal cooling systems of electronic devices to ensure reliable operation.

Keywords: **Vapor chamber; jet liquid impingement; central processing unit**

I. INTRODUCTION

In order to operate in the range temperature, the heat dissipation must be increased. The electronics devices must be operated in the specific temperature ranges. There are many techniques for cooling electronic devices. The heat transfer characteristics of the vapour chamber been widely studied by researchers. Hsieh et al. [1,2] considered the thermal efficiency of the vapor chamber with and without pillar for cooling electronic devices. Hu and Tang [3] investigated on the thermal and flow characteristics of a micro phase-change cooling system. Effect of surface, fill ratios of working fluid and input heating power on the thermal efficiency are presented by Xie er al. [4]. Chang et al. [5] considered the effects of the surface, fill ratios of working fluid and input heating powers on the thermal performance of the heat pipe. Chen et al. [6] numerically investigated the vapor chamber with plate-fin heat sink. Zhang et al. [7] numerically and experimentally investigated the flat two-phase thermosyphon. Ma et al. [8] applied an innovative one-side actuating piezoelectric micro pump for cooling a laptop. Vasiliev et al. [9] applied the heat pipe for cooling the high-power electronic components. Ming et al. [10] experimentally and numerically investigated the grooved vapor chamber. Khandekar et al. [11] investigated the multiple quasi-steady states in a closed loop pulsating heat pipe. Kang et al. [12] experimentally investigated of the nanofluids on sintered heat pipe thermal performance. Tsai et al. [13] experimentally investigated the effects of heat source, fill ratio of working fluid, and evaporator surface structure on the thermal performance of the vapor chamber. Wang et al. [14] considered the thermal performance of the vapor chamber for the high-power LEDs. Wong et al. [15] studied a novel vapor chamber with inner groove surface. Wang et al. [16] analyzed the thermal characteristics for board-level high performance package equipped with vapor chamber. Li et al. [17-18] investigated effects of the width, height and number of fins and of the Reynolds number on the thermal performance and surface temperature distributions of vapor chamber. Harmand et al. [19] presented a theoretical investigation of a flat heat pipe for cooling electronic components. Wang et al. [20] analyzed the pressure-difference phenomenon in the heat pipe. Reyes et al. [21] experimentally and theoretically studied on the vapour chamber based heat spreader. Attia et al. [22] experimentally investigated the effects of different working fluids, different charge ratios on the thermal performance of the vapor chamber. Ji et al. [23] studied the vapor chamber performance with sintering the copper foams pieces. Choi et al. [24] studied a new CPU cooler design based on an active cooling heat sink combined with heat pipes. The most productive studies were continuously carried out by Naphon et al. [25-28]. They applied the vapor chamber with air or liquid cooling system for cooling electronic components. As mentioned above, the numerous papers presented the study on the heat transfer characteristics of the vapor chamber. There are many techniques for cooling electronic components. As compare to other cooling techniques such as fans, thermoelectric module, liquid pump loop device, the vapor chamber cooling technique has simple structures, no moving parts and does not use electricity. Heat dissipation increased but in contrary the size of the processor reduced. For the electronic cooling with vapor chamber, the bottom copper plate is the evaporator section that may be mounted on the electronic components to absorb the generated heat, and the other is the condenser section which heat is transferred to heat sink and air, respectively. However, the heat transfer capability is limited by the transport properties of air. One of the methods for the heat transfer enhancement is the application of additives to the working fluids to change the fluid transport properties and flow features. Therefore, the purpose of this paper is to study the thermal cooling

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 3, September 2013

of central processing unit by using the vapor chamber with jet liquid impingement. The results obtained from this cooling technique are compared with those from others cooling techniques.

II. EXPERIMENRAL APPRATUS AND METHOD

The test loop consists of a set of PC, a set of vapor chamber cooling system and data acquisition system as shown in Fig. 1. The close-loop of cooling water consists of a storage tank, water pump, flow meter, and radiator. The de-ionized water in the radiator is chilled by the atmospheric air. After the temperatures of the water are cooled to achieve the desired level, the cooling water is pumped out of the storage tank, and is passed through a flow meter, and is passed the CPU cooling system, and returned to the storage tank.

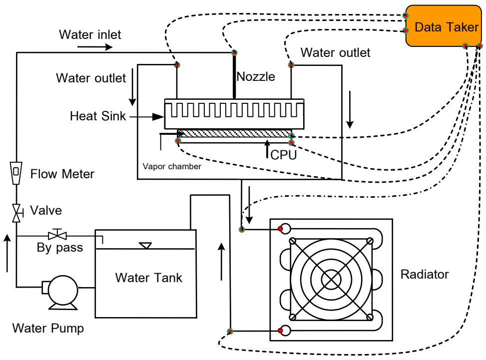

Fig 1 Schematic diagram of experimental apparatus

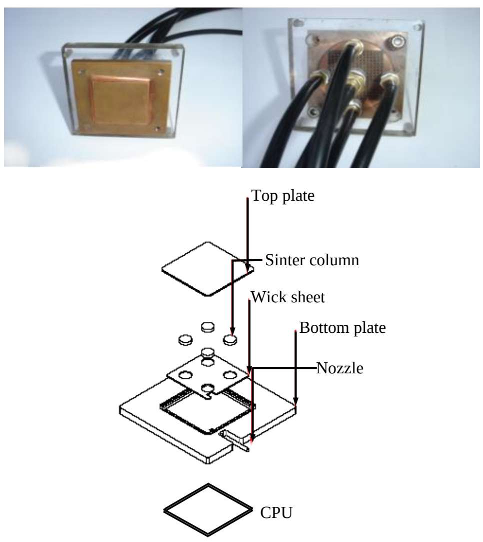

Fig 2 Schematic diagram of the vapor chamber details

The inlet and outlet positions of the coolant are shown in Fig. 2. The vapor chamber is fabricated from copper plate which consists of bottom copper plate, wick sheet, sinter column, and top copper plate as shown in Fig. 3. The wick sheet and the sinter column are fabricated from the copper powder. The bottom copper plate is the evaporator section that may be mounted on CPU of the PC to absorb the generated heat, and the other is the condenser section which heat is transferred to heat sink and cooling water, respectively. In order to minimize thermal resistance between the CPU-vapor chamber, vapor chamber-heat sink unit, a thin film of high thermal conductivity grease is applied at their junction interface. The working fluid (de-ionized water) in the vapor chamber is evaporated on the heated side and condensed on the cooling side and then returns to the evaporator section under gravity. The flow rates of the cooling water are controlled by adjusting the valve and measured by the flow meter with an accuracy of ±0.2% of full scale. The mini-rectangular fin heat sink is fabricated from the block of copper by a wire electrical discharge machine (WEDM). Type T copper-constantan thermocouples with an accuracy of 0.1% of full scale are employed to measure the temperatures. Four and two type T copper-constantan thermocouples are applied to measure the vapor chamber temperature and inlet and outlet water temperatures, respectively. A thermocouple is applied to observe the ambient temperature. A groove within the chamber walls is machined and the high conductivity cement is utilized to embed the thermocouples within the chamber wall. The CPU temperature is measured by four type-T copper-constantan thermocouples. All thermocouples are pre-calibrated with dry box temperature calibrator. The de-ionized water was pumped into the mini-rectangular fin heat sink which was installed on the CPU of the PC in the normal direction. The inlet temperature of coolant before entering the cooling section was kept nearly constant at 28.5-29°C. Experiments were conducted with various cooling water flow rates and operating conditions of PC. The supplied load into the CPU was adjusted to achieve the desired level by setting the operating conditions of the PC: no load and, 50%, 90% operating loads. The operating conditions of the computer can be controlled by setting the software of computer system. The energy consumption of the PC was measured by the watt-hour meter. The temperatures at each position and energy consumption were recorded in the period time of 200 min. Data collection was carried out using a data acquisition system (DataTaker).

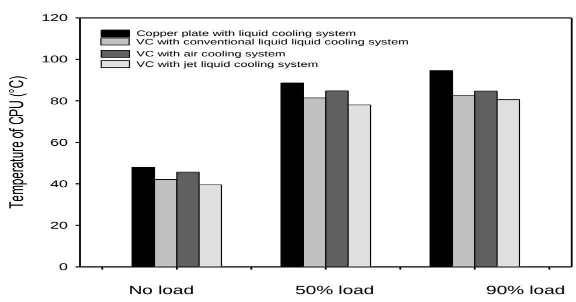

Fig 3 Variations of CPU temperature for different cooling techniques

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 3, September 2013

III. RESULTS AND DISCUSSION

Initially experiments are performed with the copper plate with liquid cooling system which forms the basis for comparison of the results with vapor chamber cooling technique. Based on the optimum condition (Naphon et al. 25-28), the vapor chambers with 20% fill ratio of working fluid are tested. After installing the all components, the experiments are performed with different operating conditions of personal computer and different cooling techniques. The results obtained from the vapor chamber with jet liquid impingement cooling technique are compared with those from others techniques. Figure 3 shows the variation of the CPU temperature for different cooling techniques. The copper plate with liquid cooling technique represents the cooling system in the sensible heat term while others represent the cooling system in the latent heat term (vapor chamber). For a given operating condition, the copper plate with liquid cooling gives the highest CPU temperature among all the models. This is because the latent heat term has significant effect on the thermal cooling of the CPU. In addition, the CPU temperature rapidly increases as the operating condition load increases. Due to the heat transfer capability limitation of air, the CPU temperatures obtained from the air cooling are higher than those from the liquid cooling technique. From the present model, it can be seen that fluid flows in and flows out the heat sink in the normal direction. It looks like a jet impinging on the bottom of the heat sink. The recirculation zones appear in the inlet section (Naphon et al. [25]) which the recirculation zones have significant effect on the heat transfer enhancement. Therefore, the vapor chamber with jet liquid impingement cooling gives the CPU temperature lower than those from

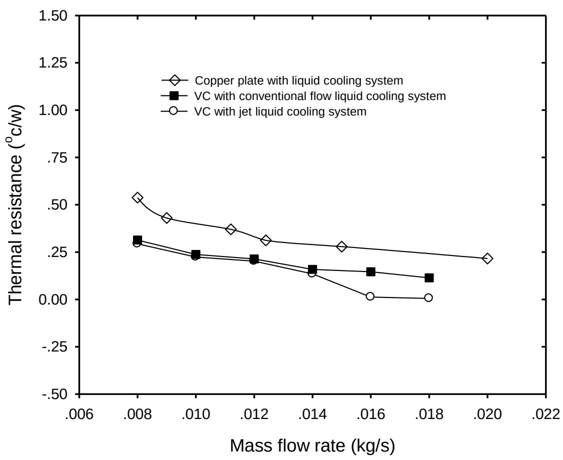

Fig 4 Comparison thermal resistant with mass flow rate for different cooling techniques

Figure 4 shows the variation of thermal resistance with the coolant mass flow rate for different cooling techniques. For a given operating condition, a decrease temperature difference is found for a larger coolant flow rate. The reason for this is because a larger coolant flow rate results in lower capacity resistance and consequently lower heat sink thermal resistance which corresponding to the variation of CPU temperature as mentioned above. In addition, the thermal resistance of the vapor chamber with jet liquid impingement cooling gives the CPU temperature lower than those from the conventional liquid flow cooling. The total thermal resistance of the vapor chamber cooling technique is the summation of the contact resistance, the evaporation resistance, the condensation resistance, and the convection resistance. For the same operating condition of PC, the thermal resistance ratio for the CPU can be written as

$$\frac{R_{vc}}{R_{con}} = \frac{T_{CPU,vc} - T_{coolant}}{T_{CPU,con} - T_{coolant}} \qquad (1)$$

Where R_{vc} is the thermal resistance of the vapor chamber cooling system, R_{con} is the thermal resistance of the copper plate cooling system. $T_{cpu,vc}$, $T_{cpu,con}$ are the CPU temperature of the vapor chamber cooling system and CPU temperature of the copper plate cooling system, respectively.

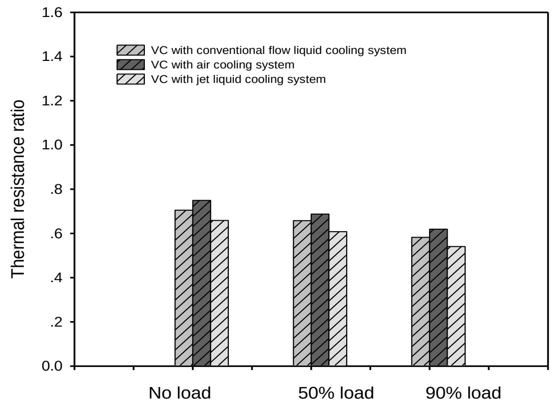

Fig 5 Variations of thermal resistance ratio for different operating conditions of PC

Figure 5 shows the variation of the thermal resistance ratio for different cooling techniques. At a lower operating load, the heat is mainly transferred through natural convection. However, the increasing operating load induces a larger superheat, which activates and intensifies nucleate boiling and consequently leads to higher heat transfer efficiency. Therefore, the vapor chamber cooling technique has significant to heat transfer enhancement especially higher operating load as shown in Fig.6. In addition, the thermal resistance for the vapor chamber with conventional flow liquid cooling technique is higher than those from with the vapor chamber with jet impingement liquid cooling technique which corresponding to the variation of the CPU temperature as mentioned above. The energy consumption obtained from 20% fill ratio of the vapor chamber cooling system are compared with those from the copper plate cooling system for the operating time of 200 minutes. As

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 3, September 2013

mentioned above, the CPU temperature obtained from the vapor chamber cooling techniques lower than those from the copper plate cooling technique. However, It can be seen from Table 1 that the energy consumption obtained from the vapor chamber cooling techniques tend to increase as comparing with the copper plate cooling technique.

Table 1 Comparison of energy consumption between the various cooling techniques and the copper plate with air cooling technique for operating time of 200 minutes

Cooling techniques	Energy consumption (W·h)	
	No load	90% load
VC with the conventional flow liquid cooling system	9.79%	13.14%
VC with air cooling system	6.90%	10.53%
VC with the jet liquid cooling system	12.77%	14.67%

IV. CONCLUSION

For the CPU or electronic devices, the air heat transfer limitation, the space limitation, and high level of the generated heat are the encountered problems of the cooling system development. The vapor chambers application for electronic cooling have many advantages as compared to other cooling devices such as fans, thermoelectric module, liquid pump loop device are that it has simple structures, no moving parts and does not use electricity. However, selection of the coolant with different flow features has significant effect to the thermal cooling. It is found that the CPU temperatures obtained from the vapor chamber with jet liquid impingement cooling system are lower than those with conventional flow liquid system.

V. ACKNOWLEDGEMENT

The author would like to express their appreciation to the Excellent Center for Sustainable Engineering (ECSE) of the Srinakharinwirot University (SWU) for providing financial support for this study. The author also wishes to acknowledge Fujikura Electronics (Thailand) Ltd. for their assistance in some of the vapor chamber samples.

REFERENCES

[1] S.S. Hsieh, R.Y. Lee, J.C. Shyu, S.W. Chen, Analytical solution of thermal resistance of vapor chamber heat sink with and without pillar, Energy Conversion and Management 48 (2007) 2708–2717.

[2] S.S. Hsieh, R.Y. Lee, J.C. Shyu, S.W. Chen, Thermal performance of flat vapor chamber heat spreader, Energy Conversion and Management 49 (2008) 1774–1784.

[3] X. Hu, D. Tang, Experimental investigation on flow and thermal characteristics of a micro phase-change cooling system with a microgroove evaporator, International Journal of Thermal Sciences 46 (2007) 1163–1171.

[4] X.L. Xie, Y.L. He, W.Q. Tao, H.W. Yang, An experimental investigation on a novel high-performance integrated heat pipe–heat sink for high-flux chip cooling, Applied Thermal Engineering 28 (2008) 433–439.

[5] Y.W. Chang, C.H. Cheng, J.C. Wang, S.L. Chen, Heat pipe for cooling of electronic equipment, Energy Conversion and Management 49 (2008) 3398–3404.

[6] Y.S. Chen, K.H. Chien, T.C. Hung, C.C. Wang, Y.M. Ferng, B.S. Pei, Numerical simulation of a heat sink embedded with a vapor chamber and calculation of effective thermal conductivity of a vapor chamber, Applied Thermal Engineering 29 (2009) 2655–2664.

[7] M. Zhang, Z. Liu, G. Ma, S. Cheng, Numerical simulation and experimental verification of a flat two-phase thermosyphon, Energy Conversion and Management 50 (2009) 1095–1100.

[8] H.K. Ma, B.R. Chen, J.J. Gao, C.Y. Lin, Development of an OAPCP-micro pump liquid cooling system in a laptop, International Communications in Heat and Mass Transfer 36 (2009) 225–232.

[9] L. Vasiliev, D. Lossouarn, C. Romestant, A. Alexandre, Y. Bertin, Y. Piatsiushyk, V. Romanenkov, Loop heat pipe for cooling of high-power electronic components, International Journal of Heat and Mass Transfer 52 (2009) 301–308.

[10] Z. Ming, L. Zhongliang, M. Guoyuan, The experimental and numerical investigation of a grooved vapor chamber, Applied Thermal Engineering 29 (2009) 422–430.

[11] S. Khandekar, A.P. Gautam, P.K. Sharma, Multiple quasi-steady states in a closed loop pulsating heat pipe, International Journal of Thermal Sciences 48 (2009) 535–546.

[12] S.W. Kang, W.C. Wei, S.H. Tsai, C.C. Huang, Experimental investigation of nanofluids on sintered heat pipe thermal performance, Applied Thermal Engineering 29 (2009) 973–979.

[13] T.E. Tsai, H.H. Wu, C.C. Chang, S.L. Chen, Two-phase closed thermosyphon vapor-chamber system for electronic cooling, International Communications in Heat and Mass Transfer 37 (2010) 484–489.

[14] J.C. Wang, R.T. Wang, T.L. Chang, D.S. Hwang, Development of 30 Watt high-power LEDs vapor chamber-based plate, International Journal of Heat and Mass Transfer 53 (2010) 3990–4001.

[15] S.C. Wong, K.C. Hsieh, J.D. Wu, W.L. Han, A novel vapor chamber and its performance, International Journal of Heat and Mass Transfer 53 (2010) 2377–2384.

[16] T.H. Wang, C.C. Lee, Y.S. Lai, Thermal characteristics evaluation for board-level high performance flip-chip package equipped with vapor chamber as heat spreader, Microelectronic Engineering 87 (2010) 2463–2467.

[17] H.Y. Li, M.H. Chiang, C.I. Lee, W.J. Yang, Thermal performance of plate-fin vapor chamber heat sinks, International Communications in Heat and Mass Transfer 37 (2010) 731–738.

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 3, Issue 3, September 2013

[18] H.Y. Li, M.H. Chiang, Effects of shield on thermal-fluid performance of vapor chamber heat sink, International Journal of Heat and Mass Transfer 54 (2011) 1410–1419.

[19] S. Harmand, R. Sonan, M. Fakès, H. Hassan, Transient cooling of electronic components by flat heat pipes, Applied Thermal Engineering 31 (2011) 1877-1885.

[20] R.T. Wang, J.C. Wang, Analyzing the pressure-difference phenomenon between the condensing and boiling sections in a heat pipe cooling system, International Communications in Heat and Mass Transfer 39 (2012) 390–398.

[21] M. Reyes, D. Alonso, J.R. Arias, A. Velazquez, Experimental and theoretical study of a vapour chamber based heat spreader for avionics applications, Applied Thermal Engineering 37 (2012) 51-59.

[22] A.A.A. Attia, B.T.A. El-Assal, Experimental investigation of vapor chamber with different working fluids at different charge ratios, Ain Shams Engineering Journal 2 (2012) 289–297.

[23] X. Ji, J. Xu, A.M. Abanda, Copper foam based vapor chamber for high heat flux dissipation, Experimental Thermal and Fluid Science 40 (2012) 93–102.

[24] J. Choi, M. Jeong, J. Yoo, M. Seo, A new CPU cooler design based on an active cooling heat sink combined with heat pipes, Applied Thermal Engineering 44 (2012) 51-56.

[25] P. Naphon, S. Klangchart, S. Wongwises, Numerical investigation on the heat transfer and flow in the mini-fin heat sink for CPU, International Communications in Heat and Mass Transfer, 36 (2009) 834-840.

[26] P. Naphon, S. Wiriyasart, Liquid cooling in the mini-rectangular fin heat sink with and without thermoelectric for CPU, International Communications in Heat and Mass Transfer, 36 (2009) 166-171.

[27] P. Naphon, S. Wiriyasart, Study on the vapor chamber with refrigerant R-141b as working fluid for HDD cooling, International Communications in Heat and Mass Transfer, 39 (2012) 1449-1452.

[28] P. Naphon, S. Wongwises, S. Wiriyasart, Application of two-phase vapor chamber technique for hard disk drive cooling of PCs, International Communications in Heat and Mass Transfer, 40 (2013) 32-35.

AUTHOR'S PROFILE

P. Naphon was born in Thailand on July 28, 1972. He received the Master D., and Dr.Ing. degrees in mechanical engineering from King Mongkut's University of Technology Thonburi, Bangkok, Thailand, in 1998, and 2004, respectively. His areas of interest include heat transfer enhancement, heat pipe testing, modeling and simulation, electronic cooling. He has published several papers in international journals and conferences in the field of heat pipe, and desalination. He has carried out several projects on heat transfer enhancement, electronics cooling, in 2012; He has a temporary contract now with Srinakharinwirot University – Bangkok-Thailand