CPU Cooling by Vapor Chamber with R-141b as Working Fluid

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ABSTRACT---- ***Air cooling and the space limitations are encountered problems of the thermal cooling electronic development for electronics devices or computer. In the present study, results of the experimental investigation on the thermal cooling of vapor chamber with refrigerant R-141b as working fluid for cooling computer processing unit of the personal computer are presented. Parametric studies including different aspect ratios, fill ratios, and operating conditions of PC on the thermal cooling are considered. Average CPU temperatures obtained from the vapor chamber cooling system with R-141b are 19.55%, 18.61% lower than those from the conventional cooling system for no load and 90% operating loads, respectively. In additional, this cooling system requires 50% lower energy consumption for no load operating loads.***

Keywords--- Vapor chamber; electronics cooling; central processing unit

1. INTRODUCTION

In general, heat is a normal by-product of electronic devices which depending on the model of these devices and application running. Due to the high-performance processor and graphics capabilities, it is normal for a high performance computer to feel warm. There are many techniques for cooling electronic devices. Conventional thermal management devices using active devices such as fans, thermoelectric coolers, refrigerators, and liquid pump loop. In general, liquid cooling system is a highly effective method of removing excess heat. The advantages of water cooling system over air cooling system include water's higher thermal conductivity and specific heat capacity. As compare to air cooling system, liquid cooling system generates noise in low level. However, disadvantages of liquid cooling include complexity and less reliable installations for a coolant leak which leaked water can damage any electronic components. As compare to other cooling devices 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. The heat transfer characteristics of the vapour chamber been widely studied by researchers. Hsieh et al. [1,2] considered the thermal efficiency cooling of the vapor chamber with and without pillar for cooling electronic devices. Xie et al. [3] investigated the thermal efficiency of the heat pipe for cooling the chip. Chang et al. [4] considered the effects of the surface, fill ratios of working fluid and input heating powers on the thermal performance of the heat pipe. The numerically and experimentally investigated the vapor chamber and the thermosyphon are presented by many researchers [5,6,7,8]. Kang et al. [9] experimentally investigated of the nanofluids on sintered heat pipe thermal performance. Tsai et al. [10] experimentally investigated on 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. [11] considered the thermal performance of the vapor chamber for the high-power LEDs. Wong et al. [12] studied a novel vapor chamber with inner groove surface. Wang et al. [13] analyzed the thermal characteristics for board-level high performance package equipped with vapor chamber. Li et al. [14-15] 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. Reyes et al. [16] experimentally and theoretically studied the vapor chamber based heat spreader. Attia et al. [17] experimentally investigated of the effects of different working fluids, different charge ratios on the thermal performance of the vapor chamber. Ji et al. [18] studied on the vapor chamber performance with sintering the copper foams pieces. Choi et al. [19] 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. [20-22]. 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 or thermosyphon. The trend of the processor performance and heat dissipation increased significant every year. Heat dissipation increased but in contrary the size of the processor reduced. 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 of central processing unit by using the vapor chamber with refrigerant R-141b as working fluid. The results obtained from this cooling technique are compared with those from others cooling techniques.

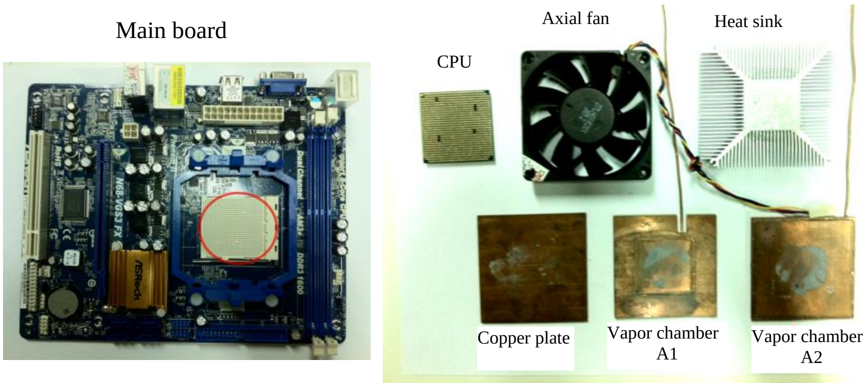

Figure 1: Schematic diagram of the main board and the vapor chamber cooling system

2. EXPERIMENTAL APPARATUS AND METHOD

2.1 Experimental apparatus

As shown in Fig. 1, the experimental apparatus consists of a set of PC, a set of vapor chamber cooling system and data acquisition system. The vapor chamber cooling system consists of the vapor chamber with heat sink unit, and axial fan unit. The details of the vapor chamber are listed as shown in Table 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. 2. The wick sheet and the sinter column are fabricated from the copper powder. The tests are performed on the vapor chamber with refrigerant R-141b as working fluid. 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 air, respectively. To fill poorly conducting air gaps due to imperfectly flat and smooth surfaces, high thermal conductivity grease is interposed between the CPU-vapor chamber, vapor chamber-heat sink unit. 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. First of all, all thermocouples are pre-calibrated with dry box temperature calibrator. The CPU temperature is measured by four type-T copper-constantan thermocouples. Four and two type T copper-constantan thermocouples are applied to measure the vapor chamber temperature and ambient temperature, respectively. A groove within the chamber walls is machined and the high conductivity grease is utilized to embed the thermocouples within the chamber wall.

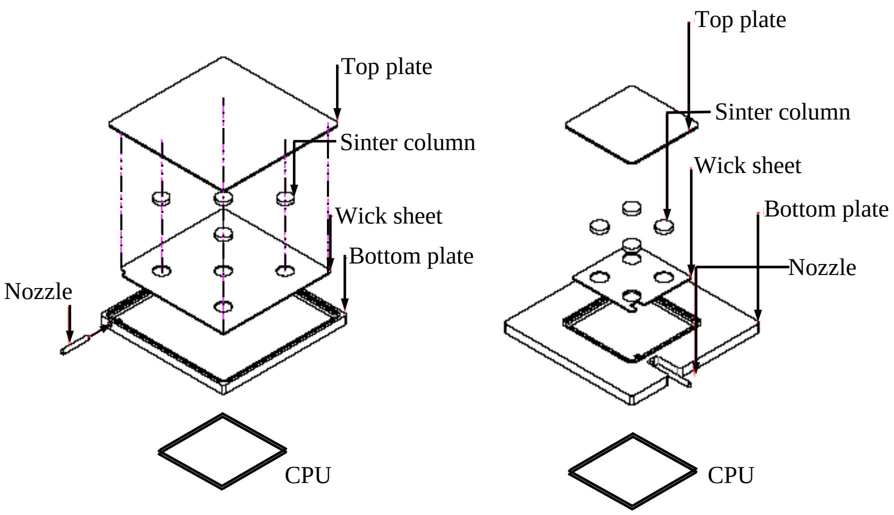

Figure 2: Schematic diagram of the vapor chamber details used in the present study

2.2 Experimental method

Experiments were conducted with various fill ratios 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, 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). The uncertainty and accuracy of the measurement are given in Table 1.

Table 1: Accuracy and uncertainty of measurements

Instruments	Accuracy	Uncertainty
Voltage supplied by power source, (volt)	0.2%	$\pm$0.5
Current supplied by power source, (ampere)	0.2%	$\pm$0.5
Thermocouple type T, data logger, (^{o}C)	0.1%	$\pm$0.1

3. RESULTS AND DISCUSSION

All computers or electronic devices require electricity to function, and some electronic components require more electricity than others. As electricity passes across circuits and through wires, it meets a natural degree of resistance and creates heat. The central processing unit and graphics processing unit require considerably more electrical input. Moreover, the amount of electricity used by those components is highly variable, depending on the model and number of applications running. After installing all components, the tests are done with different vapor chamber models, fill ratios and operating conditions of personal computer. In general, heat is a normal by-product of computer or electronic devices operation. Under typical operating conditions, generated heat from computer should not be a cause for concern. In fact, generated heat is generally a sign that the computer is normal operation. Figure 3 shows the variation of the CPU temperature for different operating loads. It can be seen that the CPU temperature tends obtained from three vapor chamber models are similar to the one from the conventional cooling system. The CPU temperature rapidly increases as the operating condition load increases.

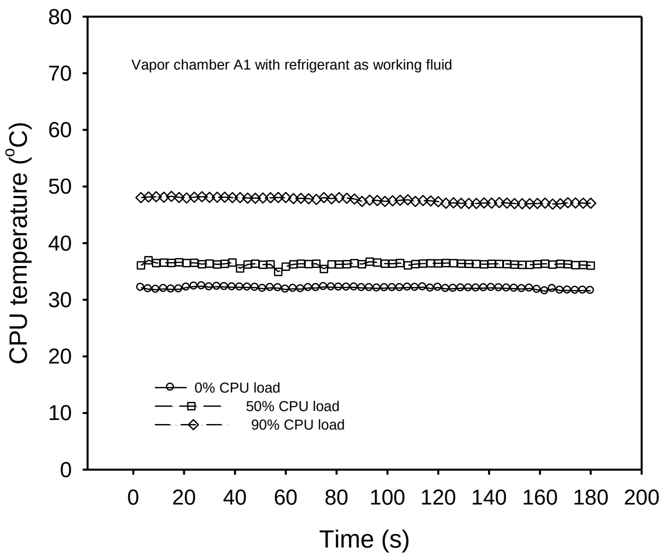

Figure 3: Variation of CPU temperature with time for different operating conditions

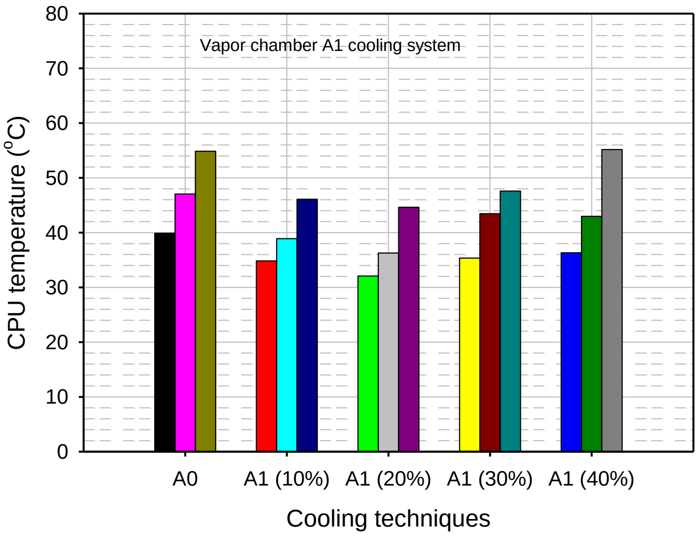

Figure 4: Variations of CPU temperature of the vapor chamber A1 cooling system for different fill ratios

Figures 4 and 5 show the variation of the CPU temperatures obtained from model A1 and model A2 with different fill ratios, respectively. The total volume of the vapor chamber for the present study is measured to be about 8000 ml. The heat phenomenon by working fluid in the vapor chamber, the working fluid absorbs heat from the heat source (CPU) and evaporates in the evaporator (bottom plate). The evaporating fluid moves through the wick sheet and toward the condenser, and then condenses in the condenser (top plate). For a given operating load and aspect ratio, it can be seen that model A1 with fill ratio of 20% and model A2 with fill ratio of 30% give the lowest CPU temperature among the fill ratios. It may be due to low fill ratio, and the dry out phenomenon might happen. The condensing liquid cannot promptly reflow at this operating load. However, for higher fill ratio, the thermal resistance of the liquid film also increases with increasing fill ratio. Therefore, the CPU temperature tends to increase as the fill ratio increase over 20% and 30% for model A1, and model A2, respectively. The conventional cooling system with copper plate 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.

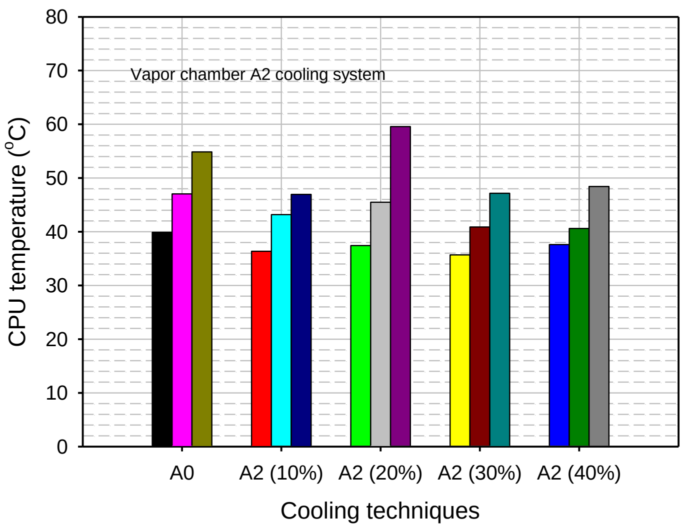

Figure 5: Variations of CPU temperature of the vapor chamber A2 cooling system for different fill ratios

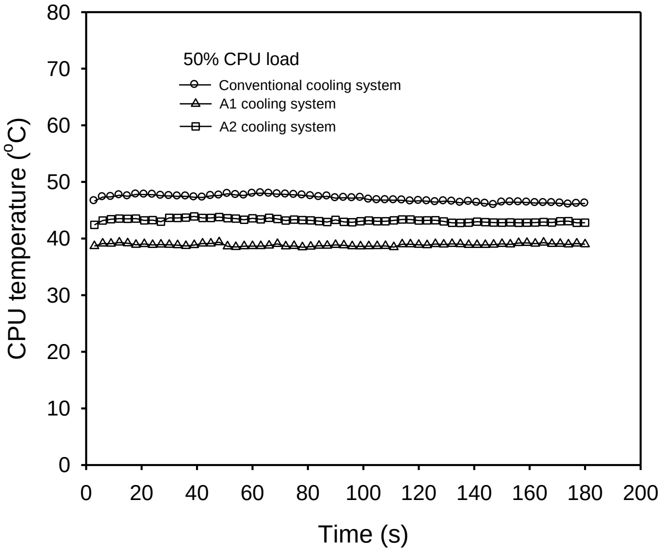

Figure 6: Variation of CPU temperature with time for different cooling techniques

Effect of aspect ratio (CPU surface area to bottom plate surface area) on the CPU temperature is shown in Figure 6. For model A1, there is only the thin liquid film in the heat input region. For model A2, however, due to the local boiling and the effect of capillary pressure of the vapor chamber, the liquid film at the heat input region is much thinner than that at the other region (heat input region outside). The thermal resistance of the phase change heat transfer will also increase with the thickness of the liquid film. For a given fill ratio, therefore, model A1 with an aspect ratio of 1 gives the CPU temperature lower than those from model A2 with an aspect ratio of 0.29. As comparing with the conventional cooling system, it can be seen that the vapor chamber cooling systems give the CPU temperature lower than those from the conventional cooling system.

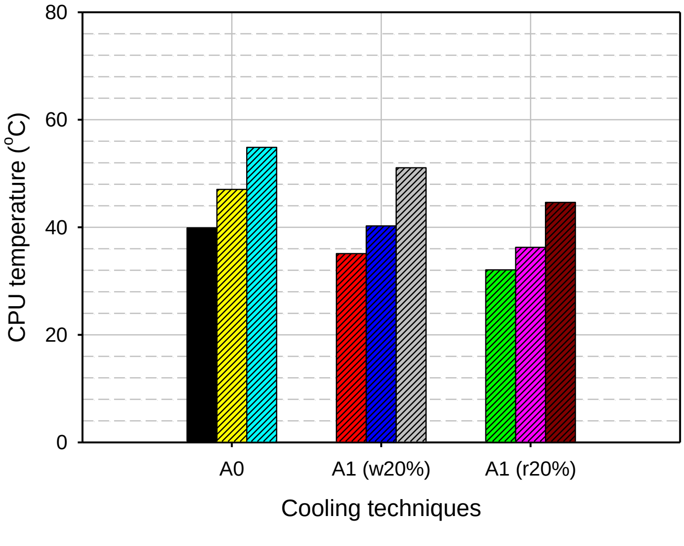

Figure 7: Comparison of CPU temperature of the vapor chamber cooling system
for different cooling techniques

Figure 7 shows effects of working fluid types on the CPU temperature of model A1 at 20% fill ratio. The heat phenomenon by working fluid in the vapor chamber, the working fluid absorbs heat and evaporates at the hot surface. The vapor travels to the other cool surface (condenser), where it condenses, giving up its latent heat. The liquid returns to the hot surface by gravity or capillary action and repeats the cycle. Vapor chambers have a much higher effective thermal conductivity than solid materials. Therefore, the CPU temperatures obtained from the vapor chamber cooling systems are lower than those from the conventional cooling system. In addition, the model A1 with refrigerant R-141b as working fluid give the CPU temperature lower than that with de-ionized water as working fluid.

The CPU temperature and the energy consumption obtained from 20% fill ratio of the vapor chamber cooling system are compared with those from the conventional cooling system for the operating time of 200 min. It can be seen from Table 3 that the CPU temperatures obtained from the vapor chamber with water as working fluid cooling system are 6.37%, 3.11% lower than those from the conventional cooling system for no load and 90% operating loads, respectively. In addition, the vapor chamber with refrigerant R-141b gives CPU temperature 19.55%, 18.61% lower than those from the conventional cooling system for no load and 90% operating loads, respectively. In addition, the energy consumption also decreases 50.00% for no load.

4. CONCLUSIONS

Heat is a normal by-product of computer or electronic devices operation which depends on the model and application running. For reliable operation, the temperature must never exceed a specified maximum permissible value for each component. Air cooling limitations are encountered problems of the cooling electronic development. Liquid cooling is a highly effective method of removing excess heat, with the most common heat transfer fluid in desktop PCs being water. The advantages of water cooling over air cooling include water's higher specific heat capacity and thermal conductivity. However, the vapor chamber cooling technique has simple structures, no moving parts and does not use electricity. Vapor chambers have a much higher effective thermal conductivity than solid materials.

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6. 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, Vol. 48, pp. 2708–2717, 2007.

[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, Vol. 49, pp. 1774–1784, 2008.

[3] 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, Vol. 28, pp. 433–439, 2008.

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

[5] 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, Vol. 29, pp. 2655–2664, 2009.

[6] M. Zhang, Z. Liu, G. Ma, S. Cheng, "Numerical simulation and experimental verification of a flat two-phase thermosyphons", Energy Conversion and Management, Vol. 50, pp. 1095–1100, 2009.

[7] 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, Vol. 52, pp. 301–308, 2009.

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

[9] 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, Vol. 29, pp. 973–979, 2009.

[10] 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, Vol. 37, pp. 484–489, 2010.

[11] 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, Vol. 53, pp. 3990–4001, 2010.

[12] 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, Vol. 53, pp. 2377–2384, 2010.

[13] 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, Vol. 87, pp. 2463–2467, 2010.

[14] 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, Vol. 37, pp. 731–738, 2010.

[15] 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, Vol. 54, pp. 1410–1419, 2011.
[16] 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, Vol. 37, pp. 51-59, 2012.
[17] 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, Vol. 2, pp. 289–297, 2012.
[18] X. Ji, J. Xu, A.M. Abanda, "Copper foam based vapor chamber for high heat flux dissipation", Experimental Thermal and Fluid Science, Vol. 40, pp. 93–102, 2012.
[19] 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, Vol. 44, pp. 51-56, 2012.
[20] P. Naphon, S. Wongwises, S. Wiriyasart, "On the thermal cooling of central processing unit of the PCs with vapor chamber", International Communications in Heat and Mass Transfer, Vol. 39, pp. 1165-1168, 2012.
[21] 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, pp. 1449-1452, 2012.
[22] 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, Vol. 40, pp. 32-35, 2013.