JOURNAL OF ENGINEERING AND TECHNOLOGY, Vol. 7 No. 2 December 2009 ISSN 1684-4114
http://www.iutoic-dhaka.edu/jet

Parallel Miniature Heat Pipes: The Silent Way to Manage Desktop Thermal Problems

Chowdhury Md. Feroz* and **Ahmed Imtiaz Uddin***

Received 10 June 2009; Accepted after revision 25 August 2009

ABSTRACT

Heat transfer performance of parallel miniature heat pipes (MHP) of 2.8 mm ID used for cooling desktop computer processor is presented in this paper. In cooling desktop processors, MHP consists of six single tube heat pipes connected by a copper block at the evaporator section and fifteen parallel copper sheets used as external fins at the condenser section. Ethanol is used as working fluid. The copper block is placed above the heat source (on the top of the processor) and the condenser section is provided with external fins perpendicular to the MHP. Experimental results show that the maximum and steady state temperature of the processor surface has been reduced significantly by using MHP instead of conventional cooling fan. Addition of fan at the condenser section shows much low and steady state temperature of the processor surface.

Keywords: *CPU Cooling, Desktop Processor, Heat Transfer Performance, Parallel Miniature Heat Pipes.*

* *Department of Mechanical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh. Email: cmferoz@me.buet.ac.bd*

1 INTRODUCTION

The computer industry has recognized the importance of thermal management and that identifying the component's thermal necessities at the beginning of the design process will eliminate costly redesigns. The complexities of the thermal management are compounded due to the increasing heat fluxes concentrated on decreasing component sizes. The concentrated heat sources are making standard extruded heat sinks less effective due to the inherent conduction losses.

With the increasing power of today's microprocessors, a processor cooling fan is used to these local heat sinks. Fan sinks placed directly over the processor occupy the most valuable real estate in a computer and can interfere with the placement of add-on boards and other system components. Heat pipe (HP) sinks provide the system designer with a powerful tool. The heat pipes transport heat away from the obstructions and constraints of neighboring boards to where it can be conveniently dissipated. The ability of heat pipe to be formed to meet location and space availability and its characteristics low temperature potential as a function of length permit the heat pipe sink system to provide the maximum effective heat sink surface area with the minimum volume demand. A heat pipe is essentially a passive heat transfer mechanism results in heat transfer capabilities from one hundred to several thousand times that of an equivalent piece of copper. It is a sealed vessel that is partially filled with a fluid, which serves as the heat transfer media. The envelope is typically made of cylindrical copper tubing, although rectangular cross sections are available. The wall of the envelope is lined with a wick structure, which generates the capillary force that pulls the condensate from the condenser section of the heat pipe back to the evaporator section. **Fig.1** shows a schematic illustration of the heat pipe operation. As heat is applied to the surface of the heat pipe, the working fluid is vaporized. The vapor at the evaporator section is at a slightly higher temperature and pressure than other areas, and creates a pressure gradient that forces the vapor to flow to the cooler regions of the heat pipe. As the vapor condenses on the walls, the latent heat of vaporization is transferred to the condenser. The capillary wick then transports the condensate back to the evaporator section. This is a closed loop process that continues as long as the heat is applied.

At present, heat released by the Central Processing Unit (CPU) of a desktop and server computer is 80 to 130 W and of notebook computer is 25 to 50W [1]. In the latter case, the heating area of the chipset has become as small as 1– 4 cm^2. This problem is further complicated by both the limited available space and the restriction to maintain the chip surface temperature below 100^oC [2]. It is expected that the conventional cooling fan system will not be able to meet the

1 INTRODUCTION

The computer industry has recognized the importance of thermal management and that identifying the component's thermal necessities at the beginning of the design process will eliminate costly redesigns. The complexities of the thermal management are compounded due to the increasing heat fluxes concentrated on decreasing component sizes. The concentrated heat sources are making standard extruded heat sinks less effective due to the inherent conduction losses.

With the increasing power of today's microprocessors, a processor cooling fan is used to these local heat sinks. Fan sinks placed directly over the processor occupy the most valuable real estate in a computer and can interfere with the placement of add-on boards and other system components. Heat pipe (HP) sinks provide the system designer with a powerful tool. The heat pipes transport heat away from the obstructions and constraints of neighboring boards to where it can be conveniently dissipated. The ability of heat pipe to be formed to meet location and space availability and its characteristics low temperature potential as a function of length permit the heat pipe sink system to provide the maximum effective heat sink surface area with the minimum volume demand. A heat pipe is essentially a passive heat transfer mechanism results in heat transfer capabilities from one hundred to several thousand times that of an equivalent piece of copper. It is a sealed vessel that is partially filled with a fluid, which serves as the heat transfer media. The envelope is typically made of cylindrical copper tubing, although rectangular cross sections are available. The wall of the envelope is lined with a wick structure, which generates the capillary force that pulls the condensate from the condenser section of the heat pipe back to the evaporator section. **Fig.1** shows a schematic illustration of the heat pipe operation. As heat is applied to the surface of the heat pipe, the working fluid is vaporized. The vapor at the evaporator section is at a slightly higher temperature and pressure than other areas, and creates a pressure gradient that forces the vapor to flow to the cooler regions of the heat pipe. As the vapor condenses on the walls, the latent heat of vaporization is transferred to the condenser. The capillary wick then transports the condensate back to the evaporator section. This is a closed loop process that continues as long as the heat is applied.

At present, heat released by the Central Processing Unit (CPU) of a desktop and server computer is 80 to 130 W and of notebook computer is 25 to 50W [1]. In the latter case, the heating area of the chipset has become as small as $1-4\ cm^2$. This problem is further complicated by both the limited available space and the restriction to maintain the chip surface temperature below 100^oC [2]. It is expected that the conventional cooling fan system will not be able to meet the

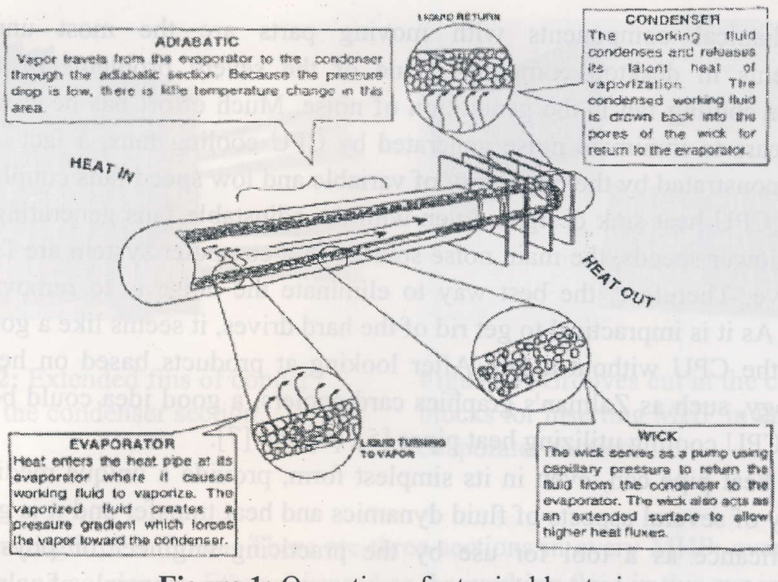


Figure 1: Operation of a typical heat pipe.

futuristic thermal needs of the next generation computers. Other technologies like liquid cooling and thermoelectric coolers have good potential but still create major integration, reliability and cost issues. With the development in the two-phase heat transfer systems and porous media technology, heat pipes have come up as a potential candidate to meet these challenging needs. Notebook computers involved the first high volume use of heat pipes when Intel introduced the Pentium® TCP packages in 1994 [3]. The main reason for the use of heat pipes is the Pentium® power dissipation level and the limitation and constraints of space and weight in notebooks. Compared to metal plates or heat sinks, heat pipes offer excellent thermal performance with much less weight and can spread the heat away from the CPU to other areas where the heat can be rejected. Today, Pentium® based notebooks and sub-notebooks are estimated to use several millions of heat pipes annually based on the PC based notebook volume.

The performance of natural convection heat sinks is directly dependent on the effective surface area: more effective surface area results in better performance. The increase of the microprocessor speed and number of transistors cramped into the processor core silicon die has continuously driven up its power dissipation. Heat sink sizes have been increasing in personal computers, from the 2″ × 2″ aluminum extrusion heat sinks for i486 to the 3″ × 3″ heat sinks for Pentium® and even large heat sinks for the latest Pentium® II microprocessors. Heat pipes as the higher level thermal solutions are naturally being investigated as the potential thermal solutions for these systems [4].

Mechanical components with moving parts are the most unreliable components in desktop computers. One of the severe problems of today's processor cooling fan is the generation of noise. Much effort has been made in recent years to minimize noise generated by CPU cooling fans, a fact that has been demonstrated by the popularity of variable and low speed fans coupled with efficient CPU heat sink designs. Even with the adjustable fans generating lower noise at lower speeds, the main noise sources in a computer system are fans and hard drive. Therefore, the best way to eliminate the noise is to remove these sources. As it is impractical to get rid of the hard drives, it seems like a good idea to cool the CPU without a fan. After looking at products based on heat pipe technology, such as Zalman's graphics card coolers, a good idea could be to try passive CPU cooling utilizing heat pipes [5], [6] and [7].

The heat pipe can, even in its simplest form, provide a unique medium for the study of several aspects of fluid dynamics and heat transfer and it is growing in significance as a tool for use by the practicing engineer or physicist in applications ranging from heat recovery to precise control of electronic equipments. Normally for these equipments heat pipes of diameter 3 to 6 *mm* and length less than 400 *mm* are preferred [8]. Most preferable length is 150 *mm* [9]. The heat pipe applications for cooling computer CPU was started in the last decade and now 98% of notebooks PCs are cooled by using heat pipes.

Studies on the application of heat pipes having the diameter of 3 or 4 *mm* for cooling notebook PC CPU have been actively conducted by the American and Japanese enterprises [7], [10] and [11]. An experimental study is performed by Tanim et al. [12] to investigate the performance of cooling desktop processors using heat pipe of 5.8 *mm* ID and a length of 150 *mm* with respect to the normal fanned CPU unit. They reported that the use of heat pipe may eliminate the use of the processor fans. Additionally heat pipe technology is emerging as a cost-effective thermal design solution for the desktop industry. So far no investigation has been conducted for cooling desktop processor with MHP. The concept in this experiment is to draw the heat from the CPU into one end of MHP while making the other end of the MHP as extended fins of copper plate to expel the heat into the air. Finally the performance of the MHP in cooling desktop processor is investigated with respect to conventional fanned CPU cooling system.

2 EXPERIMENTAL APPARATUS AND TEST PROCEDURE

The experimental setup for this study mainly consists of four parts – parallel MHP, a desktop computer, temperature measurement system and cooling system. Six MHP are placed parallel to each other for cooling purpose. These are made of copper tube of inner diameter of 2.8 *mm* and outer diameters of 3.8 *mm*

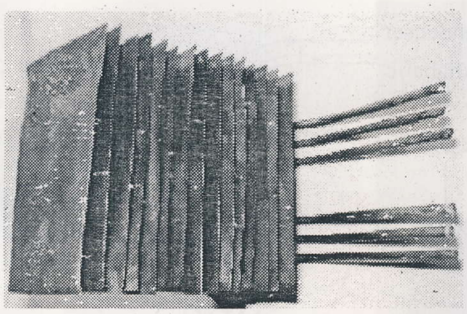


Figure 2: Extended fins of copper sheet in the condenser section.

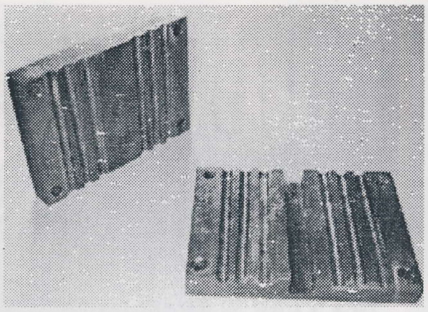
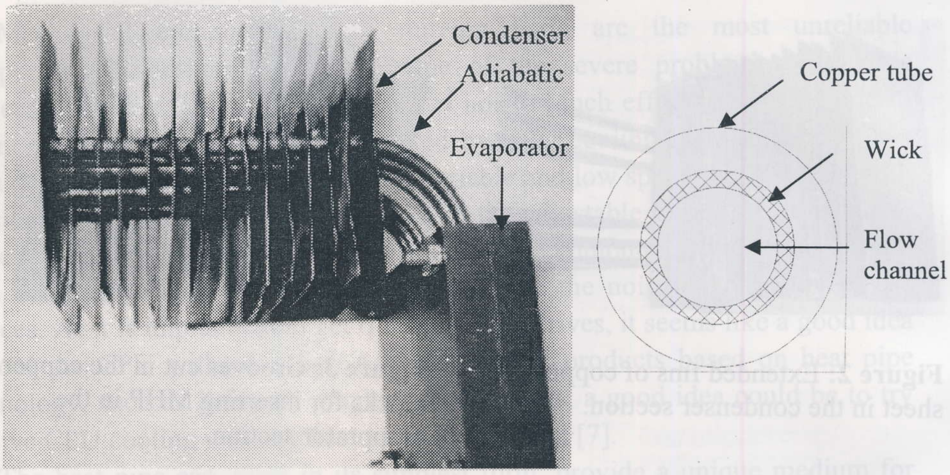


Figure 3: Grooves cut in the copper blocks for inserting MHP in the evaporator section.

having a length of 150 *mm*. There are three sections in every MHP: evaporator, adiabatic and condenser. Ethanol is used as the working fluid in this experiment.

The condenser section of MHP is made of copper sheets of 67 *mm* × 50 *mm* (thickness 0.5 *mm*) placed parallel as extended fins at a constant interval of 5 *mm* as shown in **Fig.2**. Plates are welded with the MHP for better heat transfer. As there is space constrain inside the CPU, these are bend at 90° in adiabatic section. The evaporator section is inserted into the grooves of copper blocks shown in **Fig.3**, which is placed on the top of the processor to remove the generated heat. Two copper blocks of 67 *mm* × 50 *mm* × 8 *mm* are made very precisely to mate with the MHP. Grooves are cut inside the blocks. The blocks are precise in dimension. The surfaces are finished highly to reduce the contact resistance as well as to increase the heat transfer rate. The different sections of parallel MHP are shown in **Fig.4 (a)**.

Heat generated in the processor enters the evaporator section where it causes working fluid to vaporize. The vaporized fluid creates a pressure gradient which forces the vapor toward the condenser section. Vapor travels from the evaporator to the condenser through the adiabatic section. The working fluid condenses and releases its latent heat of vaporization. The condensed working fluid is drawn back into the pores of the wick for return to the evaporator. The wick serves as a pump using capillary pressure to return the fluid from the condenser to the evaporator. Before bending in the adiabatic section to the desired angle, a single layer wick of stainless steel of 200 meshes is inserted into each MHP which remains in contact with the inner surface of the tube as shown in **Fig.4 (b)**. The amount of working fluid poured into the heat pipes has a charge ratio of 0.9. The charge ratio is defined as a ratio of the volume of the fluid



(a) Different sections of MHP. **(b)** Cross section of MHP.

Figure 4: MHP with evaporator, adiabatic and condenser sections for cooling of desktop processor.

actually charged to the volume of the evaporator section. Both ends of these are properly sealed. Nine calibrated *K*-type (Φ = 0.18 *mm*) thermocouples are attached at the wall of each MHP using adhesive to measure the wall temperature: four units at the evaporator section, one unit at the adiabatic section and four units at the condenser section. Locations of thermocouples connected on different points along the length of the HP are shown in the **Fig.5 (a)**. The surface temperature of the processor is also measured by four *K*-type thermocouples as shown in **Fig.5 (b)**. All thermocouples are connected with a digital temperature indicator (YF-160A, *K*-type thermometer) through selector switches. Thermocouples used for temperature measurement on the walls of MHP and processor surface are estimated to have uncertainty smaller than 0.2^oC.

Experiment is conducted in two arrangements. In one arrangement, the CPU is cooled by using MHP only as shown in **Fig.6**. In the other arrangement, the cooling is enhanced by using a conventional cooling fan in addition to the MHP at the condenser section as shown in **Fig.7**. Processor surface temperature and wall temperature of MHP are recorded for 150 *minutes* at an interval of 10 *minutes*. Experiments have been performed in a room condition having an ambient temperature of 28.5^oC to 29.6^oC. To simulate the experimental condition with the normal running condition of the CPU, no insulation is applied on the processor surface. For this reason, heat generation in the processor is not considered.

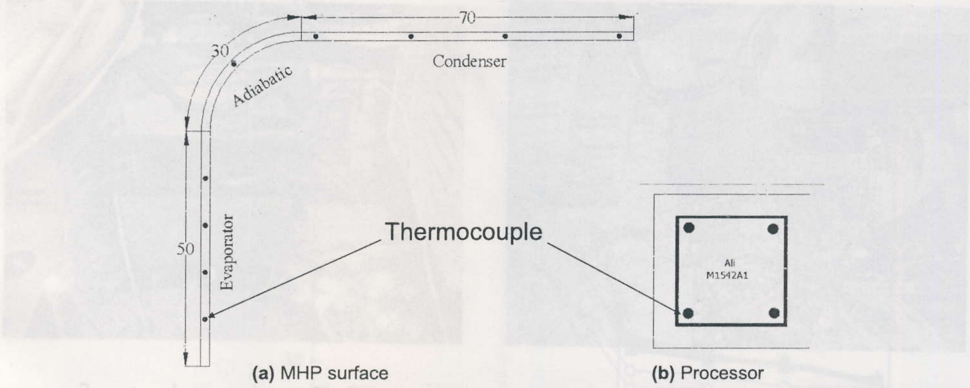


Figure 5: Locations of thermocouples on the MHP axial position and surface of the processor.

Experimental parameters and configurations of the desktop computer used in this experiment are given in **Table.1** and **Table.2** respectively.

Table 1: Experimental parameters.

Parameters	**Condition**
Number of the heat pipes	6
Diameter of the heat pipes (*mm*)	ID = 2.8; OD = 3.8
Length of the heat pipe (*mm*)	150
Length of the evaporator section (*mm*)	50
Length of the adiabatic section (*mm*)	30
Length of the condenser section (*mm*)	70
Working fluid	Ethanol
Dimension of the copper block (*mm*)	67×50×8
Dimension of the copper sheet (*mm*)	67×50×0.5
Charge ratio	0.9
Wick (SS)	200 mesh

Table 2: Configuration of the desktop computer.

Components	**Specification**
Processor	Ali M1542A1
Fan	Power logic- DC brushless Fan, Model- PL80S12H-1;DC-12V, 0.18A
Ram	16 MB
Hard disk	Seagate; Model ST34321A; 10GB
Power box	115/230 VAC,15 A/ 10 A

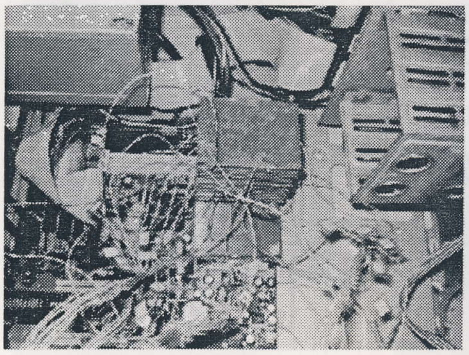


Figure 6: Experimental setup for cooling desktop processor by using MHP.

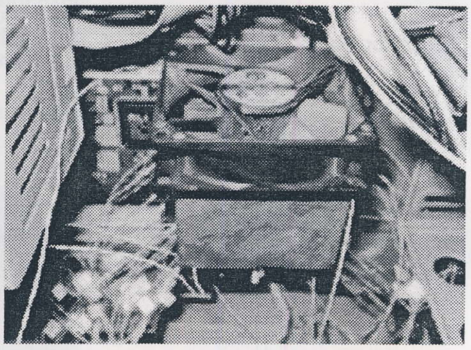


Figure 7: Experimental setup for cooling desktop processor by using MHP with cooling fan.

3 RESULTS AND DISCUSSION

Heat generated in the processor enters the evaporator section of MHP causes working fluid to vaporize. This lowers the temperature of the processor surface. **Fig.8** shows the variation of the processor surface temperature with time. Results

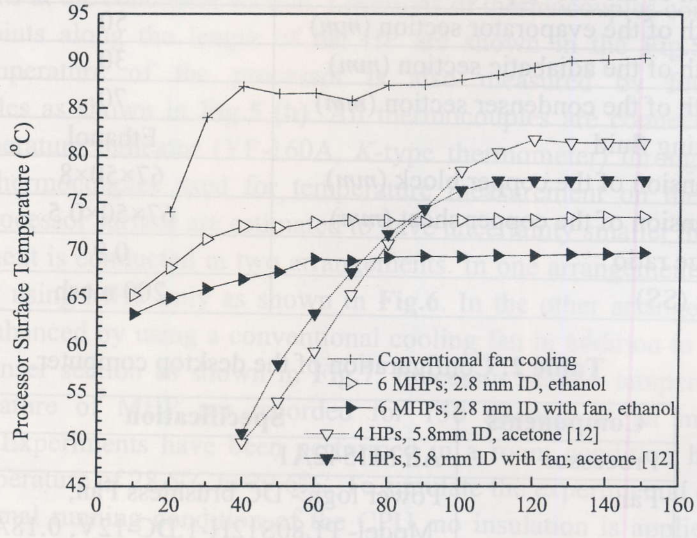
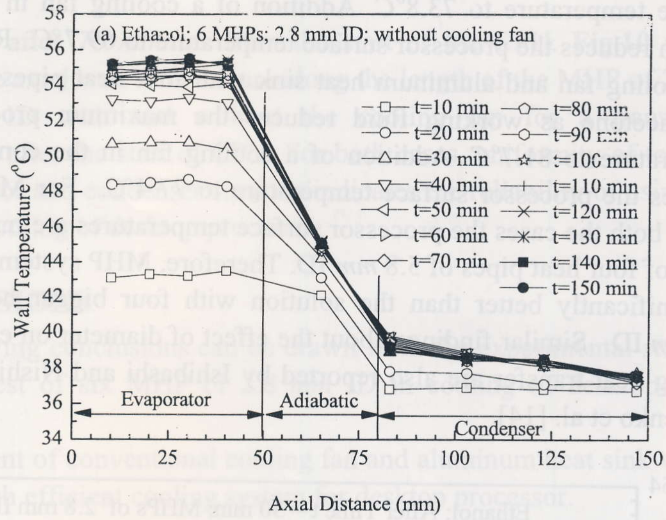
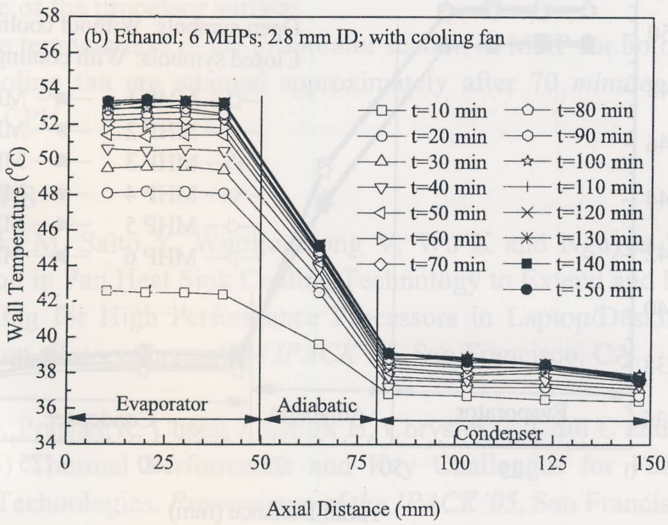


Figure 8: Variation of processor surface temperature with time.



(a).



(b).

Figure 9: Temperature profile along the length of the MHP using ethanol as working fluid.

of Tanim et al. [12] is included in this plot to compare their results with results of the present study. The figure indicates that:

- The maximum temperature on the processor surface by using conventional cooling fan and aluminum heat sink is 90.8 °*C*.
- Replacement of the cooling fan and aluminum heat sink with six MHP of 2.8 *mm* ID with ethanol as working fluid reduces the maximum processor

surface temperature to 73.8°*C*. Addition of a cooling fan in the condenser section reduces the processor surface temperature to 69.7°*C*. Replacement of the cooling fan and aluminum heat sink with four heat pipes of 5.8 *mm* ID with acetone as working fluid reduces the maximum processor surface temperature to 81.7°*C*. Addition of a cooling fan in the condenser section reduces the processor surface temperature to 77.4°*C*. For MHP of 2.8 *mm* ID, in both the cases the processor surface temperatures are much lower than those of four heat pipes of 5.8 *mm* ID. Therefore, MHP system with six MHP is significantly better than the solution with four bigger heat pipes with 5.8 *mm* ID. Similar findings about the effect of diameter on enhancement of boiling heat transfer are also reported by Ishibashi and Nishikawa [13] and Klimenko et al. [14].

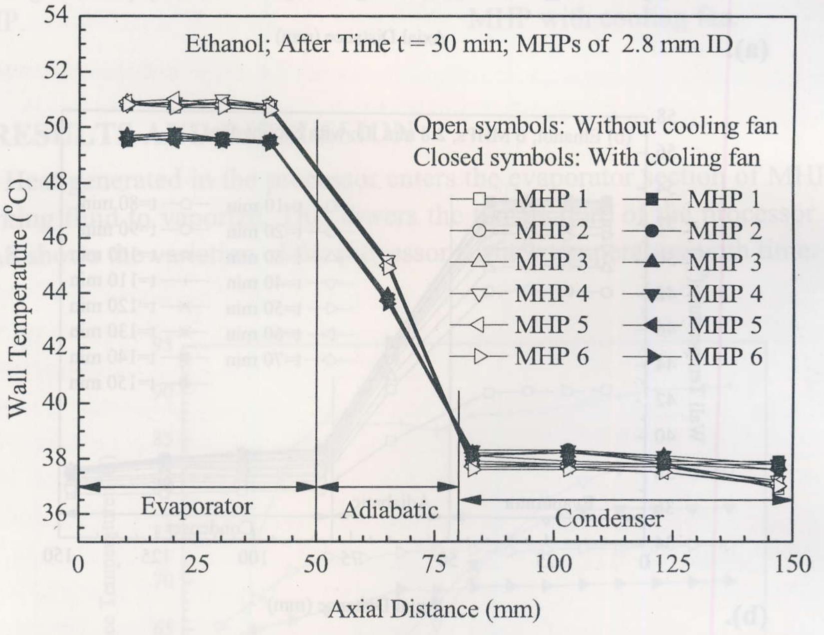


Figure 10: Temperature profile of the MHP along their length after a time $t = 30$ *min.*

Fig.9 shows the axial wall temperature distribution along the length of the MHP for the time duration of 150 *minutes*. For six MHP without fan, the maximum wall temperature in the evaporator section is 55.3°*C* as shown in **Fig.9 (a)**. Addition of a cooling fan lowers the temperature to 53.4°*C* which is shown in **Fig.9 (b)**. The steady state temperatures in both cases are attained approximately after 70 *minutes* from the start of the CPU. **Fig.10** shows the variation of the axial wall temperature along the length of the MHP of 2.8 *mm* ID and 1.8 *mm* ID with and without the cooling fan for a transient time $t = 30$ *minutes* after the start of CPU. For both cases, uniformity of temperature in the evaporator and condenser sections indicates the reliability of using parallel MHP for the cooling of desktop processor.

4 CONCLUSIONS

The following conclusions can be drawn from the experimental study of the performance test of six MHP of 2.8 *mm* ID in cooling of desktop computer processor:

- Replacement of conventional cooling fan and aluminum heat sink with MHP shows much efficient cooling system for desktop processor.
- Addition of a fan at the condenser section of MHP provides maximum low temperature of the processor surface.
- Steady state temperatures in the evaporator section of MHP for both with and without cooling fan are attained approximately after 70 *minutes* from the start of the CPU.

REFERENCES

[1] Mochizuki M, Saito Y, Wuttijumnong V, Wu X and Nguyen T. (2005) Revolution in Fan Heat Sink Cooling Technology to Extend and Maximize Air Cooling for High Performance Processors in Laptop/Desktop/Server Application. *Proceedings of the IPACK'05*, San Francisco, CA.

[2] Saucius I, Prasher R, Chang J, Erturk H, Chrysler G, Chiu C and Mahajan R. (2005) Thermal Performance and Key Challenges for Future CPU Cooling Technologies. *Proceedings of the IPACK'05*, San Francisco, CA.

[3] Xie H, Aghazadeh M, Lui W and Haley K. (1996) Thermal Solutions to Pentium Processors in TCP in Notebooks and Sub-Notebooks. *IEEE Transactions on components*, Packaging and Manufacturing Technology. Vol. 19, no.1: pp. 54-65.

[4] Xie H, Ali A and Bathia R. (1998) The Use of Heat Pipes in Personal Computers. *IEEE Inter Society Conference on Thermal Phenomena*, pp. 442-448.

[5] Babin BR, Peterson GP and Wu D. (1990) Steady State Modeling And Testing of a Micro Heat Pipe. *ASME Journal of Heat Transfer*, Vol. 112, no. 3: pp. 595-601.

[6] Zhou J, Yao Z and Zhu J. (1992) Experimental Investigation of the Application Characters of Micro Heat Pipe. *Proceedings of the 8th International Heat Pipe Conference*, Beijing, China.

[7] Eguchi K, Mochizuki M, Mashiko K, Goto K, Saito Y, Takamiya A and Nguyen T. (1997) Cooling of CPU Using Micro Heat Pipe. *Fujikura Co., Technical Note*, 9, pp. 64-68.

[8] Yoshiaki S, Takase M, Tanabe M, Teruo N, Kinoshita I, Tadashi I, Namba K and Masahiro S. (1999) A Junction Block Incorporating a Micro Heat-Pipe. *Furukawa Review*, 18.

[9] Kim KS, Moon SH and Choi C Gi. (1999) Cooling Characteristics of Miniature Heat Pipes with Woven Wired Wick. *Proceedings of the 11th International Heat Pipe Conference*, Japan, pp. 239-244.

[10] Xie H, Aghazadeh M, and Toth. J. (1995) The use of heat pipes in the cooling of portables with high power packages - A case study with the Pentium processor- based notebooks and sub-notebooks. *Proceedings of the 1995 Electronic Components and Technology Conference (ECTC)*, May 21-24, 1995, pp. 906-913.

[11] Mochizuki M, Mashiko K, Nguyen T, Saito Y and Goto K. (1997) Cooling of CPU Using Hinge Heat Pipe. *Heat Pipe Technology*, Pergamon, pp. 218-229.

[12] Tanim TR, Hussain T and Feroz CM. (2007) Cooling of Desktop Computer Using Heat Pipes. *Proceedings of the ICME*, Dhaka, Bangladesh.

[13] Ishibashi E and Nishikawa K. (1969) Saturated Boiling Heat Transfer in Narrow Spaces. *Int. Journal Heat Mass Transfer*, Vol. 12: pp. 863-894.

[14] Klimenko VV, Fyodorov MV and Fomichyov Yu A. (1989) Channel Orientation and Geometry Influence on Heat Transfer with Two-phase Forced Flow of Nitrogen. *Cryogenics*, Vol. 29: pp. 31-36.