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Thermal Performance of Phase Change Material and Water in Microchannel for CPU Processor Cooling

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Abstract – In this work, Phase Change Material (PCM) is used to enhances performance of water cooled Micro Channel Heat Sink (MCHS) for cooling of computer processor. Present study compares four different cooling methods viz., 1) Conventional air cooling method, 2) MCHS with water as coolant, 3) MCHS with water as base fluid and PCM is in suspended form, i.e., PCM slurry, 4) Water is used as primary coolant which passes through microchannel and PCM is used as a secondary coolant which absorbs heat collected by primary coolant, i.e., PCM used to absorb heat in heat exchanger. The objective is to find the effect of PCM as a primary and secondary coolant. The experiments are performed for flow rates ranging from 75 ml/min to 260 ml/min. The results show that cooling systems using PCM are advantageous in comparison to conventional cooling as well as than water cooling system. It is possible to achieve lower maximum temperature of processor for the same mass flow rate or the same pumping power. MCHS with PCM slurry as coolant can form an effective cooling system for high capacity computer processor.

Keywords - Electronic Cooling, Phase Change Material (PCM), Microchannel Heat Sink, Heat Transfer, Nusselt Number

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INTRODUCTION

The rapid development in electronic industry requires an effective cooling mechanism because in new electronic applications, the electronic chip has become more compact and coaxed to work faster it resulting in more heat generation. The generated heat may be steady or transient in multichip modules and sensors that irregularly operate or have variable power. The traditional air-cooling technology can not cool heat fluxes as high as 100 W/cm^2, and many devices operate beyond this limit. Thus, the problem of heat dissipation becomes a critical problem for the development in the electronic industry. Amongst different approaches, the forced liquid flow cooling technology is better suited for dissipating more heat. Microchannel Heat Sink (MCHS) cooling technology is one of the alternatives for removing such a high amount of heat. Tuckerman and Pease [1] in 1981 introduced the concept of microchannel heat sink for electronic cooling. W. Zhang *et al.* [2] analyzed thermal performance of a water-cooled transversal wavy microchannel heat sink for chip cooling. They found that by using liquid as coolant media cooling capacity increases as compared to air cooling system. Bhiungade *et al*. [4] did experimental work on cooling of processor using MCHS and water as coolant. They studied different leaf structures under microscope for microchannel and two designs were prepared for natural leaf pattern. After number of sets of readings they found that as flow rate increases heat removed by microchannel and heat transfer coefficient increases as well as microchannel method is effective for circuit cooling. These kinds of designs for active cooling will effectively work for steady state operations, but for transient operations, the temperature may jump above the maximum allowed temperature, which is assigned to achieve efficient performance. Additionally, using active cooling by circulating a coolant fluid to absorb the heat from these kinds of electronic chips is known to consume too much power and to add complexity to the system design.

Many researchers have studied, both experimentally and numerically, the heat transfer capability of PCM slurry with different base fluids. K. Q. Xing *et al*. [5] applied numerical simulation to laminar flow and heat transfer characteristics of micro-size phase change material particles suspended in water passing through microchannel. Numerical results show PCM enhances heat transfer rate as compared to single phase fluid and PCM needs less fluid pumping power for a given heat transfer rate. Sarada Kuravi *et al.* [6] numerically investigated heat transfer performance of Nano-Encapsulated PCM (NEPCM) slurry flowing through microchannels. Results shows that presence of NEPCM particles inside the fluid helps to increasing the Nusselt number and decreases the bulk mean temperature of the fluid. Frank Dammel *et* *al*. [7] examined experimentally and numerically if it is beneficial to add MEPCM particles to liquids in order to improve their characteristics as heat transfer fluids. Results are suspension of MEPCM as coolant can be beneficial compared to water. By using this model it is possible to achieve lower maximum channel wall temperatures for the same mass flow rate or even for the same pumping power. S. Kondle *et al*. [8] did an extensive study of fluid flow and heat transfer through circular and rectangular microchannel with different aspect ratios. The numerical simulations demonstrate that PCM fluid can enhance the heat transfer performance of micro channels with different aspect ratios.

Thus, from above literature it is concluded that MCHS and PCM have been used for electronic cooling but use of PCM in microchannel heat sink as coolant for CPU processor cooling is not explored by anyone. In this paper we explore the heat removing capacity of PCM by using it in suspended form in water and using water as primary coolant and PCM as secondary coolant. In the next section, experimental design is presented in brief.

EXPERIMENTAL DESIGN

Experiments were carried out in four different ways:

1. Conventional air cooling method. Fan operated aluminum heat sink as shown in fig.1

2. Using MCHS with water as coolant.

3. Using MCHS with water as base fluid and PCM is in suspended form. i.e., PCM slurry

4. Water used as primary coolant passes through microchannel and PCM used as a secondary coolant which absorbs heat collected by primary coolant. That is, PCM is used as heat exchanger.

Microchannel heat sink (MCHS) is machined on copper block with acrylic cover securely fixed on the top to avoid leakage of coolant.

A. Conventional air cooling

Heat sink is fitted on the processor of computer to increase the heat dissipation area for more effective cooling. Active heat sinks incorporate a fan to keep the processor cool. Cooling fan are used to blow air over the heat generating components in a computer and to draw the accumulated hot air away from the area around the components, thus lowering the temperature of the air surrounding the components.

B. Microchannel Heat Sink Cooling

Experimental work is carried on the CPU processor itself. The MCHS or test section is fitted on the CPU processor. A pump is used to pump the coolant through MCHS. After passing through MCHS the coolant absorbs the heat and rejects the same at heat exchanger and then returns to the coolant tank.

Fig.1 Microchannel design for experiments

The heat exchanger cools the working fluid by natural convection in case of water and PCM slurry. In the third case, water is used as primary coolant and the PCM is placed in a closed vessel and acts as secondary coolant in heat exchanger to remove the heat from primary coolant.

C. Phase change Material Properties

In this study, water was taken as the carrier fluid with a PCM volume concentration of 14%. N-eicosane was selected as phase change material with properties listed in Table-I.

Table I Carrier fluid and PCM physical properties

Fluid	K (W/mK)	Viscosity Ns/m^2	Density (kg/m^3)	C_p (kJ/kg-K)
Water	0.613	0.855	997	4.179
PCM	0.15	-	946.4	1.973
PCM Slurry	0.525	1.387	989.4	3.862

The leakage of coolant is the most important factor in the performance of MCHS. The collecting tank, pump, heat exchanger are all fitted in the CPU.

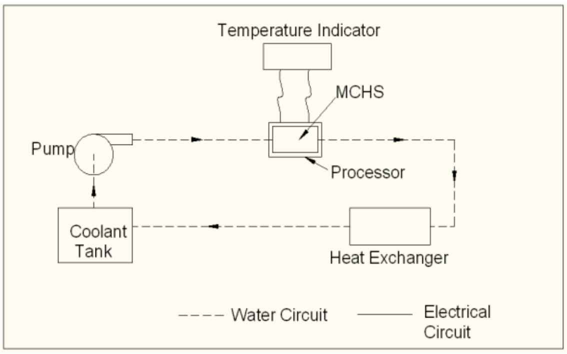

Fig.2 Block diagram for setup

D. Experimental investigation:

Fig.2 show block diagram for experimental setup. Pump is used to circulate PCM slurry through the flow loop. At MCHS coolant absorb heat from microchannel and get change its phase from solid to liquid. After being heated up in the test section, the slurry has to be cooled down well below the theoretical melting temperature of the phase change material in a heat exchanger to make sure that the PCM is in solid state again. Then, the loop is closed and the slurry flow back into the reservoir.

By using thermocouple and temperature indicator we measure the temperature of processor at various points as well as measure slurry temperature at inlet and outlet of microchannel. The performance testing is done for four different flow rates 75 ml/min, 100 ml/min, 200 ml/min, 260 ml/min by using four different cooling methods. Performance of four different cooling systems will be checked for 90min.

DATA REDUCTION

This section gives the procedure adopted for calculating the heat transfer coefficient and Nusselt number:

Heat absorbed by coolant fluid in the microchannel by convection is given by equation (1),

$$q_{channel} = m*c_p*(T_{f,o}-T_{f,i}) \quad (1)$$

The average heat transfer coefficient is given by equation (2)

$$h_{avg} = q''/(T_{f,avg}-T_{s,avg}) \quad (2)$$

where channel heat flux q" is given as

$$q''=q_{channel}/A_s \quad (3)$$

where, A_s is the surface area of MCHS. $T_{f,avg}$ and $T_{s,avg}$ are the average fluid and surface temperature respectively; these are calculated from the corresponding inlet ($T_{f,i}$, or $T_{s,i}$) and outlet ($T_{f,o}$, or $T_{s,o}$) temperature as

$$T_{f,avg}=(T_{f,i}+T_{f,o})/2 \quad (4)$$

$$T_{s,avg}=(T_{s,i}+T_{s,o})/2 \quad (5)$$

Note, that the actual $T_{f,i}$ is measured by the thermocouple placed inside the reservoir. The fluid outlet temperature $T_{f,o}$ is measured immediately after the outlet well of MCHS.

The Reynolds number is calculated using equation (6).

$$Re= (\rho*u_{avg}*D_h)/ \mu \quad (6)$$

where, D_h is hydraulic diameter

Nusselt number is calculated as,

$$Nu = (h_{avg}*D_{h)} / k_f \quad (7)$$

In the next section, the results of the experiments are presented.

RESULTS AND DISCUSSION

In this study, the tests are performed for two operating conditions namely a) working fluid (water and slurry), b) different flow rate of working fluid. Performance of four different cooling systems described earlier is tested for 90 minutes. The results obtained from this study are elaborated below.

Figures 3 and 4 show the effect of average surface temperature of processor, using different cooling systems for 75 ml/min to 260ml/min, of flow rates of cooling fluid. For conventional cooling system the fan speed cannot be varied hence the surface temperature remains the same as seen in the figures. By using conventional cooling system temperature of processor linearly goes on increase from 30˚C to 50˚C. Water cooling system maintains the temperature of processor between 45˚C to 49˚C. As compared to conventional cooling system water cooling system is better solution for cooling purpose. But when we add some PCM particles in water in suspended form it gives better results than only water as coolant.

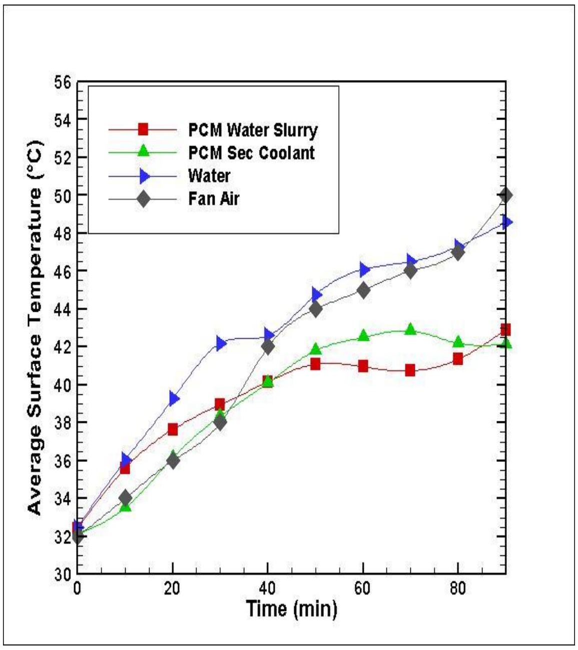

Fig.3 Effect of coolant on surface temperature for flow rate of 75 ml/min

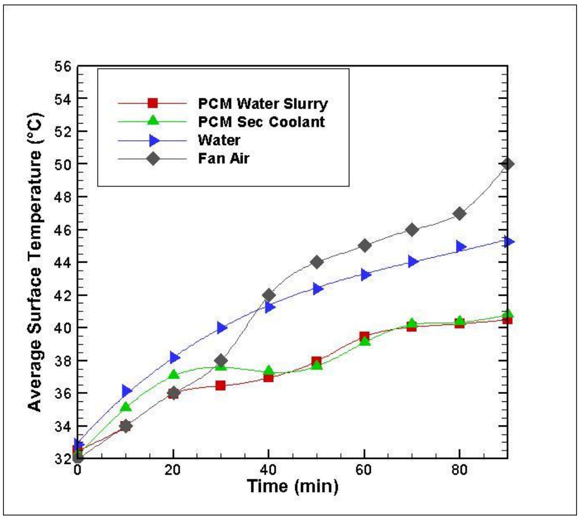

Fig.4 Effect of coolant on surface temperature for flow rate of 260 ml/min

We can see from above figures, PCM cooling system maintains the temperature of processor in between 40˚C to 42˚C. Melting temperature of PCM particles is 36˚C, so that up to that point surface temperature increases constantly. PCM melts in three phases. In first phase, initial temperature of solid PCM increases from ambient temperature to its melting temperature. In second phase, phase change occurs as the solid PCM melts under constant temperature at this point latent heat is stored. In the third phase, temperature of liquid PCM increases to the critical temperature as heat is continually supplied to the PCM. As inlet fluid temperature goes above 36˚C it started to melt as well as store latent heat at constant temperature. So, that temperature of processor is constant in phase second. PCM as secondary coolant gives better performance than water cooling system. It maintains the temperature of processor in between 41˚C to 43˚C. Increase in flow rate decreases the surface temperature for all cooling systems except air cooled system. Surface temperature of PCM + water slurry and PCM as secondary coolant drops to 40°C.

Figure 5 and 6 show the Nusselt numbers obtained for various flow rates for water and PCM slurry, respectively. As the flow rate increases, the Nu increases. The rate of increase of Nu is larger in PCM slurry than water. The higher Nusselt number can be attributed to the efficient heat absorption at processor and heat rejection at the heat exchanger which is cooled by an auxiliary fan. The melting process of PCM starts at the wall and then slowly spreads through the cross section. At the beginning only the region near the wall experiences phase change and hence temperature near the wall remains constant, whereas the bulk fluid temperature keeps increasing. Due to latent heat of vaporization of PCM more heat is absorbed in the microchannel. Similarly, at the heat exchanger area, the temperature drops below 36°C due to auxiliary fan, which results in solidification of PCM and rejection of heat to the surrounding. Higher heat absorption and heat rejection, leads to increase in the heat transfer coefficient and hence increase in the Nusselt number. But in the case of water, surface temperature and water temperature increases simultaneously. Due to this, the difference between wall temperature and water temperature remains constant or slightly vary; hence the Nusselt number is nearly constant.

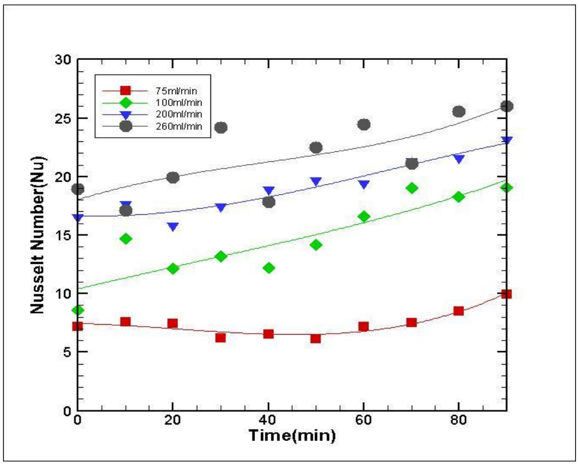

Fig.5 Nusselt number for water at various flow rates

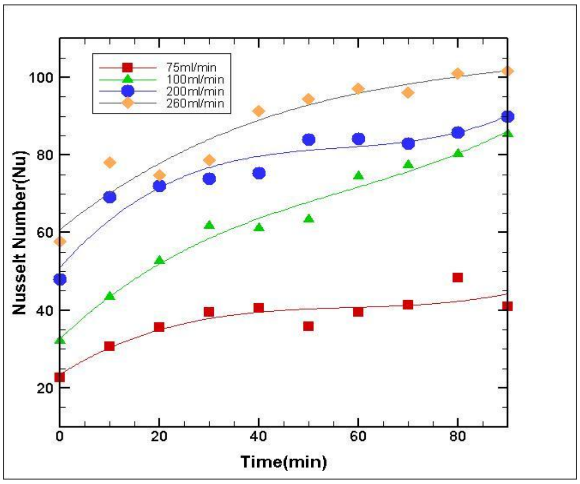

Fig.6 Nusselt number for PCM + water slurry for various flow rates

For all the tests conducted, there was no leakage detected which is the most important factor for successful running of the computer.

CONCLUSION

1. The research work was successfully able to test water and water based fluids as coolant for cooling of CPU processor in which apart from the thermal performance, absolutely zero percent leakage of coolant was equally important.
2. The experimental results show that the performance of all new designs is better than conventional air cooling system. Of the three cooling systems the use of PCM + water slurry as coolant is beneficial in comparison to water. Lower surface temperature of processor is attained by PCM cooling systems for the same mass flow rate compared to water.
3. As the flow rate increases Nusselt number of coolant fluid also increases.
4. Nusselt number of PCM + water slurry is higher as compared to water.
5. A compact cooling system for CPU processor consisting of MCHS and water and PCM as coolant can be effectively used to reduce the surface temperature of processor.

NOMENCLATURE

D_h= Hydraulic diameter (µm)

m = mass flow rate (kg/s)

C_p = Specific heat capacity (J/kg-K)

Re = Reynolds number ($\rho v D_h / \mu$)

U = flow velocity (m/s)

Q = heat (W)

T= Temperature (˚C)

q"=heat flux(W/cm^2)

h=heat transfer coefficient (kW/m^2-K)

Nu= Nusselt number (hl / k)

ρ=fluid density (kg/m^3)

µ= viscosity of fluid (N-s/m^2)

Subscript/superscript

i = inlet

o = outlet

avg = average

amb = ambient

f = fluid

s = microchannel surface

max= maximum

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