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CPU Processor Cooling by using Microchannel Heat Sink with PCM as Coolant

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***Abstract*— In this work, the potential of using phase change materials (PCMs) flowing through microchannel heat sinks for cooling of computer processor has been studied experimentally. Present study compares two cooling fluids 1) water 2) Phase change material with two different aspect ratios of 2 and 3. The experiments are performed at various flow rates ranging from 75ml/min to 300ml/min. The results show that cooling systems using PCM are advantageous in comparison to conventional cooling as well as than water cooling system. The result shows that MCHS with PCM slurry as coolant is more effective in compare 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.**

Keywords*— Electronic Cooling; Phase Change Material(PCM); Microchannel Heat Sink; Heat Transfer; Nusselt Number

I. INTRODUCTION

Continuous growth in electronics industry opens up new ideas and challenges to researchers working on thermal electronic equipment. The reliability of electronic equipment depends on several factors like temperature, humidity, vibration and so on. Even so, the most important and critical of them is temperature. Conventional air cooling system consists of more IC's in packaging so it makes system bulky. System unable to meets the growing demands of the electronics industry. In new technologies, Microchannel Heat Sink (MCHS) is an excellent cooling strategy for thermal management in cases where the application is transient or intermittent. In 1981, Tuckerman and Pease [1] introduced the concept of microchannel heat sink for electronic cooling application. Y. J. Lee et al.[2] studied numerically heat transfer enhancement techniques for conventional parallel fins in a microchannel heat sink. Design of microchannel consists of oblique fins; they broke continuous fins into oblique sections which leads to the re-initialization of both hydrodynamic and thermal boundary layers at the leading edge of each oblique fin, effectively reducing the thickness of boundary layer. Numerical results show that uniquely skewed hydrodynamic and thermal profiles are the key to the highly augmented and uniform heat transfer performance across the heat sink. Bhiungade et al.[4] did experimental analysis of MCHS for electronic circuit. Different leaf structures were studied under microscope and two designs of natural leaf pattern were prepared for experimental work. 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 they conclude that MCHS was effective method to cool electronic circuit. These kinds of cooling system were used only for steady state operations, but for transient operations the temperature of processor may go beyond the limit of Thermal Design Power (TDP). Utilization of microchannel heat sink with Phase change materials (PCM) as coolant can overcome this problem. Many geometric configurations of microchannel with different boundary conditions by using single phase fluids have been studied for electronic cooling. Also, PCM fluids have been studied in various configurations at the macroscale. However, the use of PCM fluids in microchannel for electronic cooling has not yet been studied thoroughly. K.Q.Xing et al.[5] did a numerical simulation for laminar flow and heat transfer characteristics of suspended PCM particles in microchannel. Study compares effectiveness factor e_{ff} and performance index of PCM slurry with single phase fluid water under different wall heat fluxes and different Reynolds numbers. The results show that, the PCM suspension flow with phase change has greatest e_{ff} for a given Reynolds number, considerably higher performance index than the pure-fluid flow. S. Kondle et al.[6] studied numerically heat transfer characteristics of PCM fluid under laminar flow conditions in circular and rectangular microchannel. Heat transfer characteristics of PCM slurry have been studied under different wall boundary conditions and different Aspect Ratios (AR). Results show that, nusselt number is increase by using PCM fluid compared to single phase fluid (water) for all aspect ratios. S. Kuravi et al.[7] did numerical study to check performance of nano-encapsulated PCM slurry in manifold microchannel heat sink. They investigated number of parameters such as particle concentration, inlet temperature, heat flux and results were compared with pure single phase fluid. Numerical results shows that Nusselt number increases using PCM particles inside fluid and decreases the bulk mean temperature of the fluid. F. Dammel et al.[8] investigated experimentally and numerically the heat transfer characteristics of water based suspension of Microencapsulated Phase Change Material (MEPCM) flowing through rectangular Minichannels. PCM n-eicosane had an average size of 5µm and passes through nine parallel minichannels with aspect ratio 2. The results show that use of MEPCM suspension as coolant can be beneficial compared to water. It is possible to achieve lower wall temperature for same mass flow rate. Thus from above literature it is concluded that microchannel heat sink and PCM used for electronic cooling but not explored for CPU processor cooling. In this paper we explore enhancement of heat transfer capacity of single phase fluid flowing through microchannel by adding PCM i.e. PCM slurry in it.

II. EXPERIMENTAL DESIGN

A. Factorial design

Factorial designs are most efficient for this type of experiment. Factors are those quantities that are going to be important because they are going to affect the outcome of an experiment. In our experiment there are three factors which affect on experiment: Aspect ratio of microchannel, types of coolant, Flow rate of coolant. Outcome of this experiment will be maximum amount of heat removed by MCHS and system maintains the temperature of processor as low as possible. Next one is levels, refers to the values of factors for which data is gathered. In case of aspect ratios; microchannels were design with 2 aspect ratios i.e. 2 and 3. In the case of flow rate; flow rates varied in between 75ml/min to 300ml/min. As well as coolant have two levels. In experiment two types of coolants were used i.e. water and PCM slurry. So total experiment conducted in this research work are 16 [2(AR)*4(Flow rates)*2(Coolant types)=16]. With a given flow rates, and given coolant, experiment was repeated twice; first on heater and second on CPU processor. Through heater we check the capability of microchannel to remove maximum amount of heat by using different coolants at different flow rates. Experiment was carried out in four different ways:

1. Conventional air cooling method. Fan operated aluminum heat sink for CPU processor.
2. MCHS placed on heater to vary the heat flux input
3. MCHS with water as coolant for heater cooling.
4. MCHS with water as base fluid and PCM is in suspended form. i.e. PCM slurry for heater cooling..
5. MCHS placed on CPU processor

a) MCHS with water as coolant for processor cooling application.
b) MCHS with water as base fluid and PCM is in suspended form. i.e. PCM slurry for processor cooling application.

B. Experimental analysis

1. Conventional air cooling

Aluminium heat sink is fitted on the CPU processor as shown in fig. 1 to increase the heat dissipation area for more effective cooling. Cooling fan is used to blow air over the heat generating components in a CPU and to draw the accumulated heat away from the components, thus lowering the temperature of the air surrounding the components.

Fig.1 Aluminium heat sink for conventional air cooling

2. Microchannel Heat Sink cooling:

a. MCHS placed on heater

Experimental setup consists of microchannel which is placed on cartridge heater. Fig. 3 shows Twenty- five parallel microchannels, each 1 mm wide and 1 mm high, were machined into a 43 mm long, 33 mm wide, and 7 mm thick copper plate. The copper plate is heated by cartridge heaters. MCHS and heater fixed to the wooden box and glass wool used as insulating material to restrict heat losses to surrounding. Tests were conducted at four different energy levels i.e. 45W, 70W, 90W, 130W. Through these tests we check the capacity of microchannel to maintain the temperature of processor as per the requirement of TDP ratings given by processor manufacturers.

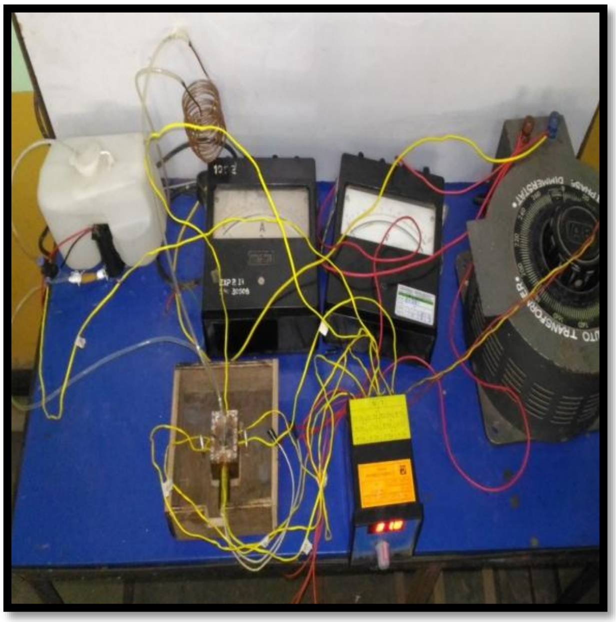

Fig. 2 Microchannel placed on heater

Fig. 3 Design of microchannel

b. MCHS placed on CPU processor

Fig.4 shows block diagram for setup. Experimental work is carried on CPU processor. Microchannel is fitted on processor. A pump is used to circulate the coolant through the flow loop. At MCHS coolant absorb the heat from processor and rejects at heat exchanger and returns to the coolant tank. The heat exchanger minimizes the temperature of coolant by natural convection. Temperature of slurry at inlet / outlet and temperature of processor at various points measure by using thermocouples and temperature indicator. Performance of system was tested on two aspect ratios for four different flow rates by using two different coolants

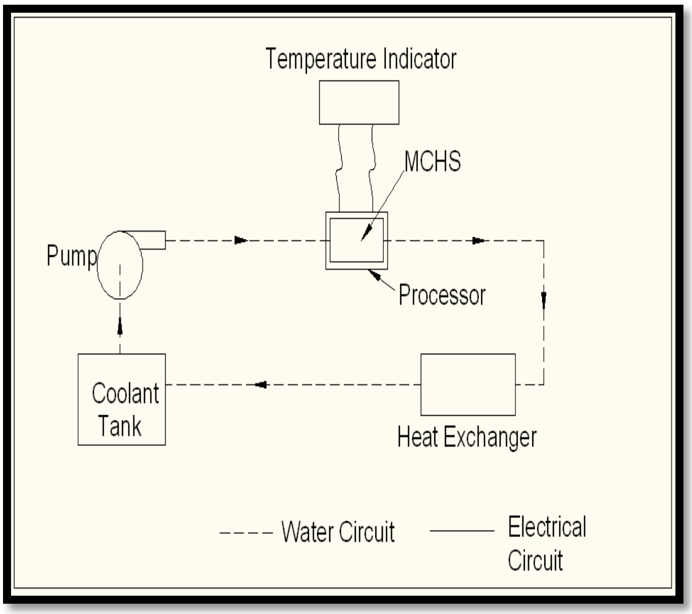

Fig. 4 Block diagram for setup

III. DATA REDUCTION

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

Channel Aspect ratio,

$\alpha_c = Hc / Wc$ (1)

Heat absorbed by coolant fluid in the microchannel by convection is given by equation, (2)

$q_{channel} = m*c_p*(T_{f,o}–T_{f,i})$ (2)

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

$h_{avg} = q''/(T_{f,avg}-T_{s,avg})$ (3)

where, channel heat flux q'' is given as

$q''=q_{channel}/A_s$ (4)

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

$T_{f,avg}=(T_{f,i}+T_{f,o})/2$ (5)

$T_{s,avg}=(T_{s,i}+T_{s,o})/2$ (6)

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,

$Re=(\rho*u_{avg}*D_h)/\mu$ (7)

where, D_h is hydraulic diameter

Nusselt number,

$Nu=(h_{avg}*D_h)/k_f$ (8)

IV. RESULTS AND DISCUSSION

In this study, the tests were perform for different values of aspect ratio of microchannel, different types of working fluid (water and slurry), and for different flow rates(75ml to 260ml) of working fluid. The results obtained from this study are elaborated below. Figures 5 to 8 shows the average surface temperature of processor by using different cooling systems for 100 ml/min and 260ml/min flow rates of cooling fluid under two aspect ratios. 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.

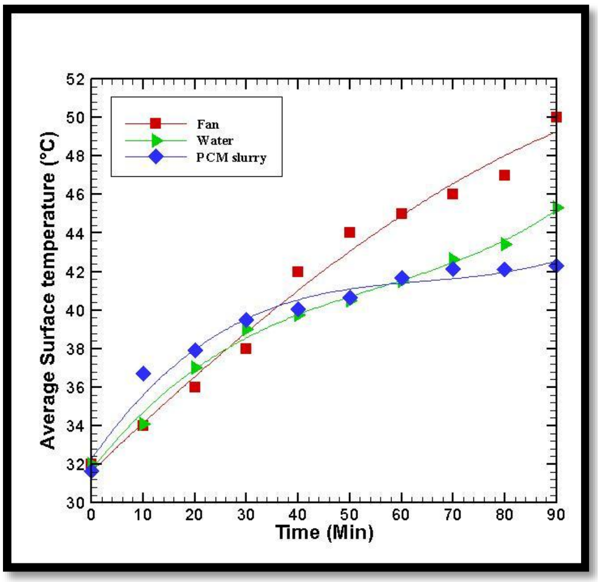

Fig.5 Effect of coolant on surface temperature for 100ml/min flow rate at AR 2

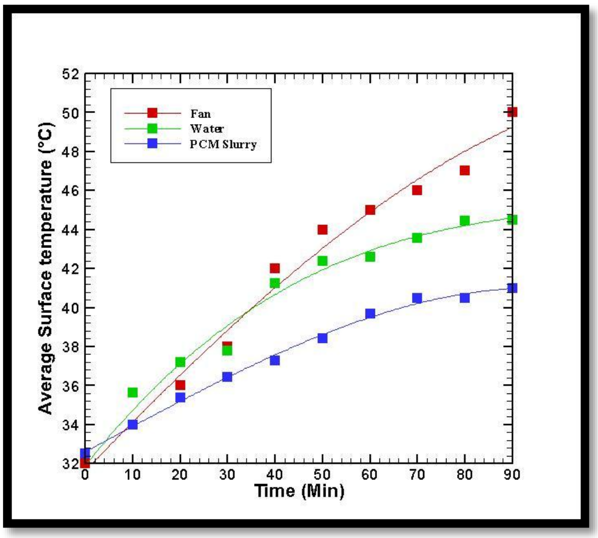

Fig.6 Effect of coolant on surface temperature for 260ml/min flow rate at AR 2

For aspect ratio 2, by using water as coolant temperature of processor increases linearly from 32˚C to 47˚C and after that it remains constant. But for aspect ratio 3, water has low temperature range which is in between 42-43°C. In second case when PCM slurry used as coolant for aspect ratio 2; temperature of processor increases gradually until it reaches to the temperature of 40°C, where it remains constant. This happens because of PCM melts in three phases. In first phase, initial temperature of solid PCM increases from ambient temperature to its melting temperature i.e. up to 36°C. In second phase, 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 absorbed by the PCM. Third phase of PCM found for 75 ml/min flow rate. So, that temperature of processor is constant in second phase. Variation of temperature for aspect ratio 3 is different than AR 2. 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. For aspect ratio 3, geometry provides maximum area than previous geometry to flow PCM slurry through the channels. Hence slurry can absorb maximum amount of heat from processor. It has lower temperature range than previous geometry. Increase in flow rate decreases the surface temperature for all cooling systems except air cooled system.

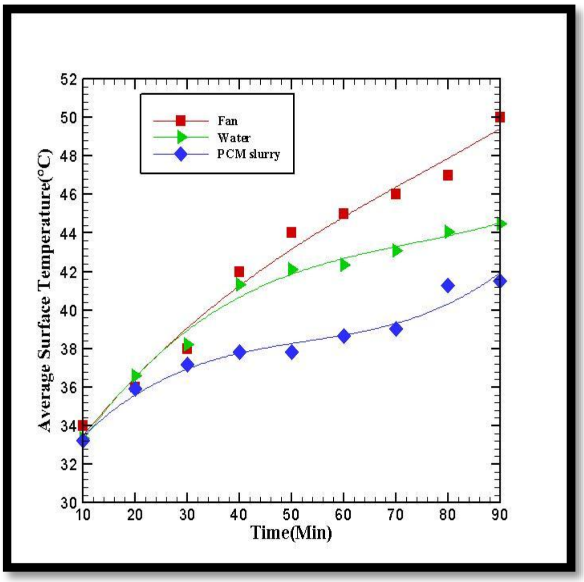

Fig.7 Effect of coolant on surface temperature for 100ml/min flow rate at AR 3

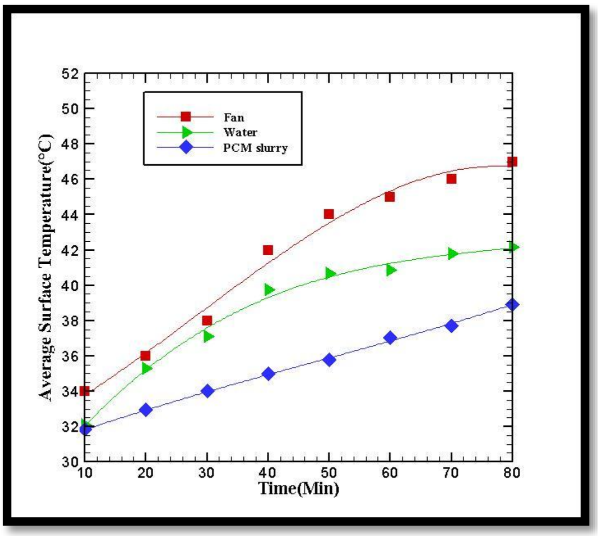

Fig.8 Effect of coolant on surface temperature for 260ml/min flow rate at AR 3

Figures 9 to 12 show Nusselt number for water and PCM slurry at different flow rates under two different aspect ratios. Variations in Nu for PCM slurry depend on melting and solidifying conditions of PCM. Nu was found to be increases during the beginning of phase change process and dropped as phase change process was near completion. This phenomenon is due to the growing and decaying trends of effective specific heat of PCM with respect to the temperature at different coolant temperature regions.

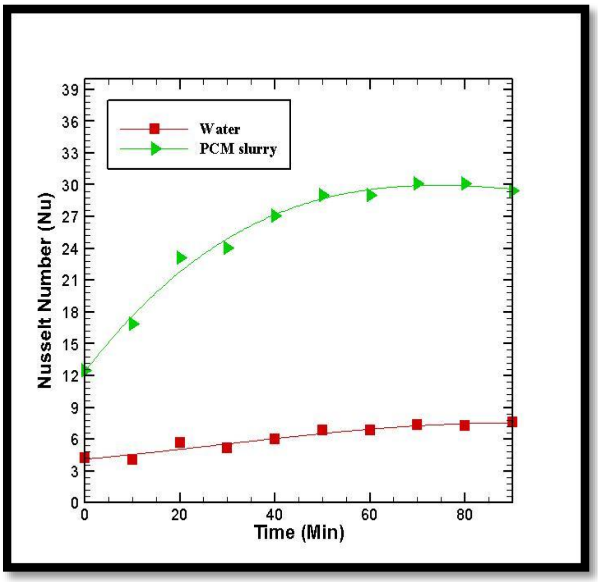

Fig.9 Effect of coolant on Nusselt number for 75ml/min for AR2

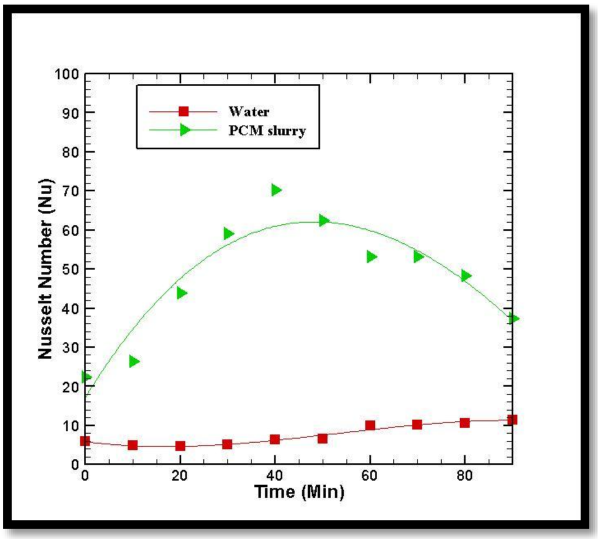

Fig.10 Effect of coolant on Nusselt number for 260ml/min for AR 2

At the inlet of heat sink, the temperature of slurry is constant and PCM particles are in solid state so the specific heat is minimum at the beginning. With increasing the wall temperature, the coolant temperature increases accordingly and depending on its value different developments are observed in specific heat of slurry and in Nusselt number. Slurry has a highest specific heat at its melting point; hence in fig.10 Nusselt number found at peak point at the middle of graph. After some time when melting process near to completion it start to decreases the Nu. All of these trends of Nu we can found in the graph for aspect ratio 2.

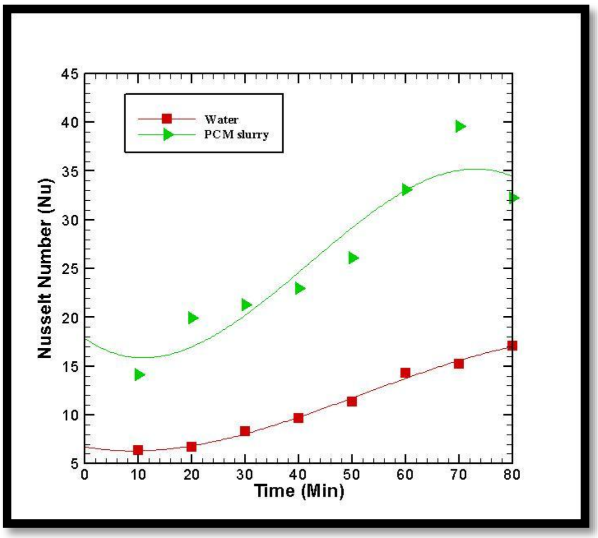

Fig.11 Effect of coolant on Nusselt number for 260ml/min for AR 3

For aspect ratio 3, geometry provides large area to flow slurry through channels. It also accelerates the melting process significantly. But at higher flow rate PCM particles did not came in contact with channel surface so that PCM particles does not melt completely. Hence in graph Nu found at up to the peak value. 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. The results show that higher aspect ratio leads to higher Nusselt number.

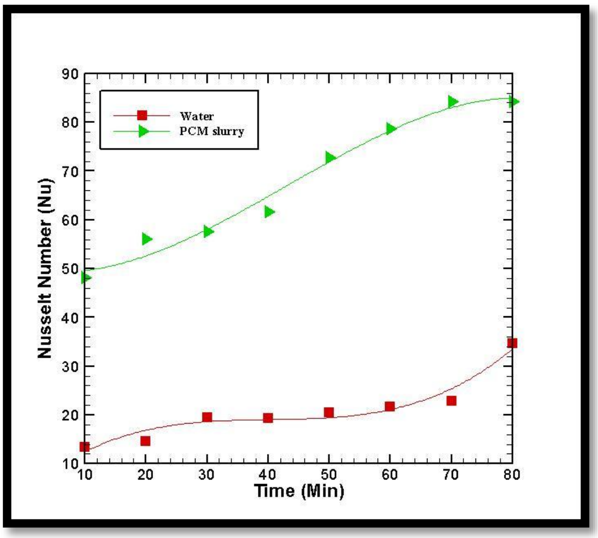

Fig.12 Effect of coolant on Nusselt number for 260ml/min for AR 3

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

V. CONCLUSION

1. The research work was successfully able to test water and water based fluid as coolant for cooling of CPU processor with absolutely zero percent leakage of coolant.
2. By using conventional air cooling system temperature of processor gradually increases from 32° to 50°C. But water and PCM cooling system maintain lower range of temperature than air cooling.
3. The experimental results show that PCM slurry as coolant can be beneficial in comparison to water. It is possible to achieve lower maximum processor temperatures for the same mass flow rate or even for the same pumping power.
4. The Nusselt number was found to increase when using PCM slurry as compared to a single phase fluid (water) for both of the aspect ratio designed in the study.
5. The experimental results show that higher aspect ratio leads to higher Nusselt number.
6. A compact cooling system for CPU processor consisting of MCHS, PCM slurry 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 ($hD_)$ / 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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