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Performance of Water and Diluted Ethylene Glycol as Coolants for Electronics Cooling

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ABSTRACT

The electronic components have been ruling the world since few decades. Heat dissipation in the electronic components is being a critical issue with the development of chip integrated circuits. Gradual decrease in size of the components has resulted in drastic increase of the amount of heat generation per unit volume. In the present work copper tubes brazed on a copper plate is used as heat sink having overall dimension 38×38×2.5mm. Diluted Ethylene glycol at volume fraction of 40% and pure water are used as cooling fluids. The surface temperature of the heated aluminum block is tested at different flow rates of water and diluted ethylene glycol. The temperature of the block is maintained below 45°c when water is used. The convection heat transfer coefficient of water flowing through the copper tubes is increased with increasing the flow rate is observed. Pump power is calculated at each flow rate of water and Ethylene glycol. In the present work

Nomenclature

d = inner diameter of copper tube, m
Q = heat transfer rate to the water, W
Q_{loss}= loss of heat energy, W
Q_{input} = heat input to the heater, W
m = mass flow rate of water, Kg/s
C_p = Specific heat, Kj/(kg-k)
ΔT = Temperature difference, K
T_i = inlet Temperature of water, K
T_o= outlet Temperature of water, K
h_w = convection heat transfer coefficient, W/m^2K
k = thermal conductivity, W/mK
Nu = Nusselt number
Re = Reynolds number
V = velocity of fluid, m/s
EG = Ethylene glycol
l = litres

Subscripts

i = inlet
o = outlet
w = water

Greek

μ = absolute viscosity of fluid [kg/ms]
ρ = fluid density [kg/m^3]

***Keywords*--** Electronics cooling, Diluted Ethylene glycol, pump power

I. INTRODUCTION

With the development of microprocessors, heat dissipation problems become more and more serious. They have made its way into practically every aspect of modern life, from toys and appliances to high speed computers. An electronic component depends on the passage of electric current to perform their duties, and they become potential sizes for excessive heating since the current flow through a resistance is accompanied by heat generation.

According to Moore's law the number of transistors mounted on a chip gets doubled for every two years. As the number of transistors increase with development of chip integration technology increases the power draw and heat load to dissipate during operation increases. With the development of chip integrated circuits gradual decrease in size of the components has resulted drastic increase in the amount of heat generation per unit volume. Unless they are properly designed and controlled high rates of heat generation result in the failure of electronic component due to high operating temperature. The failure rate of electronic components increase with increase in temperature. A hot spot created within the electronic components due to low transfer rates seems to be major failure problem. Therefore thermal control has become increasing important in the design and operation of electronic equipment.

Moore [1] in his classical paper predicted the future of integrated electronics and the advantages of integration. Integrated circuits will lead to such wonders as home computers, automatic controls for automobiles and personal portable communication equipments. The development has been possible only due to integration of millions of transistors, but one of the problem is heat problem. According to his predictions the number of transistors will get doubled every two years and heat transfer solutions to chip is a continuous research.

Kanlikar and Grande [2] studied the increased circuit density on today's computer chips is reaching the heat dissipation limits for technology, the direct liquid cooling of chips is being as a viable alternative. This paper reviews a liquid cooling with internal flow channels in technological options and challenges. The possibilities presented here in indicate a four to increase in heat flux over the air cooled system. The road map for single phase cooling technology is presented to indentify opportunities in meeting the cooling demands of future IC chips. The use of micro channels that incorporate either microstructures in the channels or grooves in the channel surface may lead to significant enhancements in single phase cooling. A simplified and well established fabrication process is described to fabricate both classes of three dimensional micro channels.

Wahib Owhaib and Bjorn Palm [3] studied the heat transfer characteristics of single phase forced convection of R – 134a through single circular micro channels with 1.7, 1.2, 0.8 mm as inner diameter were investigated experimentally. The results were compared both to correlations for the heat transfer in the macro scale channels and to correlations suggested for micro scale geometries. The results show good agreement between classical correlations and experimentally measured data in the turbulent region. Contrary, none of the suggested correlations for micro channels agreed with the data. In the laminar region the heat transfer co-efficient is almost identical for all three diameters.

Abdulah and Kua [4] experimentally the thermal contact resistance to investigate the effect of machined surface roughness at different heat rates. The interface materials have been used in order to reduce thermal contact resistance between two mild steel bars with different surface roughness. It is demonstrated that the use of heat sink compound as an interface material significantly reduce the thermal contact resistance. However the use of Aluminium foil increased the thermal contact resistance unexpectedly.

Kennith and Goodson et al [5] investigated the performance of microchannel cooling system for microprocessor and found that the surface temperatures are bellow the air cooling techniques.

Steinkel and Kanlikar [6] studied the single phase heat transfer enhancement techniques are well established for conventional and compact heat exchangers. The major techniques include flow transition, breakup of boundary layer, entrance region, vibration, electric fields, swirl flow, secondary flow and mixtures. In the present paper, the applicability of these techniques for single phase flows in micro channels and mini channels is evaluated. The micro channels and mini channel single phase heat transfer enhancement devices will help the applicability of single phase cooling for critical applications, such as chip cooling, before more aggressive cooling techniques, such as flow boiling are considered.

Gaurav Agarwal, Manojkumar Moharana and sameer kandekar [7] are studied thermo – hydrodynamic performance of hydrodynamically and thermally developing single phase flow in an array of rectangular mini channels has been experimentally investigated. The array consists of fifteen rectangular parallel mini channels of width 1.1±0.02 mm, depth 0.772±0.005 mm (hydraulic diameter 0.907 mm), inter channel pitch of 2.0 mm, machined on a copper plate of 8.0 mm thickness and having an overall length of 50 mm. Deionized water used as the working fluid, flows horizontally and the test section is heated directly using a thin mica insulated, surface mountable, stripe heater (constant heat flux boundary condition). Reynolds number between 200 and 3200 at an inlet pressure of about 1.1 bar are examined. The laminar to turbulent transition is found to occur at Re= 1100 for average channel roughness of 3.3 mm. The experimental pressure drop under laminar and turbulent flow conditions closely match with the correlations in literature on developing flow. The experimental Nusselt numbers for both laminar and turbulent flow are found within satisfactory range of values estimated from theoretical correlations existing in the literature on developing flows.

Mohapatra [8] studied the cooling of electronic parts has become a major challenge in recent times due to the advancements in the design of faster and smaller components. As a result, different cooling technologies have been developed to efficiently remove the heat from these components. The use of a liquid coolant has become attractive due to higher heat transfer co-efficient achieved as compared to air cooling. Coolants are used in both single phase and two phase applications. A single phase cooling loop consists of a pump, a heat exchanger and a heat sink. The heat source in the electronics system is attached to the heat exchanger. Liquid coolants are also used in two phase system, such as heat pipes, thermo-siphons, sub cooled boiling, spray cooling and direct immersion systems.

II. EXPERIMENTAL SETUP

The general layout of experimental setup is shown in Fig.1. The major components are heated aluminium block, heat sink made with copper plate and copper tubes, pump, high density cartridge heater and air cooled cross flow heat exchanger. An aluminium block of size 38 × 38 × 70 mm which simulates the heat generated by any electronic equipment is used as the heated block. A hole is precisely machined in the aluminium block to insert the high density cartridge heater of capacity 150 W. Any air gap between the heater and the hole would damage the heater, so heater is fitted in to the hole carefully such that there is no air gap between the two.

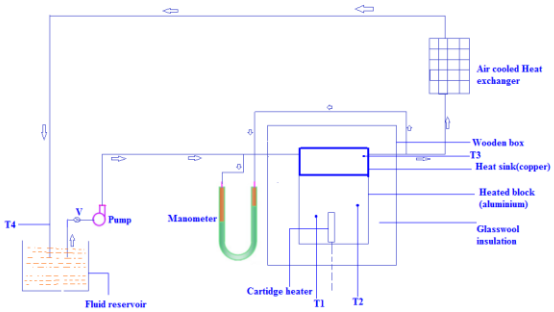

Fig.1. Line diagram of Experimental setup

For heat sink copper tubes are brazed to the copper plate. The numbers of copper tubes are 18.The length of each copper tube is 40 mm having inner diameter 0.36 mm. The overall dimension of copper plate is 38 × 38 × 2.5 mm. The top surface of aluminium block and bottom surface of copper plate are polished to minimise the gaps. Two K type thermocouples are inserted into the surface of the aluminium block at different locations to measure the surface temperature of the heated aluminium block. Another two K type thermocouples are used to measure the outlet temperature of fluid from the heat sink and inlet temperature to the heat sink.

Copper heat sink is placed firmly on the top surface of the aluminium block by using spring force to decrease the thermal resistance. To improve the thermal conductance between the heat sink and heated aluminium block, thermal interface material (TIM) is applied. To minimise the thermal losses to the surroundings glass wool of thickness 40mm is provided all around the heat sink and heated aluminium block assembly. The whole assembly is placed inside a wooden box of size 120×120×150 mm. One more thermocouple is attached to the wooden box to find out the temperature of the insulation provided. The inlet and outlet diameters of heat sink are 10 mm and 7 mm. A pump having capacity 4 l/min is used to circulate the fluid. A valve is provided between the pump outlet and heat sink inlet to regulate the flow of fluid. An air cooled cross flow heat exchanger is used to decrease the temperature of the hot fluid to room temperature. A dimmer stat is used to supply electric current through the high density cartridge heater at any required voltage. By using voltmeter and ammeter the supplied voltage and current to the heater is measured. A plastic vessel of 5 l capacity is used as a reservoir.

The heat sink and aluminium heated block is shown in Fig .2 and Fig.4 respectively. 18 number of copper tubes were brazed on to the copper plate of overall dimension 38 × 38 × 2.5 mm. The inner and outer diameters of the copper tube are 0.36 mm and 1.0 mm respectively. The length of each copper pipe is 40 mm. The copper tubes were inserted in to two more copper tubes of having inner diameter 5 mm. The fluid enters into one copper tube (larger diameter) and leaves from the other tube after flowing through the copper tubes of smaller diameter.

Fig.2. Copper heat sink

A solid aluminium block of overall dimensions 38 × 38 × 70 mm is used as heated block to simulate any electronic device. A hole was precisely machined in the aluminium block at the bottom surface to insert the high density cartridge heater which is shown in the Fig.3.

Fig.3. High Density Cartridge Heater

The diameter and length of the heater is 10 mm and 40 mm respectively. To measure the surface temperature of the heated aluminium block two K type thermocouples were inserted in to the top surface of the aluminium block.

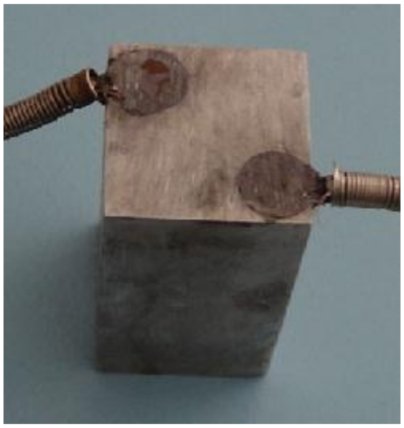

Fig.4. Heated aluminium block

Differential manometer is used for measuring the difference of pressure between two points in a pipe is shown in the Fig.5. For measuring the pressure difference one end of the U-tube manometer is connected to the inlet of the heat sink and other end is connected to the outlet of the heat sink by using the T-bends.

Fig.5. U-tube differential manometer

III. EXPERIMENTAL PROCEDURE

Initially the setup is tested to ensure that there is no leak in the circuit. For this the setup is run with pure water without giving any heat flux. By using dimmer stat constant heat flux is applied to high density cartridge heater. The voltmeter, ammeter, wattmeter and dimmer stat are used for electrical measurement. The applied heat input is 98 W.

Flow rate of water is regulated by using a control valve and the flow rate is measured by using a measuring jar. The experiment is conducted for different flow rates starting from 0.3 to 0.65 litres per minute.

For each flow rate the inlet and outlet temperature of water, surface temperature of heated aluminium block and surface temperature of wooden box are taken periodically by using digital temperature indicator. The readings are taken till the system reaches steady state. The pressure difference is taken by using u-tube differential manometer.

Ethylene glycol is diluted with water at volume fraction of 40% . The experiment is conducted at different flow rates For each flow rate the surface temperature of the aluminium block and pressure difference is measured.

IV. CALCULATIONS

Heat loss is calculated from energy balance equation and the loss is 4% of the heat supplied. Heat energy carried away by water is given by

$Q = m\, c_P\, \Delta T = m\, c_P\, (T_o - T_i)$ (1)

Heat loss is calculated by using

$Q_{loss} = Q_{Input} - Q$ (2)

Reynolds number is given by

$Re = (d_i V \rho)/\mu$ (3)

Convective heat transfer co efficient is calculated from Nusselt number which is the function of Reynolds number and prandtl number.

$h_w = (Nu \times K)/d_i$ (4)

Pump power (P) is calculated by using the fallowing formula.

p = volume flow rate ×pressure difference

$= v \times \Delta p$ (5)

V. RESULTS AND DISCUSSIONS

The surface temperature of the heated aluminium block which simulates the electrical component is the indication of performance of the cooling system. The surface temperature of the aluminium block at different flow rates of water is shown in Fig.6. From the graph the surface temperature of the aluminium block decreases with increase in flow rate. From the graph we can conclude that the surface attain a temperature of 44.8^0C when the volume flow rate of water is 0.65 litres per minute. Highest surface temperature is obtained at a flow rate of 0.41 litres per minute. In the present work a temperature reduction of 5.9^oC is obtained at 0.65 l/min when compared to the flow rate of 0.41 l/min.

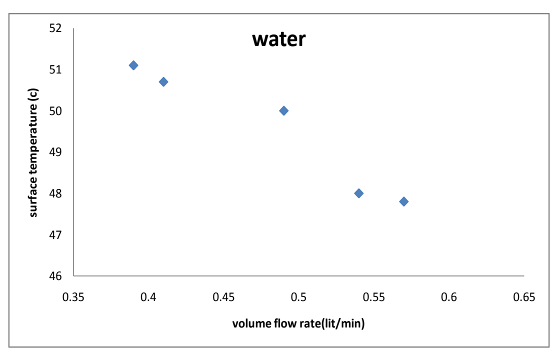

Fig.6. Effect of volume flow rate of water on surface temperature.

The effect of volume flow rate on convective heat transfer co-efficient of water is shown in Fig.7. From the graph we can conclude that the convective heat transfer co-efficient increases with volume flow rate. The convective heat transfer co-efficient increases from 9100W/m^{2}K to 10434W/m^{2}K when the volume flow rate changes from 0.41 litres per minute to 0.65 litres per minute. As the convective heat transfer co-efficient increases heat transfer rate also increases.

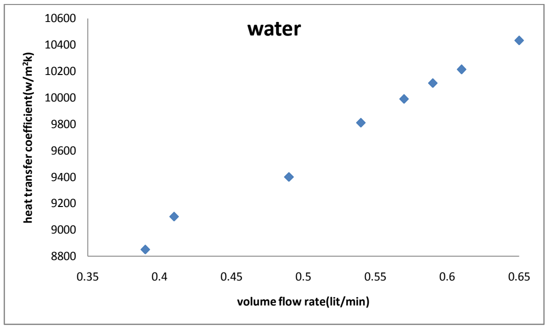

Fig.7. Effect of volume flow rate of water on convective heat transfer co-efficient

The pump power increases from 11.3W to 28.6W then volume flow rate changes from 0.41 litres per minute to 0.65 litres per minute. As the volume flow rate increases pump power also increases as shown in fig 8.

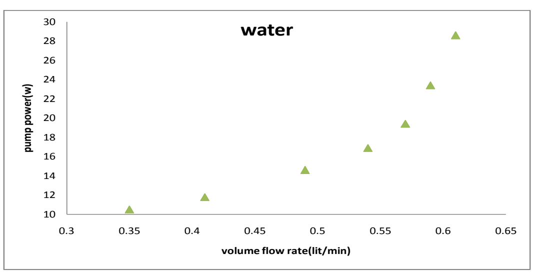

Fig.8.Effect of volume flow rate of water on pump power

The surface temperature of heated aluminium block is shown in fig.9 when diluted Ethylene glycol at a volume fraction of 40% is used for different flow rates.

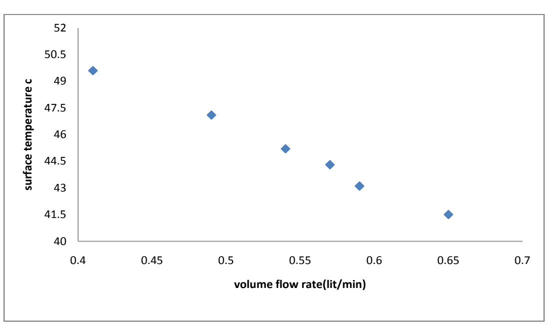

Fig.9.Effect of volume flow rate of diluted EG on surface temperature

From the Figure we can conclude that the lowest surface temperature is 41.5^{o}C when the volume flow rate of 40% diluted Ethylene glycol is 0.65 litres per minute. When compared to water the surface temperature of the heated aluminium block is decreased by 3.3^{o}C at this flow rate. The highest surface temperature of 49.6^{o}C is obtained at volume flow rate of 0.41 litres per minute with 40% diluted Ethylene glycol.

The effect of volume flow rate of diluted Ethylene glycol on pump power is shown in fig.10.

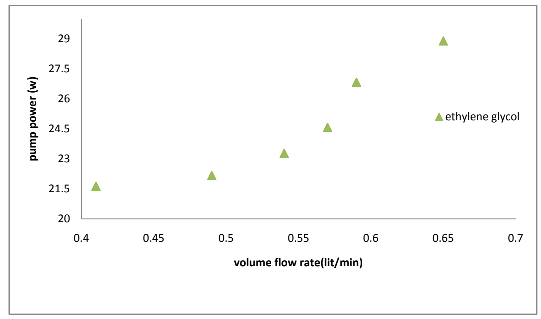

Fig.10.Effect of volume flow rate of diluted EG on pump power

VI. CONCLUSION

A mini channel liquid cooling system is designed for cooling of electronic components. Experiments are carried out at various flow rates of water and diluted ethylene glycol. When the flow rate is 0.65lit/min and the heat input is 98 W, the surface temperature of heated aluminium block is 44.8^{0}c.

When the flow rate changes from 0.41 to 0.65 litres per minute, 11.6% reduction in surface temperature is observed as 12.73% increase in convective heat transfer coefficient is observed when the flow rate changes from 0.41 to 0.65 litres per minute. There is an increase in surface temperature when diluted ethylene glycol is used as cooling medium when compared to water.

When the flow rate changes from 0.41 to 0.65 litres per minute, 59.4% increase in pump power is absorbed. There is an increase in pump power when diluted ethylene glycol is used as cooling medium when compared to water because the viscosity of diluted ethylene glycol is higher than water.

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