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Experimental Investigation on Thermal Performance of Cooling System Using Thermoelectric Module Integrated with Heat Pipe

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ABSTRACT

Cooling of electronics component is one of the major challenges faced by thermal engineers. In recent years, a significant increase in microprocessor power dissipation coupled with CPU size has resulted in an increase in heat fluxes. Microprocessor heat fluxes have also increased for many commercial applications. Therefore, thermal management is becoming one of most challenging issues and an important subject in regard to cooling system performance. For a number of applications, direct air-cooling systems like by applying blower, fan or water cooling are having moving parts and not reliable for continuous operation for long time and will have to be replaced or enhanced by other high performance compact cooling techniques. Liquid–vapor phase change, impinging jets spray, the use of thermoelectric modules and heat pipes are attractive cooling solutions for removing high heat fluxes because of their high heat transfer coefficients. In the present work we perform the initial experimental investigation and basic mathematical modeling to determine the thermal performance of thermoelectric module integrated with heat pipe for electronics cooling at different operating variables and parameters. Currently the experiments are in progress, so we put our initial experimental setup and discussions. The detail results after experiments will help us to analyze the temperature distribution and heat transfer limitation characteristic in thermoelectric module and its role in future of electronics cooling.

Keywords— **Electronics Cooling, Thermoelectric, Heat Pipe,Thermal Performance**

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I. INTRODUCTION

Cooling of electronic components is one of the major challenge faced by thermal engineers as the technology advanced the size of processor became smaller as a result they dissipate more heat .The tremendous growth in information technology causing a increase in demand of more powerful computing ability and in doing so the microprocessor are planted with billions of transistors which produce more amount of heat. The average heat produced by CPU is about 100W/Cm^2 to 140 W/Cm^2.Conventional cooling system are not capable enough to remove the heat flux produced by this CPU.So there is need of advanced and compact cooling system like liquid–vapor phase change, impinging jets spray, direct and indirect liquid cooling, the use of thermoelectric modules and heat pipes are attractive cooling solutions for removing high heat fluxes because of their high heat transfer coefficients. Several researches have been performed in these fields by many researchers. Two-phase heat transfer, involving evaporation of a working fluid in a hot side and condensation of vapor in a cold side, achieved more popularity due to their compact size, long reliability and use in multiple fields like aerospace, medical etc.

In electronics cooling use of thermoelectric cooling (TEC) combined with air cooling or liquid cooling getting more attention due to their long run availability and running life. The thermoelectric module act as heat pump as its direction of heat pumping is reversible. The amount of heat that can be removed by hot side is fully depends on efficiency, cooling load and electrical input to the thermoelectric. The important factor in thermoelectric cooling system is an optimal temperature difference between cold side and hot side module, so we need to efficiently remove this waste heat from hot side of TEC by using some natural convection, forced internal convection or external convection technique.

Putra et.al[1] investigated on a heat pipe block combined with thermoelectric module for CPU cooling,nano fluids alumina-water and titania-water were used as working fluid which passes over the system. The studied shows using nanofluids as working fluid which is used for condensation of heat pipe vapor allows greater decrease in CPU temperature as it is more efficiently carried away heat flux from hot side of TEC as compared to other conventional system. Using nanofluids in heat pipe block withthermoelectric give higher thermal performance.**Naphonet.al**[2].Investigated the de-ionized water as working fluid in heat sink with thermoelectric module. His studied found significant decrease in CPU temperature by using de-ionized water in heat sink on hot side of thermoelectric module.**Riffatet.al**[3] investigated the potential application of heat pipe and thermoelectric in refrigeration, he found using phase change equipment like heat pipe increases the thermal performance of thermoelectric inrefrigeration and cooling system. The fig shows the basic working of heat pipe.

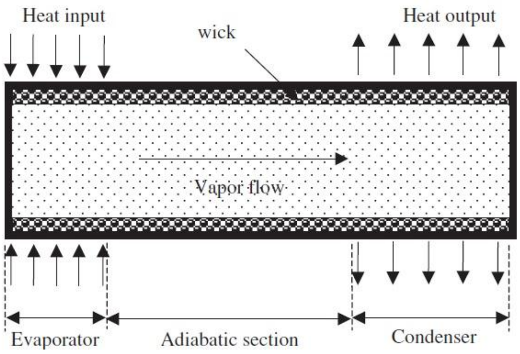

Figure.1Schematic of Heat Pipe

Chein et al. [4] investigates the cooling application of thermoelectric module, he concluded from his study that cooling capacity of TEC and COP can be increased by increasing the cold side temperature or minimize the temperature difference between the thermoelectric hot and cold side temperature. **Zhao et.al**[5] investigates the method for enhancement of thermoelectric cooling system integrated with phase change material. The performance of thermoelectric module has been analyzed. A simplified analytical model for thethermoelectric module has been adopted to investigate the theoretical performance characteristics of themodules **Russel et.al**[6] experiments were performed to develop an operating envelope to characterize the TEC based thermal management system for peak and off peak operating conditions. Parametric studies were performed to analyze the effect of the number of TEC module(s) in the system, geometric factor of the thermo-elements and thecold to hot side thermal resistances on the system performance. The results showed that there is a tradeoff between the extent of off peak heat fluxes and ambient temperatures when the system can be operated at a low power penalty region and the maximum capacity of the system.**Tan et.al**[7] gives the methodology for search and selection of thermoelectric cooler module to optimize a cooling system design. Themethodology assists the designer to size and select the TECs from different manufacturers.

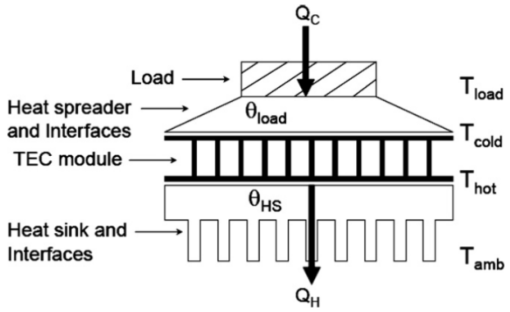

Figure.2 A typical thermoelectric cooling (TEC) assembly

II. BASIC MATHEMATICAL MODELLING

A. a *Basic Mathematical Model of Heat Pipe*

Heat pipes are very efficient heat transfer devices, there are various parameters that put limitations and constraints on the steady and transient operation of heat pipes. There are major parameters which govern the function of heat pipes.

A heat pipe consists of three main parts: vapor region, liquid wick region, heat conduction

Vapor Region consists of three major equations: [5]

Continuity Equation:

$$\frac{du}{dx}+\frac{dv}{dy} = 0 \quad (1)$$

Applyingnavier stokes for vapor flow in core we get the equation:

$$\rho\frac{Du}{Dt} = -\frac{\partial P}{\partial x} + \rho g_x + \mu[\frac{\partial}{\partial x}(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y})+\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}] \quad (2)$$

$$\rho\frac{Du}{Dt} = -\frac{\partial P}{\partial x} + \rho g_x + \mu\nabla^2 u(3)$$

$$\rho\frac{Dv}{Dt} = -\frac{\partial P}{\partial y} + \rho g_y + \mu[\frac{\partial}{\partial y}(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y})+\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}] \quad (4)$$

$$\rho\frac{Dv}{Dt} = -\frac{\partial P}{\partial y} + \rho g_y + \mu\nabla^2 v(5)$$

Energy Equation:

$$\rho c_p = u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)(6)$$

Wick Region Equations:

Continuity:

$$\frac{du}{dx}+\frac{dv}{dy} = 0 \; (7)$$

Momentum equation:

$$\frac{Du}{Dt} = -\frac{\partial P}{\partial x} + \rho g_x + \mu\nabla^2 u + R_x(8)$$

$$\rho\frac{Dv}{Dt} = -\frac{\partial P}{\partial y} + \rho g_y + \mu\nabla^2 v + R_y(9)$$

Rx & Ry representing porous media which gives resistance to flow.

Energy equation:

$$\rho c_p = u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = k\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) + Q_v(10)$$

Qv=Volumetric flux

The steady state thermal conductivity equation to predict the wall temperature is:

$$K_s\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) = 0(11)$$

B. *Basic Mathematical Model of Thermoelectric Module*

This section is to describe mathematical models for governing physical behaviors of a thermoelectric module so as to approach practical applications of thermoelectric modules on heat flow detection. For commercial products, the thermoelectric module is typically made of two ceramic plates of various sizes and shapes covering an array of (n −

p) sequentially-paired semiconductors. In general, the thermoelectric modules are widely used as heat pumps in electric cooling/heating when the DC current from a power source flows through the thermoelectric module, which subsequently causes heat transfer from one side (cold side) of the thermoelectric module to the other (hot side). In turn, cooling effects and heating effects are generated according to thermal demands at the cold side and at the hot side, respectively. In fact, the thermoelectric module can be considered a thermal–electrical circuit as depicted on the right side.

This is mathematically derived by: [6]

$$v = \beta(T_h - T_c) + RI (12)$$

Where v = Voltage across the thermoelectric module
β = Seeback Coefficient
T_h = Temp. at hot side, Tc = Temp. at cold side
R = Resistance of the thermoelectric module,
I = Electric current flowing within the circuit

The amount of heat rejected by the thermoelectric module at the hot side can be determined by

$$Q_H = \beta I T_h + \frac{1}{2} I^2 R - K(T_h - Tc) (13)$$

On the other hand, the amount of heat pumped by the thermoelectric module at the cold side can be determined by:

$$Q_c = \beta I T_c + \frac{1}{2} I^2 R - K(T_h - Tc) (14)$$

Where k is the thermal conductivity coefficient of the thermoelectric module. The first term on the right side of Eqns. (13)–(14) is the Seeback heating/cooling effects. The second term characterizes the Joule heating effect associated with electrical power developed in the resistance. The third term represents the Fourier effect of heat conduction from the hot side to the cold side.

From the principle of energy balance, the electrical power and the rate of heat pumped from the cold side as well as the rate of heat rejected to the hot side can be written as:

$$Q_h = Q_c + IV (15)$$

The heat conduction from the cold side of the thermoelectric module to the heat sink can be expressed as:

$$Q_s = T_c - T_s / r_s (16)$$

The heat convection from the heat sink to the air can be written a

$$Q_s = T_s - T_a / r_a (17)$$

Wherers is the thermal contact resistance between the thermoelectric module and the heat sink, ra is the thermal resistance of the natural convection at the heat sink,Ts is the temperature of heat sink, and Ta is the temperature of air.

III.EXPERIMENTAL SETUP

A Schematic diagram of experimental setup is shown in fig 2.The Experimental set up consists offlexible heater which resembles the CPU.The cold side of Thermoelectric is in direct contact with CPU and hot side of thermoelectric is in contact with evaporator side of heat pipe. The evaporator side of heat pipe takes away the heat generated from thermoelectric by changing the phase of water inside heat pipe. The condensation of water happens on condensation section of heat pipe by using water as working fluid for condensation. An AC variable transformer is used to Supply power to heater. A multimeter is used to measure the power input into heater. The temperature of the heater was measured using two T-type thermocouples mounted between the heater and the Cold side ceramic substrate of the TEC device. A Dc regulated power supply is used for Thermoelectric. A submersible pump is used to pump the water inside the heat pipe for cooling of vapor in condensation section.

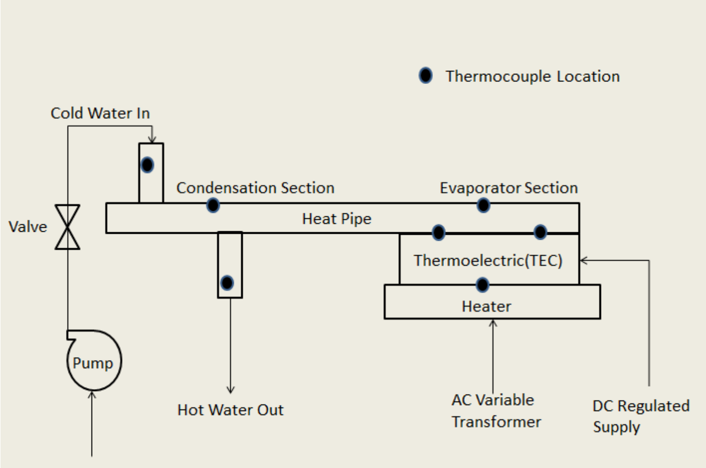

Figure 3 Schematic of experimental set up

The flow rate will measured using a turbine flow meter and demodulator .The water temperature at inlet and outletof heat pipe is measured by thermocouples. The selection of heat pipe is based on the working temperature.

IV. CONCLUSION

Figure.4 Initial set up showing the work in progress

The set up in fig.4 shows the thermoelectric with heat pipe which is the basic setup for taking initial reading. We take initialreading by supplying varying input current to thermoelectric and its heat dissipation is measured. A heat pipe is attached to the thermoelectric hot side to take away the heat generated or heat flux from hot side of thermoelectric. The initial reading in fig.5 shows the heat dissipation in watts from thermoelectric with varying input current.

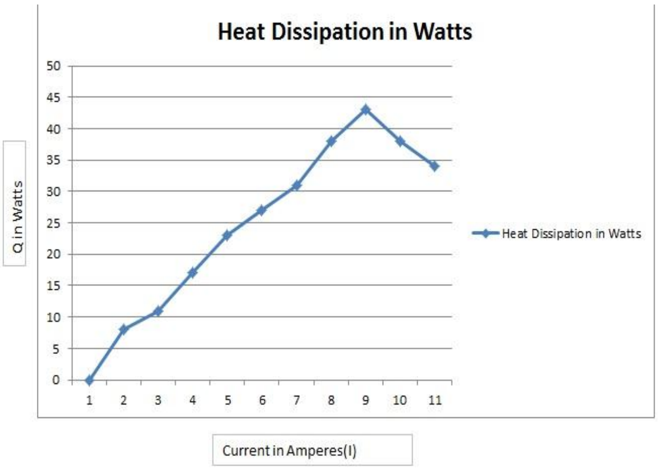

Figure 5: Initial readings for TEC

V.FUTURE WORK IN PROJECT

We are going to develop the full experimental set up as shown in fig.2 and take different readings by changing different variables and parameters like Input current to thermoelectric & heater, varying flow rate of water inside heat pipe, changing the working fluid presently water with some Other fluids .We compare our result for determining the thermal performance of thermoelectric. This study will help in advancement in future of electronics cooling using thermoelectric module and a major impact on cooling industry.

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