Study of Thermal Performance of Thermoelectric Module with Heat Pipe in Electronic Cooling

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ABSTRACT

In our day-to-day life we are surrounded by lots of Electronic devices. In every electronic device uses of the integrated circuit such as a small chip which is made up of semiconductor materials and having the large quantity of transistors, capacitors, and resistors. During the operation of electronic device a larger amount of heat is generated in the small amount of area. This excessive heat generated is responsible for around 55% of failure of electronics devices. It is required to remove this excessive heat within a short period of time to protect the electronic device & enhance the life span of the electronic device.

It gives scope to study and investigate the integration of both cooling system as heat pipe & Thermoelectric Cooler (T.E.C.) Module and developing the better cooling system for the electronic device. A thermoelectric module with heat pipe is designed and thermal performance of combined system is studied under different cases with change in heater which can be treated as electronic chip inputs and TMC Module inputs. Temperature of the heater initially decrease for the heater current input 0.17 A and 0.25 A with increase in module current from 1.4 A to 1.8 A. The maximum reduction in temperature difference is occurred about 2 degrees Celsius for the heater current input as 0.25 A. For the heater current input 0.29 A and 0.33 A the temperature of the heater is not significantly decreases even module current increase from 1.7 A to 1.8 A. For the heater current input 0.29 A and 0.33 A single module is not capable to extract more heat from the heater in order to reduce the temperature of heater.

Keywords:- Electronics cooling, Heat pipe, Thermoelectric module, Thermal performance.

INTRODUCTION

Heat fluxes have increased in recent years as a result of a considerable rise in microprocessor power dissipation combined with CPU size. Heat fluxes from microprocessors have also grown in several commercial applications. As a result, thermal management has emerged as one of the most demanding challenges and a crucial topic in terms of cooling system performance.

The heat fluxes can no longer be eliminated by traditional air-cooled cooling systems. Other high performance compact cooling methods may need to be used in place of or in addition to direct air-cooling systems for a variety of applications. Changes in the liquid-vapor phase Due to their high heat transfer coefficients, thermoelectric cooler and heat pipes are appealing cooling options for eliminating significant heat fluxes.

Several experiments were performed to find the performance of thermoelectric in cooling of electronics components such as chip, electronic packaging. Experiments were performed by using thermoelectric with heat pipe.

The following figure no 1 shows the Schematic representation cooling module TEC and heat pipe,

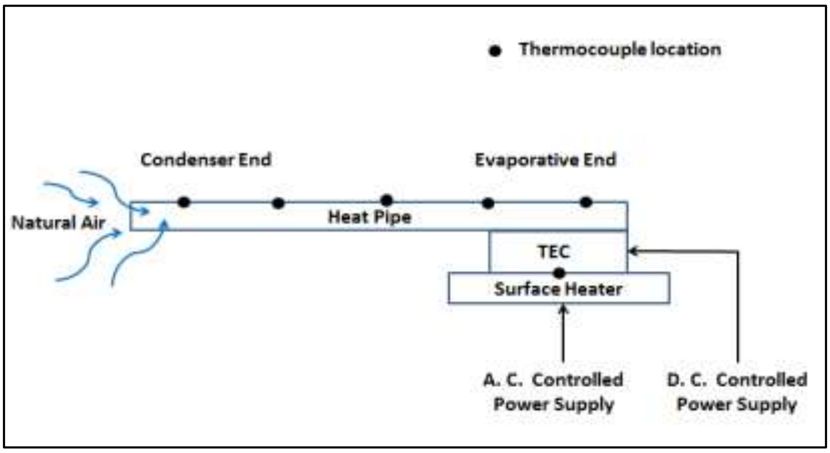


Figure 1 Schematic representation of cooling module TEC and heat pipe

LITERATURE REVIEW

S B Riffat [1] provides findings from research done to determine the use of thermoelectric heat pipes in thermoelectric refrigeration. The setup consists of designing and building a thermoelectric refrigeration prototype. The purpose of the tests was to determine the outcomes in two distinct configurations. Fin heat sinks are employed on the thermoelectric module's cold side in the first arrangement. In alternative configurations, the heat sink is made of phase-changing material, such as heat pipes. The thermoelectric refrigeration system's performance and cooling storage capacity are enhanced when a heat pipe is used in place of a traditional heat sink. The goal of this study is to identify innovative ways to enhance the heat transfer process and TEC performance.

Russel [2] investigates the thermoelectric based thermal management system used in electronics packaging it operates under different ambient conditions and loads. Experimental investigation shows that model predictions are similar to experimental results. Analyses of the impact of the thermo elements' geometric factor and number of modules were conducted. The thermal performance of T.E.C. based thermal management system during off peak situations was investigated using a model of the thermal resistance network for a thermal management system that incorporates T.E.C. modules. A packed computer running at a range of heat loads and atmospheric temperatures, i.e. (T_{design}-T_{∞}) was the subject of a thermal management system case study. The outcomes demonstrated that the TEC module only worked at higher atmospheric temperatures. The results showed that while the system may be operated at a very low power penalty region, there is a trade-off between the maximum capacity of the system and the quantity of off peak heat fluxes and air temperatures.

A. M. Mohamed et al. [3] conducted the FEA simulation for CPU cooler design based on heat pipes is also used in many applications in which heat sink with heat pipe is used. Recently, fans have been utilized to increase CPU cooling using forced convection; in this experiment, fans with heat pipes are employed to cool the chip more effectively. CFD simulation is performed to find the most suitable selection and design of the cooling system. The major components of experimental set up are dummy heater to represents the chip, a variable transformer to supply variable power to heater. The Set of het pipes mounted aover heater, the evaporation part of heat pipe is to remove the heat from the hot section and condensation side is in under fan range for cooling or heat dissipation from the heat pipe condensation section. The results show the fan with the heat pipe is superior over the other conventional cooling systems.

Masami Ikeda [4] are putting up the notion of cooling CPUs using thermoelectric coolers (TEC). By maintaining the same form factor, the suggested cooling system which has no any moving parts can increase thermal performance. This system will reduce the noise of the cooling solution and/or support an increase in the CPU thermal design power. Together with the optimization for low TEC power consumption and low acoustic noise, the thermal performance of this suggested device will be demonstrated. Consequently, we discovered that the "Hybrid structure," which consisted of a thermoelectric cooler i.e. T.E.C. integrated with heat sink and a heat pipe distant heat sink, could lower the noise from the acoustic fan and the amount of TEC power is required to keep the CPU cool. In one instance, we were successful in creating a small cooling device with COP=10.8 that could cool a CPU for 130 Watts at acoustic fan noise levels below 40 dB.

Tan et.al [5] outlines the process for finding and choosing a thermoelectric cooler module in order to maximize the design of a cooling system. The process aids the designer in choosing and sizing the TECs from various producers.

Guilherme B. Ribeiro et. al [6] determined that a unique evaporator concept's thermal behavior has been assessed. This evaporator is designed to be used in conjunction with a small refrigeration system and the heat pipe technology that is currently in use for portable (laptop) computer chip cooling. A heat transfer model that incorporates the configuration of the evaporator and heat pipes and is limited in terms of design to a certain processor operating temperature was used to calculate the heat transfer surface area and, consequently, the evaporator length. Experimental assessment of an evaporator prototype at various saturation temperatures (45 and 55 degrees Celsius), the mass flow rate of refrigerant (0.5 e 1.5 kg/h), and the rate of heat transfer (30-60 W) was conducted in addition to the study. According to the experimental results, the coefficient of heat transfer of refrigerant rises as the refrigerant mass flow rate does. Furthermore, the amount of heat transfer in an evaporator has been shown to be slightly influenced by the saturation temperature and the rate of heat transfer.

Zhao et.al [7] examines how to improve a thermoelectric cooling T.E.C. system that incorporates phase-change material. The thermoelectric module's performance has been examined. They created a basic analytical model for the thermoelectric module, which has been utilized to investigate the theoretical performance characteristics of the modules.

Mohamed H.A. Elnaggar [8] It is determined that there is a growing demand for optimal cooling systems in the computer sector in order to disperse the related heat from the recently constructed and developed computer processors to acquire their increased processing capability and quicker operations. Researchers must investigate effective methods for the central processing unit (CPU) cooling in order to meet this need. Heat pipes may therefore be a practical and encouraging answer to this problem. This chapter covers a CPU's thermal design power (TDP), electronic equipment cooling techniques, heat pipe theory and operation, and components of heat pipe including the working fluid, wick structure, and wall material. Additionally, we examine many kinds of heat pipes and their uses for computer cooling in particular as well as electronic cooling in general using experimental, analytical, and computational methods. The content, technique, and heat pipe types are compared in summary tables. This chapter undoubtedly encourages more study in computer cooling applications because of the heat pipe's many benefits in electronic cooling.

Xiaoqin Sun et. al [9] determined that a theoretical model was used to design and construct a thermoelectric cooling system with a gravity assisted heat pipe in order to improve the heat dissipation from the thermoelectric module's hot side. A climatic chamber was used to construct an experimental setup in order to determine the performance of this suggested TEC system. A thermoelectric cooler T.E.C. system with a heat sink was used to compare the temperature within the test box, the cooling capacity, and the intake and output air temperatures via the thermoelectric module. Using GAHP, the cooling capacity was improved around 73.54% but the amount of power consumed to generate the same quantity of cold energy was decreased by 42.20%. As the ambient air temperature rose, the cooling capacity of the TEC system with heat sink first grew and subsequently dropped, which would affect the electric device's performance. However, due to the heat pipe's self-adjustment, it did not change much.

H. Jouhara et. al [10] determined that the use of heat pipes are advantageous for a variety of industries and that they can be used in kilns and cryogenics at a variety of operating temperatures. Even though there is a wide range of applications, there is still a lot of effort to be done to make the system operate in every possible combination of application and temperature. Research on various temperatures and applications clearly has gaps. Numerous uses of low temperature heat pipes have been investigated in the realm of low temperature applications in order to increase their thermal capacity.

Kun Liang et. al [11] found that experimental results validate thermoelectric and heat pipe models. The thermoelectric system's cooling capability was increased by 53% because to the heat pipe. The VCR system can dissipate 200 W/cm^2, which is a significantly greater heat flow. Devices at lower temperatures can be cooled using a two-stage TE method.

Thiago Antonini Alves et. al [12] concluded that an experimental study was conducted to examine the thermal performance of several passive heat transfer devices, including mesh heat pipes, grooved heat pipes, solid rods, thermosyphons, and sintered heat pipes. With the exception of the rod and thermo-syphon in the horizontal orientation, these passive heat transfer devices performed adequately when tested in both vertical and horizontal orientations under thermal loads ranging from 5 to 45 Watts. Because of gravity, the vertical posture performed better than the horizontal one. In the vertical position, the thermo-syphon demonstrated a reasonable thermal performance. It behaved worse than a rod in the horizontal, though. Because the capillary structure and the working fluid's vaporization heat were used simultaneously, the heat pipes had the finest thermal performance of any device. Because of its increased effective thermal conductivity or lower global thermal resistance, the grooved heat pipe performed better thermally. The experimental findings shown that thermo-syphon and heat pipes may be effectively employed in TEC hot side cooling to generate cooling.

Zhihao Zhang et. al [13] studied the most recent developments in widely utilized techniques and technologies used for electronic device thermal management, and came to the conclusion that T.E.C. cooling is one of the efficient cooling techniques, is thought to be a promising thermal management solution for electronic devices. The primary problem at the moment is still improving the performance of T.E.C. materials like by discovering a new type of material that is more affordable. Furthermore, enhancing the TE cooling system's effectiveness also depends on the best possible design for the cooperative use of TE modules, which merits investigation given the variety of electronic devices. To enhance the performance of thermal management, the Thermoelectric Cooler T.E.C. might be used in conjunction with various types of heat sinks, like heat pipe, pin-fin, Micro-channel & vapor chambers.

EXPERIMENTAL SETUP

To study the thermal performance of thermoelectric module with heat pipe in electronic cooling an experimental setup is prepared which consist of thermoelectric module, heat pipe, square plate heater with clamping system, thermocouple, control panel, digital temperature indicator, digital current and voltage indicator, temperature controller, dimmer stat, sink, fan, module controller. Figure 2 shows an actual experimental setup. In this experimental setup total 6 thermocouples of chromel-alumel type are used at various locations. The detailed nomenclature and location of thermocouple is as bellow,

T1 = Temperature at evaporative section of heat pipe.
T2 = Temperature at 120 mm from evaporative section of heat pipe.
T3 = Temperature at 170 mm from evaporative section of heat pipe.
T4 = Temperature at 240 mm from evaporative section of heat pipe.
T5 = Temperature at condenser section of heat pipe.
T6 = Ambient Temperature
T7 = Temperature of Heater plate.

The table 1 shows detailed specification details of thermoelectric Module,

Name of Manufacturer	TD RETAIL
Model No	1117ZD16VXJ
Dimension	40 x 40 x 3.6 mm
Current	6 A
Operating Temperature	-50 to 180 ° C

Table1 Specification of Thermoelectric Module with its actual picture

The table 2 detailed specification of heat pipe used,

Material	Copper
Outside Diameter	20 mm
Length of Heat Pipe	400 mm
Weak	Helical coil type springs Wire Diameter 0.20 mm × 345 mm length
Fluid	Distilled Water 25 ml

Table 2 Specification of Heat Pipe

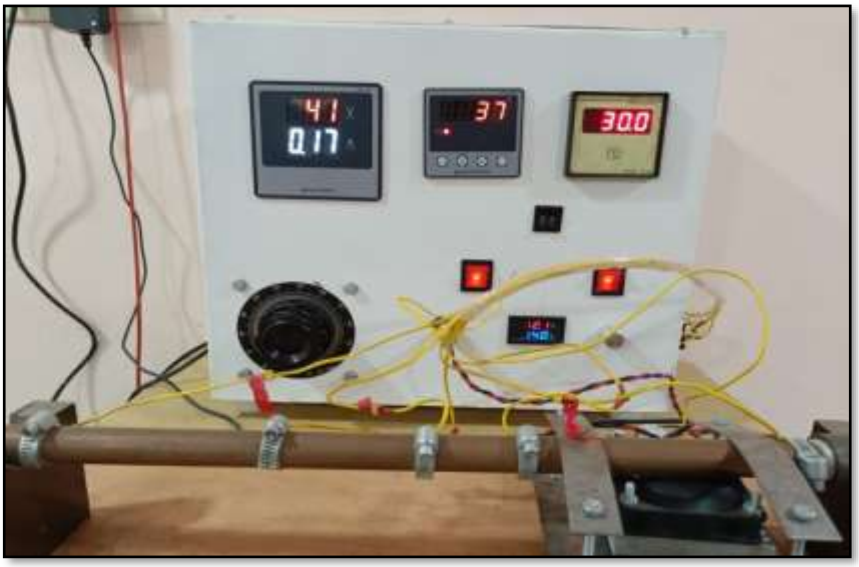


Figure 2. Actual Experimental Setup

With this prepared experimental setup reading was taken as per the following observation table and studied temperature variation with change in TMC inputs i.e. change in current and power of TMC at atmospheric temperature around 30°C. In total five different case were studied as per follows,

Observation Table for Case I - Heater input power as 6.8 W

Heater Inputs		**V**	**40**	**I**	**0.17**	**P**	**6.8**	
TMC Module			**Temperature Variation on Heat Pipe**					
V	**I**	**P**	**T1**	**T2**	**T3**	**T4**	**T5**	**T7-HT**
12.1	**1.4**	16.94	31.5	31.7	31.1	30.9	30.6	40
12.1	**1.5**	18.15	33.8	34.7	33.1	32.9	32.6	40
12.1	**1.6**	19.36	34.6	35.5	33.9	33.6	33.3	39
12.1	**1.7**	20.57	34.5	35.7	33.7	33.4	33.1	38.5
12.1	**1.8**	21.78	34.8	35.9	34	33.7	33.4	37.8

Table 3 Observation table with heater input power as 6.8 W

Observation Table for Case II - Heater input power as 10 W

Heater Inputs		**V**	**50**	**I**	**0.2**	**P**	**10**	
TMC Module			**Temperature Variation on Heat Pipe**					
V	**I**	**P**	**T1**	**T2**	**T3**	**T4**	**T5**	**T7-HT**
12.1	**1.4**	16.94	32.7	32.9	32.1	31.8	31.5	44
12.1	**1.5**	18.15	33.9	34.9	33.2	33	32.7	43
12.1	**1.6**	19.36	34.5	35.6	33.7	33.5	33.1	42

12.1	**1.7**	20.57	34.5	35.8	33.6	33.3	33	42
12.1	**1.8**	21.78	34.7	35.9	33.8	33.5	33.1	42.5

Table 4 Observation table with heater input power as 10 W

Such a five variation are studied, after complementation five different case, we have prepare an observation table which indicate that variation of heater temperature with change in module current. The detailed variation is as follows,

Summery Table for Variation in Heater Temperature with change in Module Current.

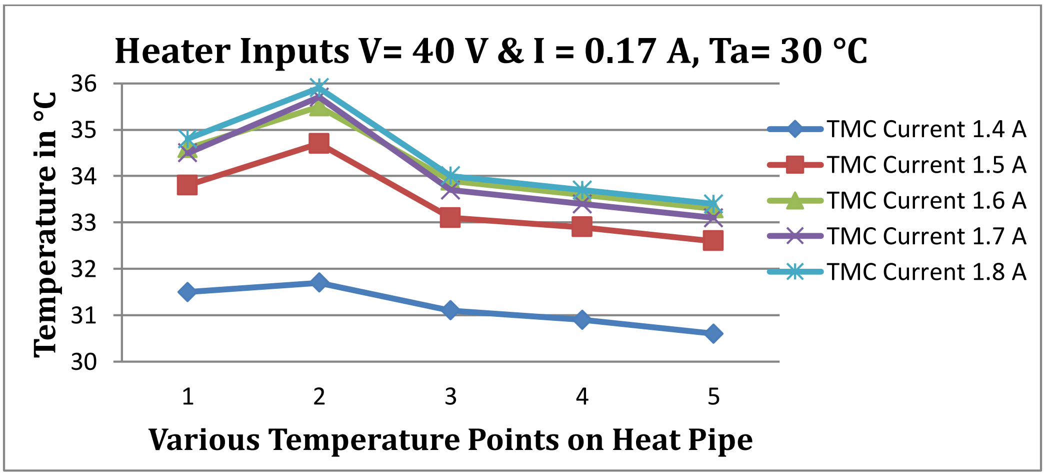
Heater Input current (A)	**Module Current (A)**				
	1.4	**1.5**	**1.6**	**1.7**	**1.8**
	Temperature of Heater				
0.17	40	40	39	38.5	37.8
0.2	44	43	42	42	42.5
0.25	46	46	46	45	44
0.29	51	51	50	50	50
0.33	55	53	55	55	55

Table 5 Observation table for Variation in Heater Temperature with change in Module Current

GRAPHS, RESULT & DISCUSSION

Based on the observation table graphs are plotted as temperature in degree Celsius vs. various temperature points on the heat pipe.

Graph for Case - I



Graph 1 Temperature vs. various temperature points on the heat pipe with Heater Inputs V= 40 V & I = 0.17 A, Ta= 30 °C

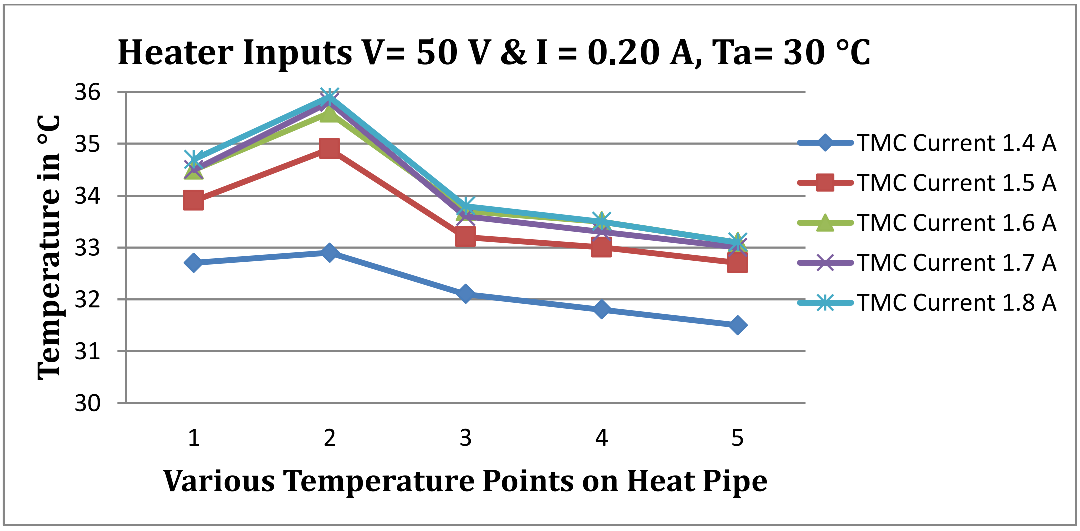
The graph shows the temperature variation at different points on a heat pipe when the heater is operating under specific input conditions (40 V and 0.17 A) at an ambient temperature of 30°C. The module current (TMC Current) is varied between 1.4 A and 1.8 A, and the temperatures at five distinct points on the heat pipe are plotted for each current level.

Interpretation of graphs:-

1. For the TMC Current 1.4 A, the temperature range is 31°C to 32.5°C. This curve shows a steady, gradual decline in temperature from point 1 to point 5, with the highest temperature at point 2 (~32°C).
2. For the TMC Current 1.5 A, the temperature range is 33°C to 35°C. This curve peaks sharply at point 2 (~35°C) and then experiences a sharper decline than the higher current levels, settling around 33°C at the point 5.
3. For the TMC Current 1.6 A, the temperature range is 33.5°C to 35.5°C. There is a sharp rise at point 2 (~35.5°C), followed by a more gradual decline than the 1.5 A curve. The temperature remains higher at the later points compared to lower currents.

4. For the TMC Current 1.7 A, the temperature range is 33.5°C to 35.5°C. The curve follows a similar pattern to the 1.6 A current, with a peak at point 2 (~35.5°C), but slightly lower temperatures at points 4 and 5 compared to the 1.8 A curve.
5. For the TMC Current 1.8 A, the temperature range is 34°C to 35.5°C. This curve is the highest overall, with a peak at point 2 (~35.5°C) and a very slight decline afterward, indicating the most uniform heat distribution across the heat pipe.

Graph for Case- II



Graph 2 Temperature vs. various temperature points on the heat pipe with Heater Inputs V= 50 V & I = 0.20 A, Ta= 30 °C

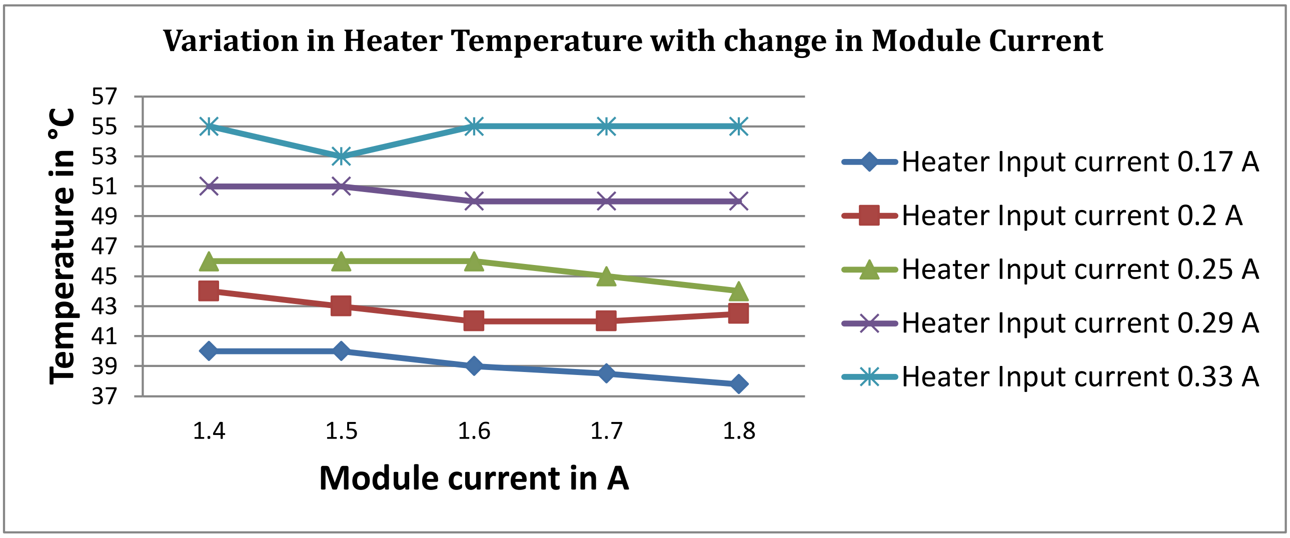
The graph shows the temperature variation at different points on a heat pipe when the heater is operating under specific input conditions (50 V and 0.20 A) at an ambient temperature of 30°C. The module current (TMC Current) is varied between 1.4 A and 1.8 A, and the temperatures at five distinct points on the heat pipe are plotted for each current level.

Interpretation of graphs:-

1. For the TMC Current 1.4 A, the temperature range is 31°C to 32.5°C. This curve shows, the temperature is the lowest among all currents and exhibits a slight rise at point 2 (~32.5°C), followed by a steady decrease from points 3 to 5.
2. For the TMC Current 1.5 A, the temperature range is 33°C to 35°C. This curve shows temperature rises sharply to 35°C at a point 2, then decreases more quickly compared to higher current settings, settling around 33°C by point 5.
3. For the TMC Current 1.6 A, the temperature range is 33.5°C to 35.5°C. The temperature peaks at point 2 (~35.5°C) and shows a more gradual decline compared to 1.5 A, indicating better heat retention at points 3, 4, and 5.
4. For the TMC Current 1.7 A, the temperature range is 33.5°C to 35.5°C. The temperature profile is similar to the 1.6 A setting, with a peak at point 2 (~35.5°C) and a slight decrease afterward. The temperature at point 5 remains higher than that of lower current settings.
5. For the TMC Current 1.8 A, the temperature range is 34°C to 35.5°C. The temperature reaches its maximum at point 2 (~35.5°C), with the most uniform and stable temperature profile across all points on the heat pipe.

Following graphs indicate that variation of heater temperature with change in module current,

Graph for Variation in Heater Temperature with change in Module Current



Graph 3 Variation in Heater Temperature with change in Module Current

Interpretation of graphs,

The graph illustrates how the heater temperature varies with changes in the module current for five different heater input currents. The following are key observations and interpretations for each input current setting, along with general trends,

1) **Heater Input Current 0.17 A: -** For this current setting, as the module current increases from 1.4 A to 1.8 A, the heater temperature decrease from the 40 °C to 39 °C. It means module is working efficiently and pumping the heat from the heater towards the heat sink.
2) **Heater Input Current 0.2 A: -** For this current setting, temperature of the heater is initially decreases up to the module current 1.7 A. Then at the end heart temperature is slightly increase even increase module current is increase.
3) **Heater Input Current 0.25 A: -** For this current setting, module is performing at the best efficiency. It reduces the temperature of the heater by 2 °C. The module current is increases from 1.4 A to 1.8 A and the heater temperature is decreases from 46 °C to 44 °C.
4) **Heater Input Current 0.29 A: -** For this current setting, temperature of the heater is nearly constant. As the module current is changes from the, 1.5 A to 1.6 A only temperature is decreases by 1 °C. After that temperature is almost constant.
5) **Heater Input Current 0.33 A: -** For this current setting, temperature of the heater is nearly constant. As the module current is changes from the, 1.4 A to 1.5 A only temperature is decreases by 1 °C. After that temperature is again increased from the module current chaining from the 1.5 A to 1.6 A then it is almost constant. It means that module is not able to extract the heat from the heater to grate extend.

CONCLUSION

A Thermoelectric Module with Heat Pipe was designed and experimental setup was built for electronics cooling. To study the thermal performance of combined system, experiments were carried out at atmospheric temperature about 30 degrees Celsius. In total 30 readings were taken with 5 different case by varying heater input and module input. The following points are concluded,

1. Temperature of the heater which can be treated as electronic chip is initially decrease for the heater current input 0.17 A and 0.25 A with increase in module current from 1.4 A to 1.8 A.
2. The maximum reduction in temperature difference is occurred about 2 degrees Celsius for the heater current input as 0.25 A.
3. For the heater current input 0.29 A and 0.33 A the temperature of the heater is not significantly decreases even module current increase from 1.7 A to 1.8 A.

4. For the heater current input 0.29 A and 0.33 A single module is not capable to extract more heat from the heater in order to reduce the temperature of heater.

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