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Simulation of Minichannel Liquid Based Thermoelectric Cooling System by Changing Dimension of Minichannel and Type of Heat Transfer Fluid

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Abstract: In recent time, due to exponential growth in electronic devices there is significant increase in heat dissipating element like integrated circuits(IC), graphical [2]Assistant Professor, processing units (GPU) and central processing units (CPU). If there is no proper arrangement for heat removal it can permanently damage whole system. There are several methods used for this, one of which is thermoelectric cooling which works on peltier effect, thermoelectric devices with proper cooling arrangement act like heat pump which removes heat from one side and provide it to another side. The drawback of this system is low efficiency. In this project CFD analysis is done for minichannels of different dimensions along with thermoelectric. Simulation is performed by changing parameters such as hydraulic diameter of minichannel, changing type of heat transfer fluid and mass flow rate of fluid. The study reveals that by optimizing these parameters performance of thermoelectric system can be improved. The aim of this study is to optimize these parameters in order to improve overall heat transfer coefficient and coefficient of performance of the system.

Keywords: Thermoelectric cooling, Peltier effect, Minichannel, Overall heat transfer, CFD

I. INTRODUCTION

The cooling methods used in electronic system can be categorized basically in two types. The first one is passive cooling method and later is active cooling. In passive cooling there is no used of external devices like heat pump , blower radiating fan which take another source of energy as input. Examples of these systems are heat pipes, heat abrasives and many other. The most common method is active cooling which uses external devices as power source like vapour compression refrigeration system, Liquid impingement method and surface cooling method. Most efficient method is VCR but its size and noise makes it difficult to use. Other active cooling methods include air cooling by natural and forced convection also by using different types of fins.

Liquid cooling system is more complex but it is becoming popular because of its improved cooling capacities. Liquid has high heat capacities and high viscosity as compared to air. The methods used in liquid cooling are vapour chamber which abstract and reject heat by phase change, liquid impingement which uses jet stream of liquid on cooling surface, Minichannel liquid cooling which uses minichannel in order to improve surface area.

A. Thermolectric Device

It works on peltier effect which says that electric temperature gradient is developed in two dissimilar metals when potential difference is applied in lateral direction. The most commonly used peltier module is TEC12706 which contain bismuth telluride semiconductors and alumina as ceramic. Total number of semiconductors is 127 and rating is 6A.The highest operating temperature of peltier module is 138 ˚C.

B. Minichannel

The minichannels are small crossection channels with small opening and high surface area to volume ratio.The classification of these channels is given different authors.

Satish Kandlekar proposed classification based on hydraulic diameter (Dh)

1) Convetional channels Dh>3mm
2) Minichannels 200µm<Dh<3mm
3) Microchannel 10µm<Dh<200 µm

SS Mehandale propose classification as follow:

a) Convetional channel Dh>6mm
b) Compact passage 1mm<Dh<6mm
c) Meso channel 100µm<Dh<1mm
d) Minichannels 100µm<Dh<1mm

These minichannels have high surface to volume ratio, it may be in circular or non circular crossections. In rectangular and triangular channels, liquid film attracted towards corners because of high surface tension. Thus heat transfer rate is more in non circular channels as compared to circular channels.

C. Heat Transfer Fluid

Heat transfer fluid in liquid form has high heat capacities ad thermal conductivities as compare to gaseous form. Thermally cooled liquid can be passed through any complex shape with proper arrangement. Water has highest heat capacity of 4187 kJ/kgK at 4˚C. But higher heat capacity can increase the temperature of hot side of module above 138˚C which could damage the module. Other thermal fluids used are FC72, Ethylene Glycol and Nano fluid ethylene glycol with 1% TiO_2

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In this study, CFD simulation is performed for minichannel of different diameters such as 0.6mm, 0.8 mm and 1mm .This minichanneles coupled with TEC12706 peltier module and a DC fan of 1.2W is used in order to cool down the hot side of peltier module. Different heat transfer fluid such as FC72, Ethylene glycol and Nano fluid Ethylene glycol with 1% TiO_2 is passed through it .These fluids are passed at mass flow rates 0.001kg/s, 0.002kg/s and 0.003kg/s and results for overall heat transfer coefficient and coefficient of performance is obtained.

II. LITERATURE REVIEW

Fankai meng et al.[1] have numerically studied the use of thermoelectric generator with air cooling in heat recovery device. He observed that water cooling is more effective than air cooling but structure is complex in case of water cooling. He also studied studied the effectiveness of thermoelectric bismuth telluride semiconductor module with air cooling. He observed that cost of this type of system make it difficult to use but they are compact and less noisy as compared to conventional system.

Akim burak et emoglu [2] have studied different methods of cooling for electronic devices. He also made study on jet impingement cooling technique by varying structure of different type of nozzle also by varying other parameters like nozzle height, nozzle shape, air velocity, air temperature nozzle pitch made a comparative study using different type of nozzle

Lian Tuu Yeh [3] have done CFD analysis of different types of fins including pin fin, extruded fin plain and cell fin. He used copper heat sink for different air speed and allowed them to flow on fin surface. He observed that as air the cell fin heat sink is most effective for velocity greater than 2.2, especially at higher velocities, and is followed by the plain fin heat sink. However, the plain fin heat sink works well over wide range of the air velocities. The extrusion heat sink is the most inefficient because of the least surface area for the heat transfer.

Allwin Jose et [4] al from IIT Bombay made a conceptual model of air conditioner with thermoelectric module. By studying this thermoelectric air conditioner they observed that this system have advantage of small size because of absence of compressor but have very low coefficient of performance. But this system can be used for small size of application.

Ali Ijam and R saidur [5] used nanofluids are the suspension of ultrafine solid nanoparticles in a base fluid. A minichannel heat sink with a 20x 20 cm bottom is analyzed for SiC-water manofluid and TiO2-water nanofluid turbulent flow as coolants through hydraulic diameters. The results showed that enhancement in thermal conductivity by dispersed SiC in water at 4% volume fraction was 12.44% and by dispersed TiO2 in water was 9.99% for the same volume fraction. It was found that by using SiC-water nanofluid as a coolant instead of water, an improvement of approximately 7.25% to 12.43% could be achieved and by using TiO2-water 7.63%to 12.77%. The maximum pumping power by using SiC-water nanofluid at 2 m/s and 4% vol. was 0.28 W and at 6 m/ s and 4% volume equal to 5.39 W. By using TiO2-water nanofluid at 2 m/s and 4% vol. it was found to be 0.29 W and 5.64 W at 6 m/s with the same volume of 4%.

Bladimir Ramos-Alvaradop [6] et al perform CFD simulation by Ansys fluent software for liquid flow in microchanel based coling system for electronic devices thar solar cells. He observed that for different flat plates the plate which that maximum surface area and good thermal properties give much better result and thermal distribution.

Mark Hodes [7] studied the optimal Pellet Geometries for Thermoelectric Refrigeration, he observed that the effectiveness of this type of cooling depends upon the height of pillet and pillet surface area. He derived from mathematical modeling that optimum results from TEM depends upon voltage current resistance.

Kazuhiko Fukutani and Ali Shakouri [8] perform design of Bulk Thermoelectric Modules for Integrated Circuit Thermal Management. They make mathermatical modeling for different parameters optimum module thickness and an optimum operating current which depend on the overall heat dissipation and on the external thermal resistances. Optimized TE modules with 0.8, will have a cross section over leg length ratio of 0.037 m, can increase the chip operation power by 15% in comparison with the case without a TE cooler while maintaining the chip temperature below 100˚ C. This is for a package thermal resistance of 0.2 K/W. Prospects for TE material with higher values and the effect of contact resistance on the power dissipation density are also discussed.

Paisarn Naphon, Songkran Wiriyasart [9] Liquid cooling in the mini-rectangular fin heat sink with and without thermoelectric for CPU. Six mini-rectangular fin heat sinks with two different material types and three different channel widths are fabricated from the copper or aluminum with the length, the width and the base thickness of 37, 37, 5 mm, respectively. The de-ionized water is used as coolant. Effects of channel width, coolant flow rate, material type of heat sink and run condition of PC on the CPU temperature are considered. The liquid cooling in mini-rectangular fin heat sink with thermoelectric is compared with the other cooling techniques. The thermoelectric has a significant effect on the CPU cooling of PC. However, energy consumption is also increased.

Kenan Yakut et Al [10] have done experimental investigation of thermal resistance of a heat sink with hexagonal fins . In the present work, the effects of the heights, widths of the hexagonal fins, streamwise and spanwise distances between fins and flow velocity on thermal resistance and pressure drop characteristics were investigated using Taguchi experimental design method. Also the temperature distribution within the selected pin fins was determined. . Then, all the goals were optimized together, considering the priority of the goals, and the optimum results were found to be fin width of 14 mm, fin height of 150 mm, span wise distance between fins of 20 mm, stream wise distance between fins of 10 mm and flow velocity of 4 m/s.

Tianyi Gao et al [11] made mathematical models for different high density chips incliuding cntral processing units ad graphical processing units for direct liquid cooling using cold plates. They have also performace CFD analysis. They observed that effective ness of liquid coolog depends on parameters like plate design which gives high surface area, liquid flow velocity and liquid supply temperature. Abu Raihan Mohammad Siddique et al [12] perform experimentation and simulation using CFD for microchannel based thermoelectric cooling by varying thermal loads. They used heat exchanger to take heat from liquid and peltier module to enhance performance. They observed that for this type of arrangement COP is around 3.2 to 2.81. This model is very economical also.

A. Research Gap

The above study focused on improved cooling techniques using different methods but the optimum use of all parameters which will give good overall heat transfer coefficient and better Cop has not seen. Parameters like dimensions of minichannel, type of heat transfer fluid and mass flow rate that can be optimized in order to obtain better performance has been studied in this project. In this study is done by simulation in Auto desk CFD 2018 software and results obtained are verified from previous work.

III. METHODOLOGY

A. Geometrical Modeling

Figure 1 shows proposed cooling system which contain minichannel of diameter 1mm, 0.8mm and 0.6mm. Fluid used are fluorescent 72(FC72) and Ethylene glycol, properties of these fluids are taken from datasheets. Three values of mass flow rates are used i.e 0.001kg/s, 0.002kg/s and 0.003kg/s, these mass flow rates are used such that temperature of hot side of peltier module must be within operative temperature limit which is 138˚C that can be taken from data sheet.

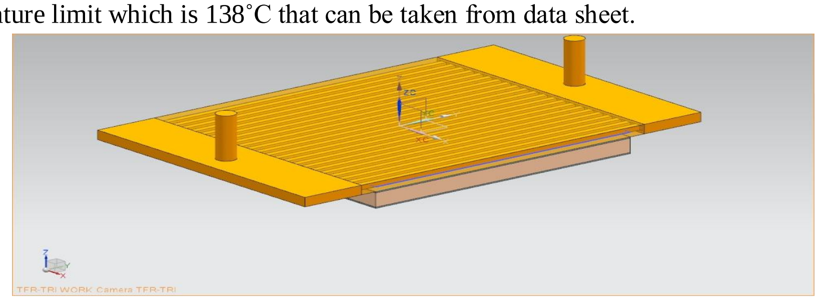

Figure 1 Cooling System Model

B. Mathematical Modeling

In order to find out the effect of mass flow rate, hydraulic diameter and type of fluid on heat transfer coefficient of fluid and coefficient of performance of given system, CFD simulation is to be carried out on proposed model. After simulation different of temperature contours, power consumed can be easily find out. By applying following equations values for overall heat transfer coefficient and coefficient of performance can be calculated.

Heat given by fluid= Qr=mCp(Tinlet-Toutlet)

Heat taken by system= UA(Tavg-Ts)

Overall heat transfer coefficient= Qr/Ax(Tavg-Ts)

Power consumed by Peltier module= $P_{Module=}$ IaV

Power consumed by fan= P_f = (9.81xQxp_t)/60

Here, Q= volume flow rate of air taken from fan curve datasheet [3]

Power consumed by pump=P_p= m(p_2-p_1)/ ρ

Coefficient of performance= (Heat given by fluid/power supplied) =Qr/($P_{Module+}$ P_f + P_p)

Reynold number= ρVD_h/μ= mD_h/Aμ = 4m/ΠDhμ

Prandtl number = μCp/k

Nusselt Number = hDh/k

IV. RESULT AND CONTOUR

There will be 3 models with microchannel of hydraulic diameter 1mm,0.8mm and 0.6mm.For each model two fluids which are FC72 and Ehthyl glycol are used. These fluids are passed on mass flow rates of 0.001kg/s, 0.002kg/s and 0.003kg/s. So there will be total 18 models simulated in Autodesk CFD software.For every model heat transfer rates, overall heat transfer coefficient, Reynold number, Prandl number and Nusselt number is calculated. Also different graphs and temperature contours are obtained which are as follow.

A. Graphs

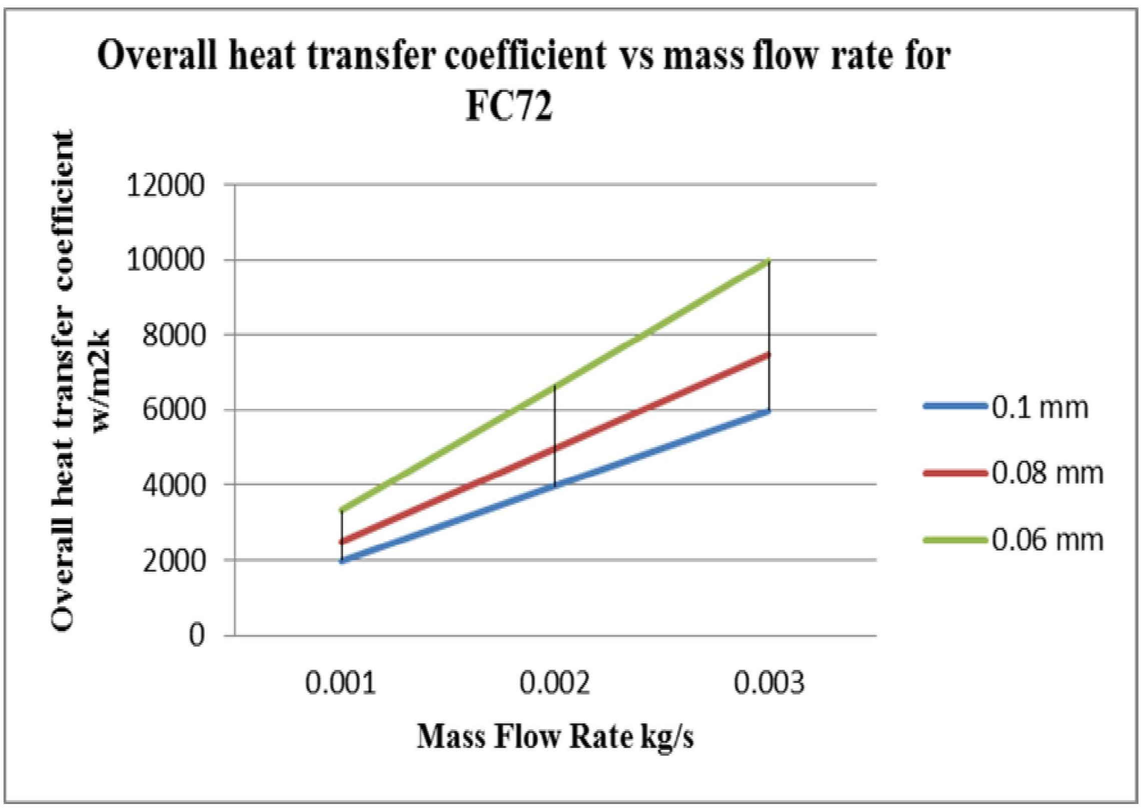

Fig 2 Overall heat transfer coefficient verses mass flow rates for different hydraulic diameter for FC72

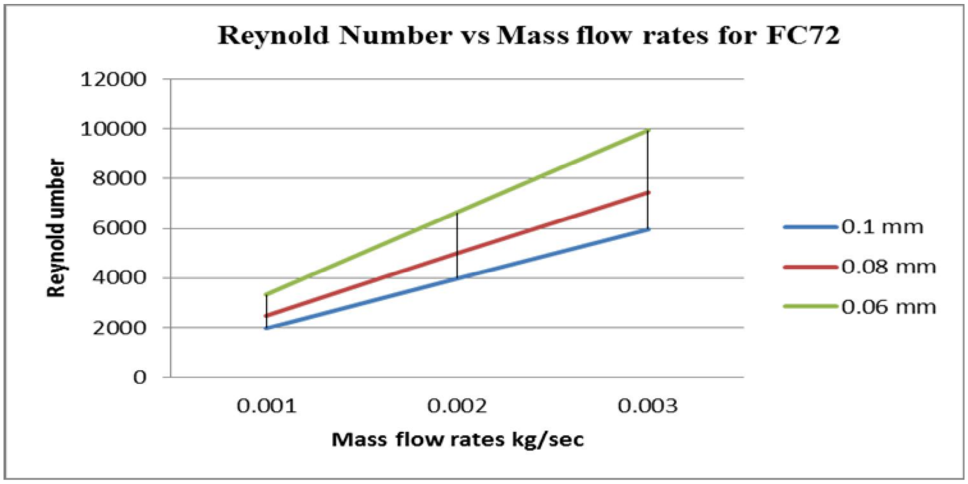

Fig 3 Reynold number verses mass flow rates for different hydraulic diameter for FC72

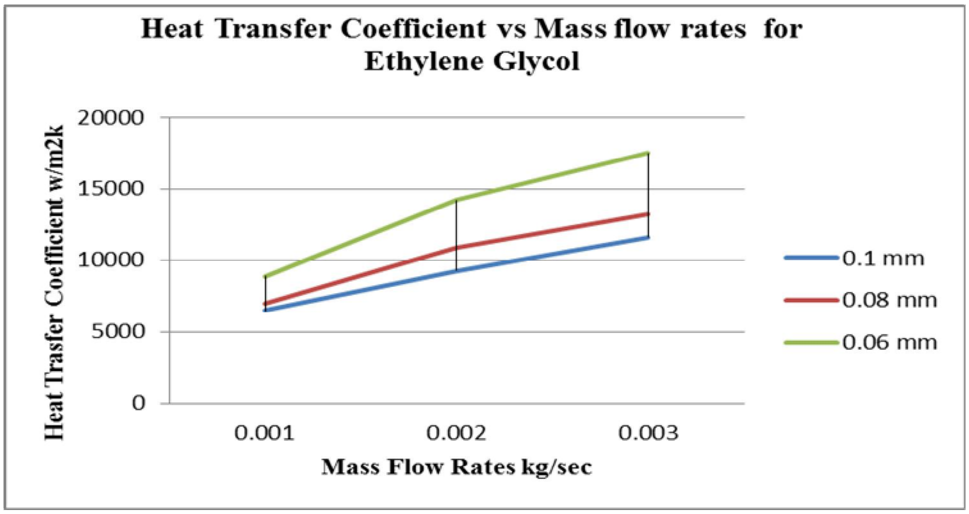

Fig 4 Overall heat transfer coefficient vs Mass Flow rates for different hydraulic diameter for Ethylene Glycol

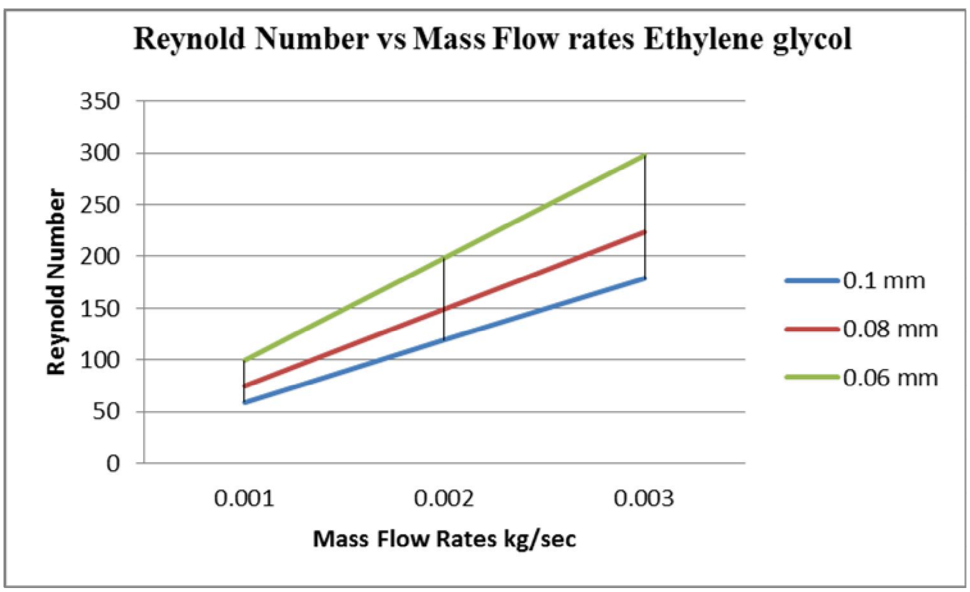

Fig 5 Reynold Number verses Mass flow rates for different hydraulic diameter for ethylene glycol

B. Temperature Contour

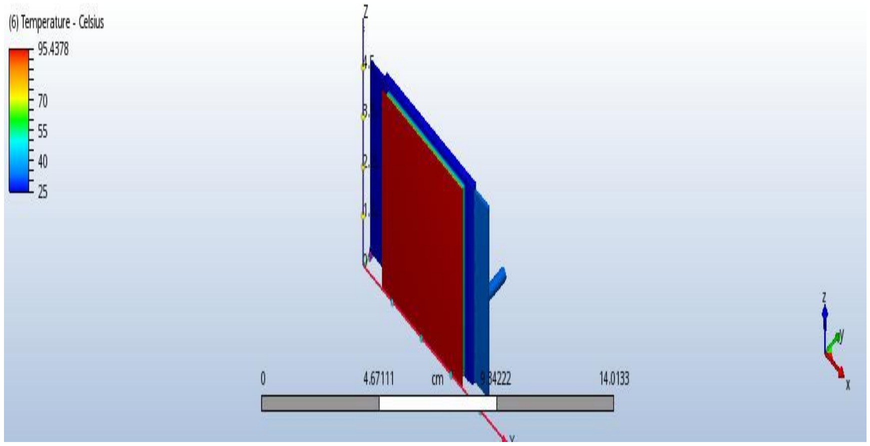

Fig 5 Temperature contour for 0.6mm hydraulic diameter and 0.001 kg/sec mass flow rate for FC72

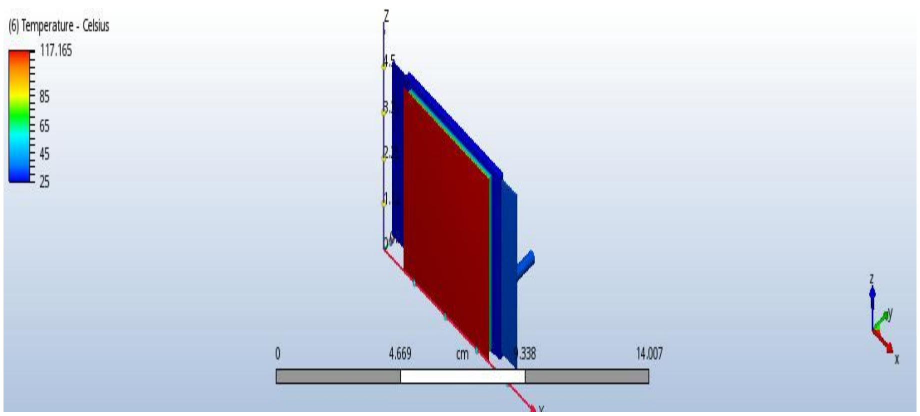

Fig 6 Temperature contour for 0.6mm hydraulic diameter and 0.001 kg/sec mass flow rate for Ethylene Glycol

Fig 2 and Fig 4 shows overall heat transfer coefficient of cooling system increases as hydraulic diameter of Minichannel decreases and with increase in mass flow rate of heat transfer fluid. The Reynolds number is also increasing with decrement in hydraulic diameter and with increase in mass flow rates as shown in Fig 3 and Fig 5. Temperature contour is also shown in fig 5 and fig 6 which shows that the temperature of hot side is 95.4378˚C and 117.165˚C which below the maximum operating temperature of peltier module 140 ˚C.

V. CONCLUSIONS

In this project, CFD analysis of minichannel liquid based thermoelectric cooling system is done by varying hydraulic diameter, mass flow rate and type of heat transfer fluid. It can observe that as hydraulic diameter of minichannel is decreased and as mass flow rate is increased, overall heat transfer coefficient of system is increased. This is because as hydraulic diameter is decreased the heat transfer area through minichannel is increased. By using Nano fluid FC72 and liquid coolant ethylene glycol cooling system can be operated within operating temperature limit of thermoelectric module.

A. Nomenclature

Qc: Heat at cold side of module
Qh:Heat at hot side of module
k:Thermal conductivity in w/mk
Qr: Heat gained by fluid at outlet
μ_v:Dynamic viscosity of fluid
m: mass flow rate of fluid in kg/s
Tout:Outlet temperature of fluid

Tin:inlet temperature of fluid
Tavg:average temperature of fluid
Th:Temperature at hot side of module
Tc:Temperature at cold side of module
Ts:Surface temperature of minichannel
A: Surface area of minichannel in contact with fluid
Cp:specific heat of fluid
Dh:Hydraulic diameter of minichanel
Pr:prandtl number
Nu:nusselt number
Re:Reynold number

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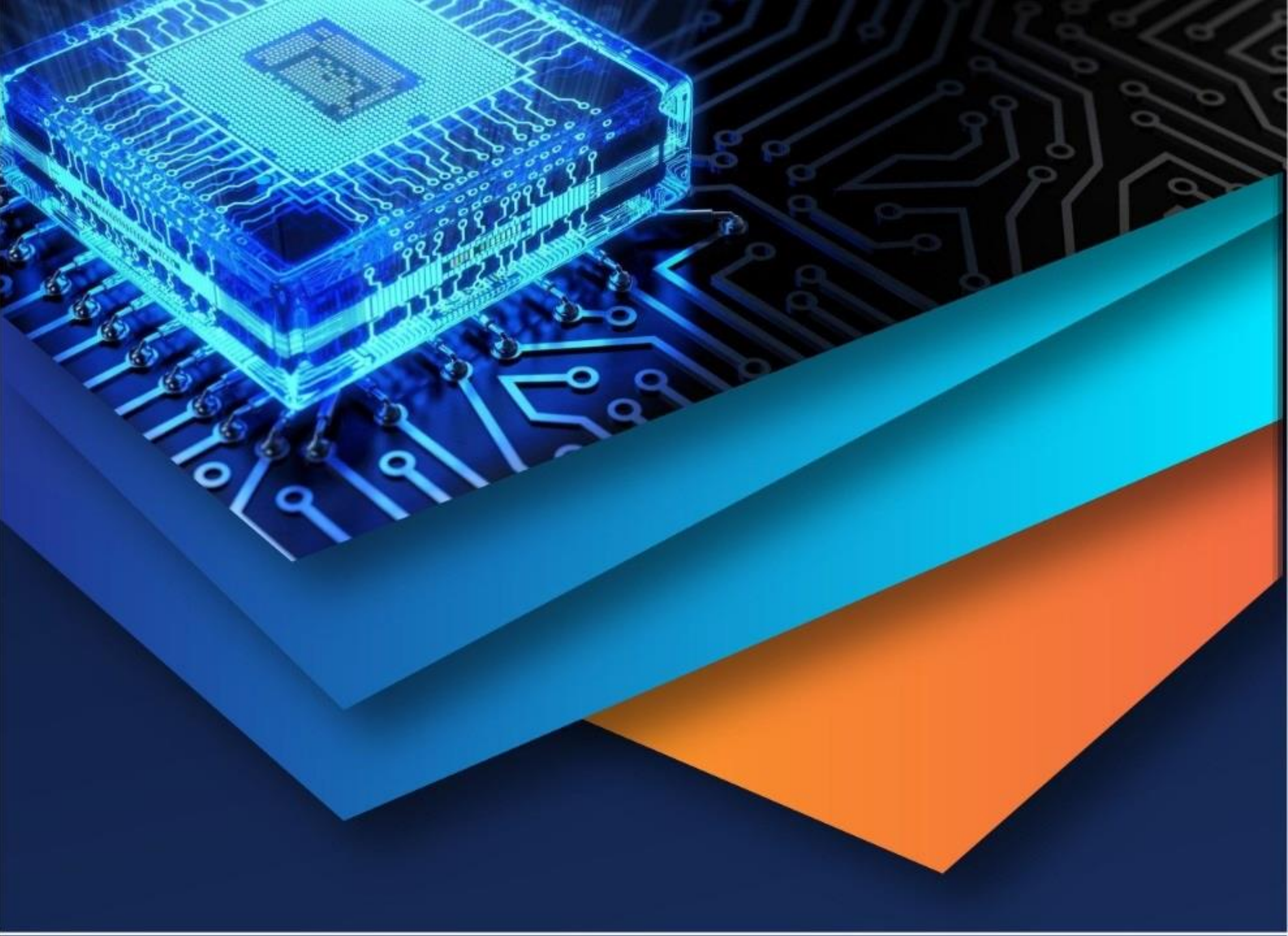

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