DESIGN OF LIQUID COOLING FOR HIGH HEAT DISSIPATION ELECTRONIC BOARDS USING CFD

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ABSTRACT

The current trend of miniaturization and higher performance of electronic devices demands cost-effective cooling solutions capable to dissipate increasingly larger heat fluxes. Several technological challenges exist in the fields of materials, manufacturing, packaging and thermal management of high-power electronics. Conventional cooling technologies, such as natural and forced convection of air in heat sinks, are limited to meet the cooling requirements of new generation high-power electronics boards used for high end applications.

Liquid-cooling is a promising thermal management method, where larger heat transfer coefficients may be achieved due to the intrinsic thermo physical properties of liquid coolants in combination with larger heat transfer areas achieved through small flow passages.

In this work a liquid cooling channel is designed for the high dissipation microprocessor board which is not cooled by conventional fan/air cooling. The liquid channel is designed and optimized using CFD for different parameters like mass flow rate and channel sizes.

KEYWORDS: *liquid cooling, heat dissipation rate, electronic chips, CFD simulation*

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1. INTRODUCTION

The use of electronic equipment in today's modern life is very practically from toys and appliance to high power computers. In the electronic equipment due to the current flow through a resistance its heat mean dissipate large amount of heat. The failure of electronic equipment increases exponentially with temperature. The major causes of electronic failure as shown in figure1.

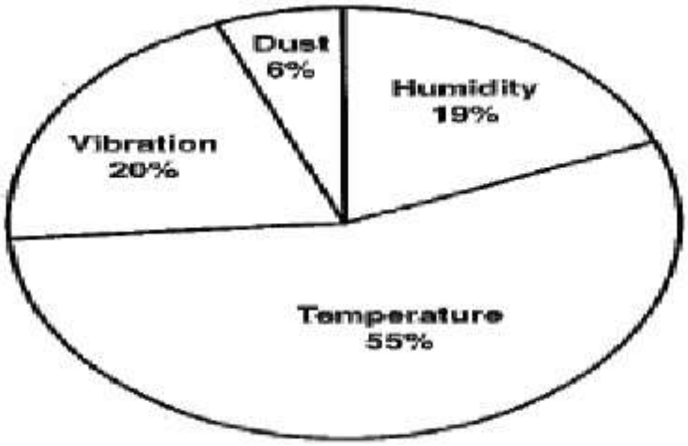


Figure1: Major causes of electronics failure [1].

Due to consumer demand, day by day new updated laptop, computer launched. The updated mean higher processor, improved graphics, security for zero compromise this lead to consume high electrical power, at same time generate more heat while in operation. For instance, Intel launched the 5th Generation Intel® Core ™ i7 Processor. Its fast and multifunctional [2].

The main heat source in laptop computer is CPU (central processing unit) GPU (graphic processing unit) HDD (hard disk drive). Also factor like Poor ventilation system and flow circulation lead overheating laptop. Due to poor design result undesired solid, such as dust on component which causes cause reduction on the heat dissipation rate. If high inlet temperature of intake air temperature as recommendation then overheated. Also overloading of processor due to large program running at the same time is overheated the laptop. Overheating of laptop computers is common especially if operated in rooms or areas with high ambient temperatures. This overheated lead system failure it lead to costly repair or replacement of hardware. Although, by default, a laptop computer is equipped with an internal cooling mechanism, the system is often not capable in maintaining appropriate operating temperature [2].

Damage from this failure is necessary to prevent mean maintain the temperature of the electronic devices within limit. This done by cooling, the various type of cooling is as follow [2].

2. TYPES OF COOLING METHOD

2.1 Air cooling

In electronic devices the air cooling is most familiar method of heat dissipation for thermal management of electronics. In an air cooling, the heat transfers directly from the heat source to the surrounding air. Heat sinks are the most commonly employed, cost effective electronics thermal management hardware in air cooling. In heat sink design mainly three parameters consist, convection type (forced or natural), heat sink geometry, and heat sink material. These parameters determine the maximum rate of heat rejection achieved by the heat sink. In air cooling fan also used instead of heat sink. Using air cooling, as the heat dissipation increases either the temperature or the fan speed must also increase. But temperature increasing is unsuitable because it will reduce reliability of the microprocessor and lead to earlier chip failure also fan speed increasing is undesirable because it’s reduce reliability of fan and increases noise [2].

The benefits of air cooling is

1) Low cost

2) Simplicity of design

3) Increased reliability

2.2 Liquid cooling

Current Applications of Liquid-Cooled Systems Liquid cooling has entered the market as a viable thermal management option. In a liquid-cooled system a secondary fluid acts as a heat spreader to more efficiently remove heat from the source before it is dissipated to the air. Heat generated by electronic components is transferred first to the secondary fluid and then to the air via a heat exchanger. In all cooling methods the final heat rejection will be to the surrounding air. Liquid cooling use began with high power microprocessors and power electronics. As home computers become more powerful, liquid cooling has begun to penetrate that market as well. Liquid cooling provides a quiet, efficient, low-energy method of heat dissipation.

The most basic definition of a cold plate is a thermally conductive metal shell with liquid flowing inside it. One side of the conductive metal shell is placed in contact with the heat source. Heat is conducted through the metal shell and removed through convection by the fluid flowing on the other side of the shell. Variation in cold plate designs occurs mainly in the shape of the conducting shell and the fluid path. The most basic cold plate is a conduction cold plate. In a conduction cold plate, the entire cold plate is a solid piece of metal. Heat is conducted to the edge of the cold plate, where it is removed by convection. In a conduction cold plate no fluid flows through the cold plate. [1][2].

3. CFD

CFD (Computational Fluid Dynamics) is the software. By using CFD solve the simulating the real flow. The CFD process consist three steps pre-processor, solver and post-processor.

1) Pre-processor:

Pre-processor consists of the input of a flow problem to a CFD program by means of an operator friendly interface and the subsequent transformation of this input into a form suitable for use by the solver. Pre processing stage involves fixing the domain, Generation of grids, Selection of physical and chemical phenomena, Definition of fluid properties, and specification of appropriate boundary conditions [3].

2) Solver

There are three distinct streams of numerical solution techniques, Finite difference method, Finite element method and Spectral method. The numerical methods that form the basis of solver perform the following steps.

1. Approximation of the unknown flow variables by means of simple functions.
2. Discretisation by substitution of the approximations into the governing flow equations and subsequent mathematical manipulations.
3. Solution of the algebraic equations.
4. The main differences between the three separate streams are associated with the way in which the flow variables are approximated and with the discretisation process [3].

3) Post-processor:

As in pre-processing a huge amount of development work has recently taken place in the post-processing field. Owing to the increased popularity of engineering workstations, many of which have outstanding graphics capabilities, the leading CFD packages are now equipped with versatile data visualization tools. These include vector plots, line and shaded contour plots, 2D and 3D plots etc [3].

4. VALIDATION OF CFD RESULTS

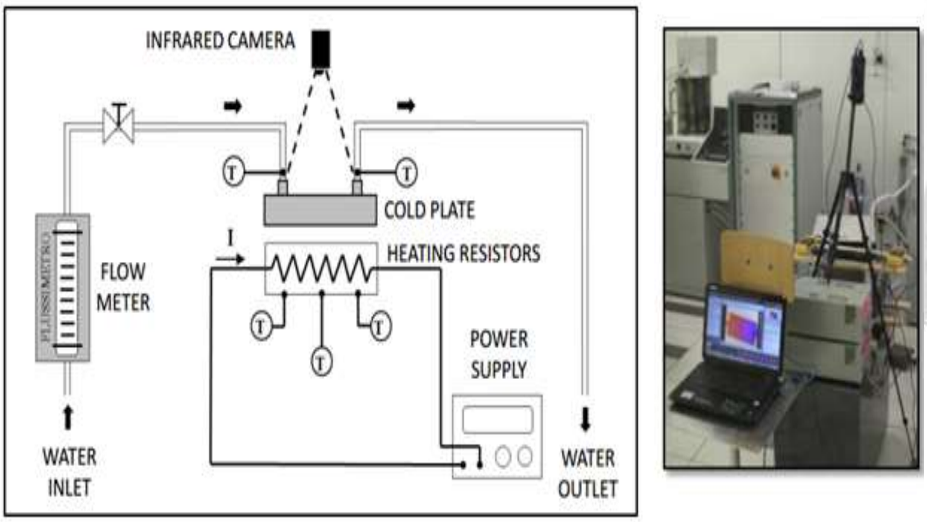
4.1 Experimental Validation

The experimental validation of temperature measurement of cold plate described as follow.

The experimental setup of cold plate temperature measurement is as shown in figure 2.

When power supply is on, coil is heated because of current passes through the coil. Three temperatures is mounted on coil these temperature measured by thermocouple. The heat is transferred from the coil to the cold plate. The inlet temperature and outlet temperature of cold plate is done by infrared camera.

The water enter to water inlet and its pass through flow meter (indicate water quantity) then these water pass through valve (valve control the flow of water) to the cold plate where temperature measured by infrared camera and finally these water to the water outlet. The isometric view of cold plate is shown in figure 3.



Reference: Thermal-Fluid Dynamic FEM Simulation of Advanced Water Cold Plates for Power Electronics, Francesco Giuliani, Nicola Delmonte, Paolo Cova, Italy, 2012

Figure 2: The experimental setup of temperature measurement of cold plate and its practical recording [4].

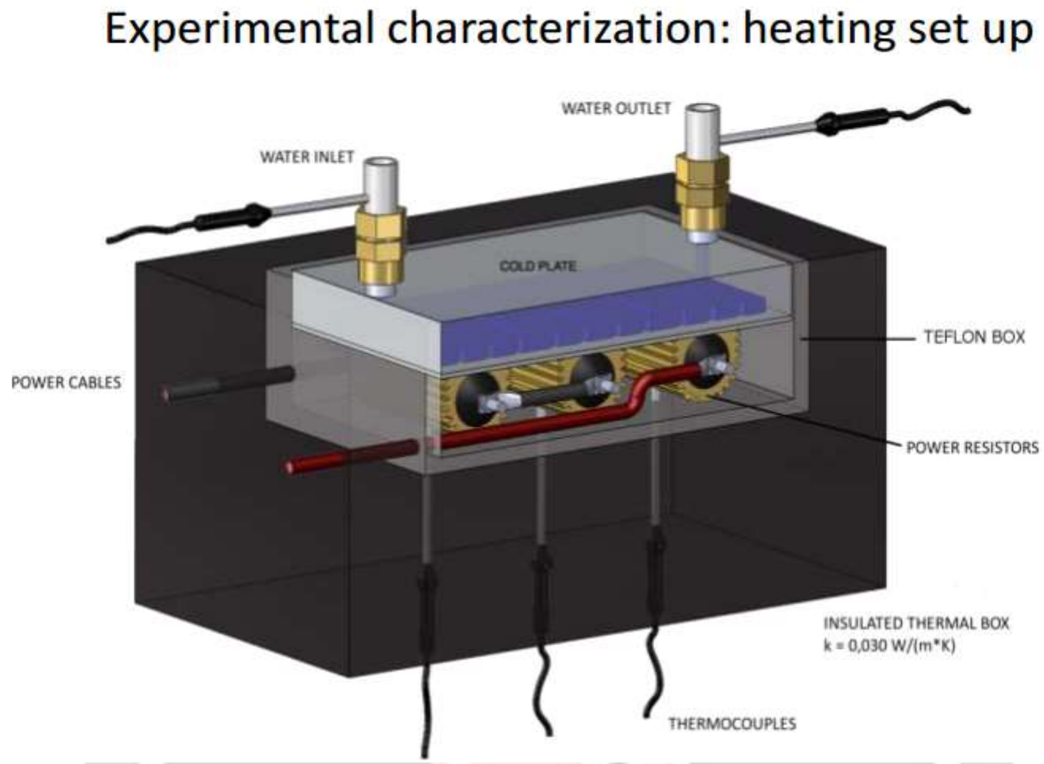


Figure 3: Isometric view of cold plate [4]

4.2 System Configuration

Processor	POSEICO AWCH_L228W140T28(Dual Core)
Cold plate Material	Aluminum
Coolant	Water
Power devices	Pin diodes, IGBT,...
Maximum flow rate	9 lit/min
Maximum power	558 W

Table 1: System configuration [4].

4.3 Thermal Design of Cold plate

Power Dissipation	558 W
Cold Plate dimensions	0.3m x 0.2m x 0.15 m
Liquid	*Pure Water*
Mass flow rate	0.022 kg/sec
Diameter of Channel	0.01 m
Max. design pressure	10 Pa

Table 2: Thermal design of cold plate [4].

4.4 Design of Cold Plate for Laptop Processor

Mean inlet velocity	V_{inlet}	0.436 m/s
Inlet temperature	T_{inlet}	18.8 ^{0}C
Total heat flux	h_{inlet}	28600 w/m^2
External temperature	T_{amb}	31 ^{0}C

→ **558 w**

Table 3: Boundary Condition [4].

Heat convected to the water $(Q_{conv}) = \dot{m}Cp(T_{in} - T_{out})$

Heat dissipation to the surrounding = $Q_{diss} = 558$ W

$$\dot{m} = \rho AV = 1000 \times \frac{\pi}{4} d^2 V$$

$$\dot{m} = 1000 \times \frac{\pi}{4} d^2 \times 0.436$$

Let assume

$(T_{in} - T_{out}) = 6$ (from experiments)

$$558 = 1000 \times 0.436 \times \frac{\pi}{4} d^2 \times 4200 \times 6$$

$$d = 4\ mm$$

$$r = 2\ mm$$

4.5 Liquid Cooling Modeling In Cfd

The construction and working of cold plate in experimental model is described as in previous section. Now the cold plate is designed by using CFD. The model consists of cold plate, processor, inlet and outlet. The cold plate is mounted on processor and inlet and outlet is given for the passing liquid. The processor and cold plate in CFD as shown in figure 4.

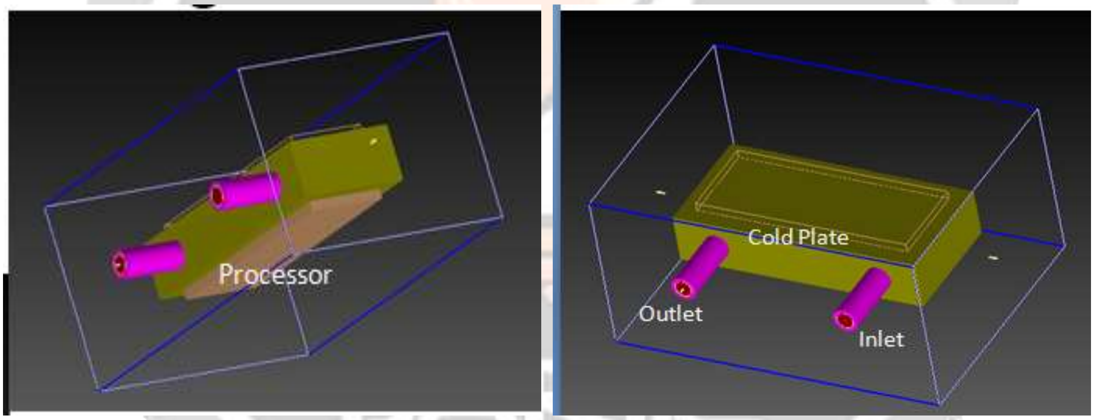


Figure 4: The processor and cooling plate modeling in CFD.

5. VALIDATION WITH EXPERIMENTS

Now find the temperature of processor and outlet temperature cooling plate by using CFD. For finding temperature the boundary condition needed like mean inlet velocity, inlet temperature, external temperature etc. this boundary condition as shown in table 4. The liquid used for cooling the plate is water its pass through tube in the cooling plate. Consider this entire factor, obtained the processor and cold plate outlet temperature. Temperature result obtained by using CFD is shown in figure 5, the outlet temperature of cold plate is 24.7 ^{0}C. Temperature of Processor as shown in figure 6, the processor temperature is 61 ^{0}C. The temperature obtained by using CFD and thermocouple is shown in table 5. This table show that the oulet temperature and delta temperature is approximately same.

Mean inlet velocity	V_{inlet}	0.436 m/s
Inlet temperature	T_{inlet}	18.8 ^{0}C
Total heat flux	h_{inlet}	28600 w/m^2
External temperature	T_{amb}	31 ^{0}C

558 w

Table 4: Boundary Conditions.

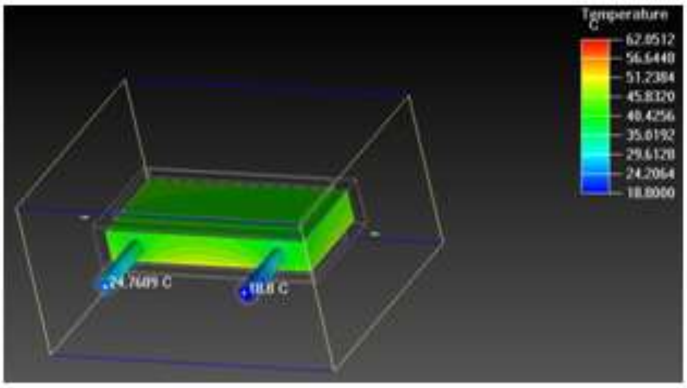


Figure 5: Temperature result of cold plate obtained by using CFD.

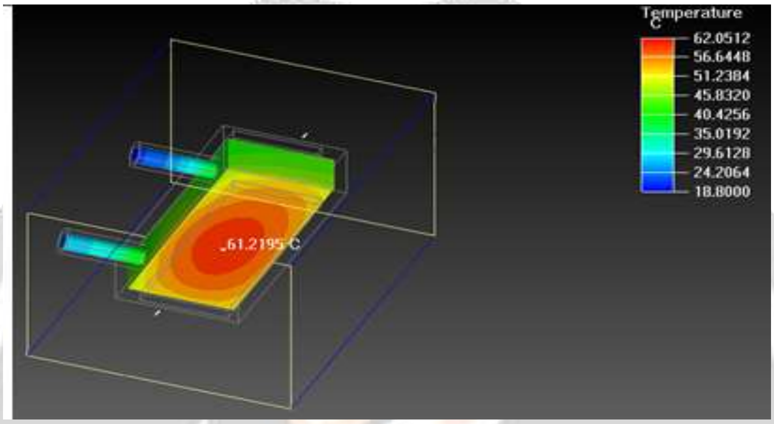


Figure 6: Temperature of Processor.

	T_{inlet}	T_{outlet}	Delta T
Thermocouple	**18.8 C**	**24.8 C**	**6 C**
CFD	**18.8 C**	**24.7 C**	**5.9 C**

Table 5: comparison of temperature results by thermocouple and CFD [4].

6. OPTIMIZATION: DOUBLE PASS LIQUID COLD PLATE

6.1 Optimization of Cold Plate

- The Base case design is optimized for different fluids.
  - Water
  - Ethylene Glycol

6.2 At Different Mass Flow Rate Velocities

- 0.01
- 0.05

6.3 For the given configuration

1) The Maximum Pressure < Design Pressure (10 Pa)
2) The Maximum Temperature < Design Temperature (63 C)

7. OPTIMIZED FOR DIFFERENT FLUIDS.

7.1 DOUBLE PASS, WATER

7.1.1 Double Pass, Water, V = 0.01

The fluid water considered for double pass for flowing in cold plate at the mass flow rate velocity 0.01 m/s. The effect or result is solved by using CFD. The result is on the two basis, one is temperature and other is pressure. Unit for temperature and pressure is ^{0}C and N/m^2 respectively. The inlet temperature of water is 18.8 ^{0}C at the pressure 5.8 N/m^2. This fluid flows in plate through tube. The maximum temperature of plate maintained up to 56.81 ^{0}C and the maximum pressure of plate is 4.4 N/m^2. The temperature at the end of tube is 33.91 ^{0}C at the pressure of -0.024 N/m^2. The CFD result as shown in figure 7 and 8.

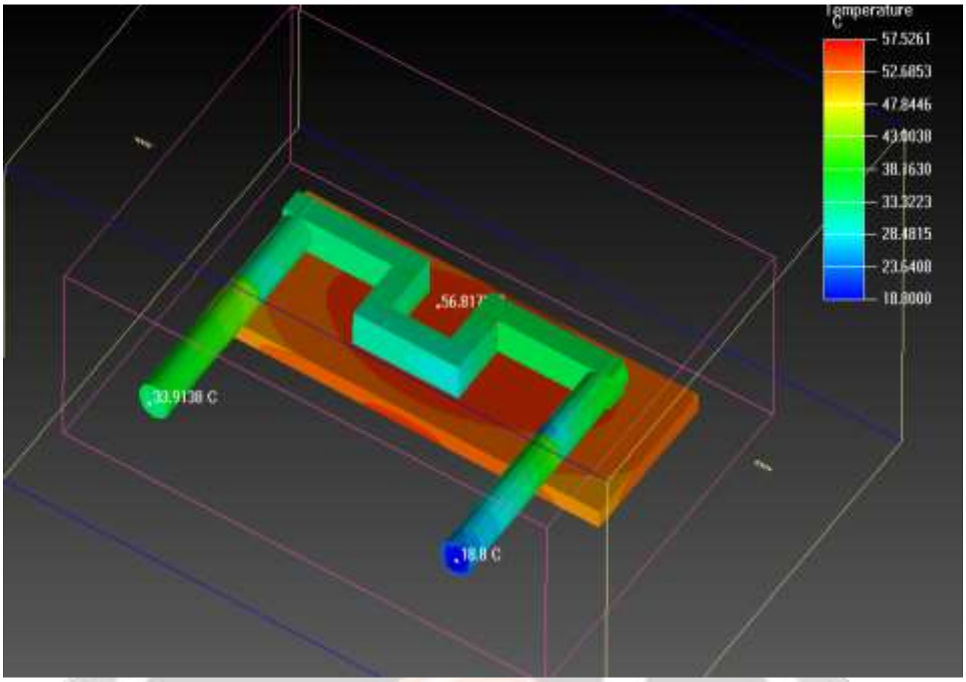


Figure 7: Temperature result by using CFD for double pass water at the mass flow rate velocity 0.01 m/s.

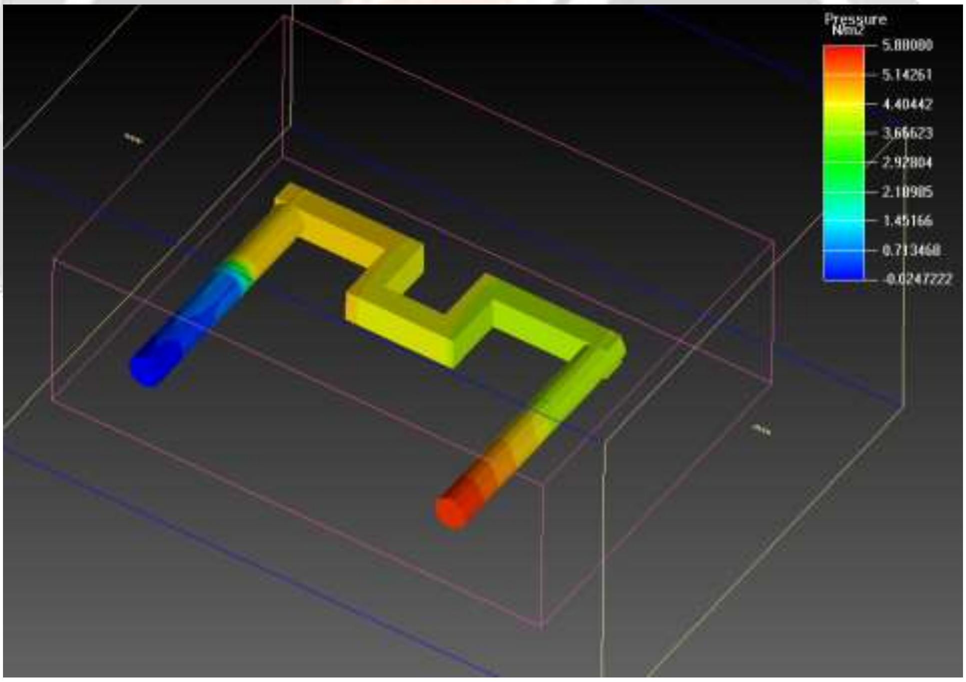


Figure 8: Pressure result by using CFD for double pass water at the mass flow rate velocity 0.01 m/s.

7.1.2 Double Pass, Water, V = 0.05

The fluid water considered for double pass for flowing in cold plate at the mass flow rate velocity 0.05 m/s. The effect or result is solved by using CFD. The result is on the two basis, one is temperature and other is pressure. Unit for temperature and pressure is ^{0}C and N/m^2 respectively. The inlet temperature of water is 18.8 ^{0}C at the pressure 9.69 N/m^2. This fluid flows in plate through tube. The maximum temperature of plate maintained up to 44.06 ^{0}C and the maximum pressure of plate is 7.26 N/m^2. The temperature at the end of tube is 22.70 ^{0}C at the pressure of -0.020 N/m^2. The CFD result as shown in figure 9 and 10.

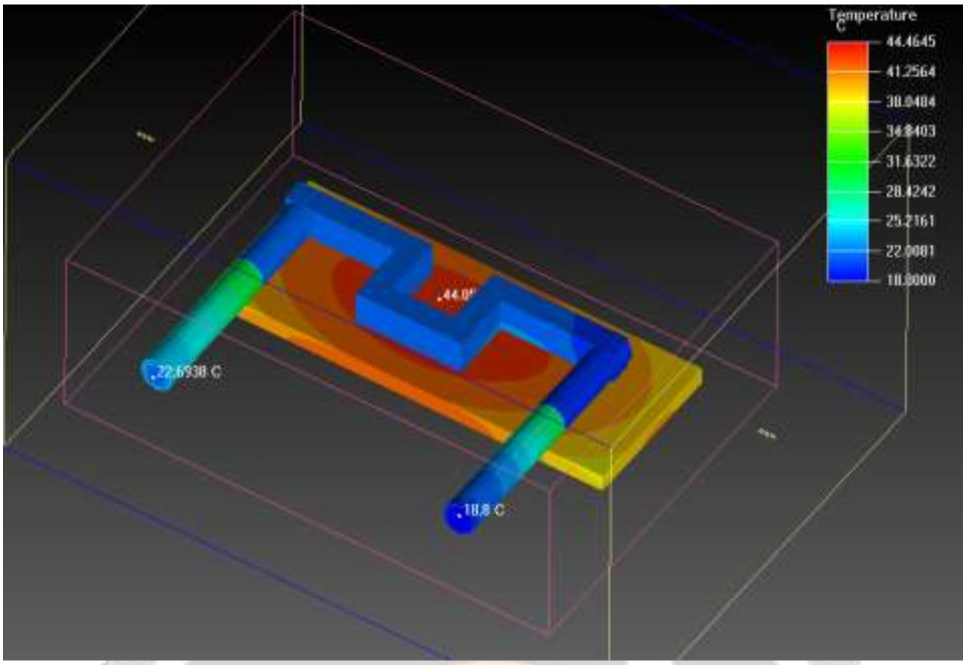


Figure 9: Temperatures result by using CFD for double pass water at the mass flow rate velocity 0.05 m/s.

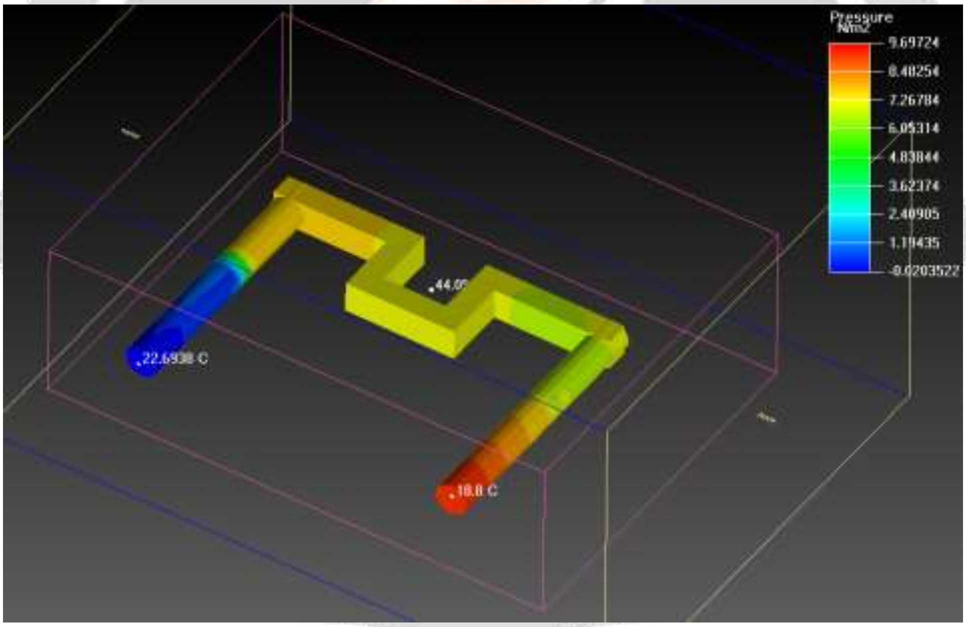


Figure 10: Pressure result by using CFD for double pass water at the mass flow rate velocity 0.05 m/s.

7.2 DOUBLE PASS E. GLYCOL

7.2.2 Double Pass E. Glycol, V = 0.01

The fluid ethylene glycol considered for double pass for flowing in cold plate at the mass flow rate velocity 0.01 m/s. The effect or result is solved by using CFD. The result is on the two basis, one is temperature and other is pressure. Unit for temperature and pressure is ^{0}C and N/m^2 respectively. The inlet temperature of water is 18.8 ^{0}C at the pressure 4.8 N/m^2. This fluid flows in plate through tube. The maximum temperature of plate maintained up to 58.29 ^{0}C and the maximum pressure of plate is 2.64 N/m^2. The temperature at the end of tube is 36.95 ^{0}C at the pressure of -0.051 N/m^2. The CFD result as shown in figure 11 and 12.

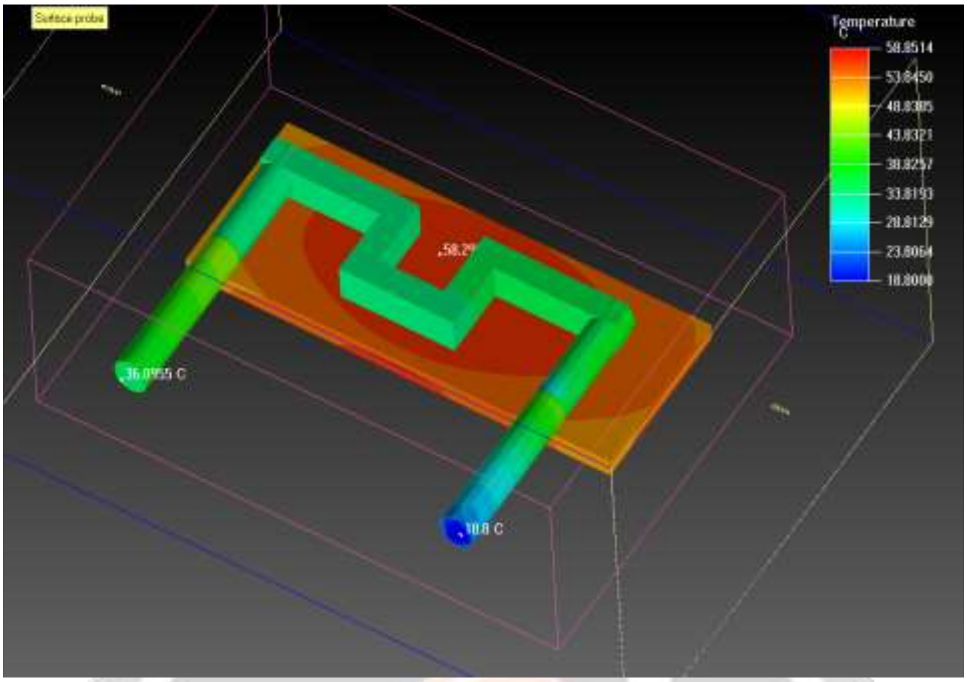


Figure 11: Temperatures result by using CFD for double pass ethylene glycol at the mass flow rate velocity 0.01 m/s.

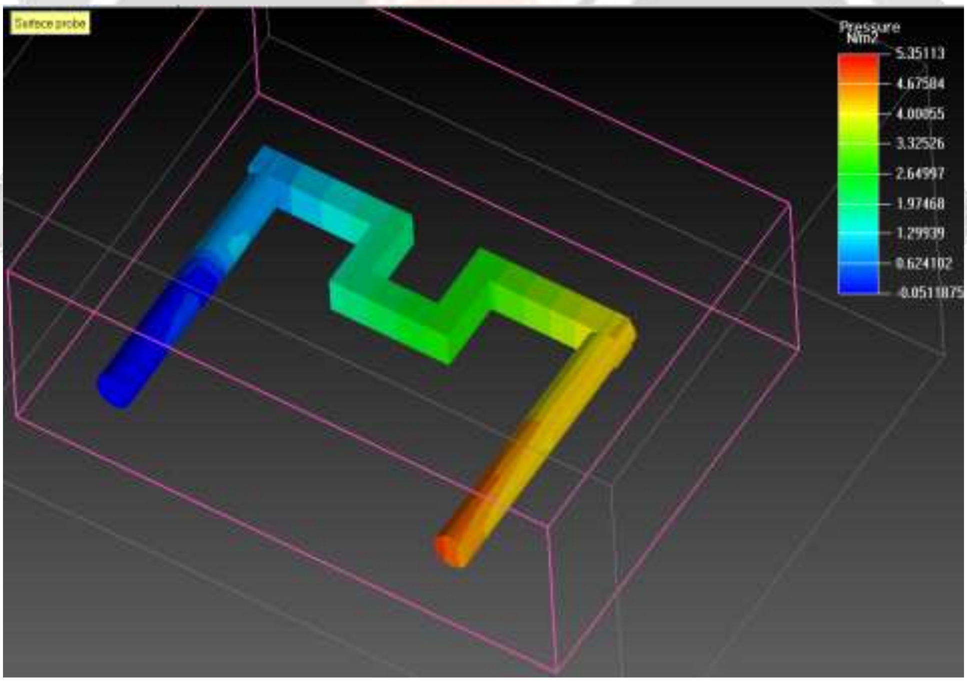


Figure 12: Pressure result by using CFD for double pass ethylene glycol at the mass flow rate velocity 0.01 m/s.

7.2.2 Double Pass E. Glycol, V = 0.05

The fluid water considered for double pass for flowing in cold plate at the mass flow rate velocity 0.05 m/s. The effect or result is solved by using CFD. The result is on the two basis, one is temperature and other is pressure. Unit for temperature and pressure is ^{0}C and N/m^2 respectively. The inlet temperature of water is 18.8 ^{0}C at the pressure 7.48 N/m^2. This fluid flows in plate through tube. The maximum temperature of plate maintained up to 46.52 ^{0}C and the maximum pressure of plate is 4.98 N/m^2. The temperature at the end of tube is 22.03 ^{0}C at the pressure of -0.025 N/m^2. The CFD result as shown in figure 13 and 14.

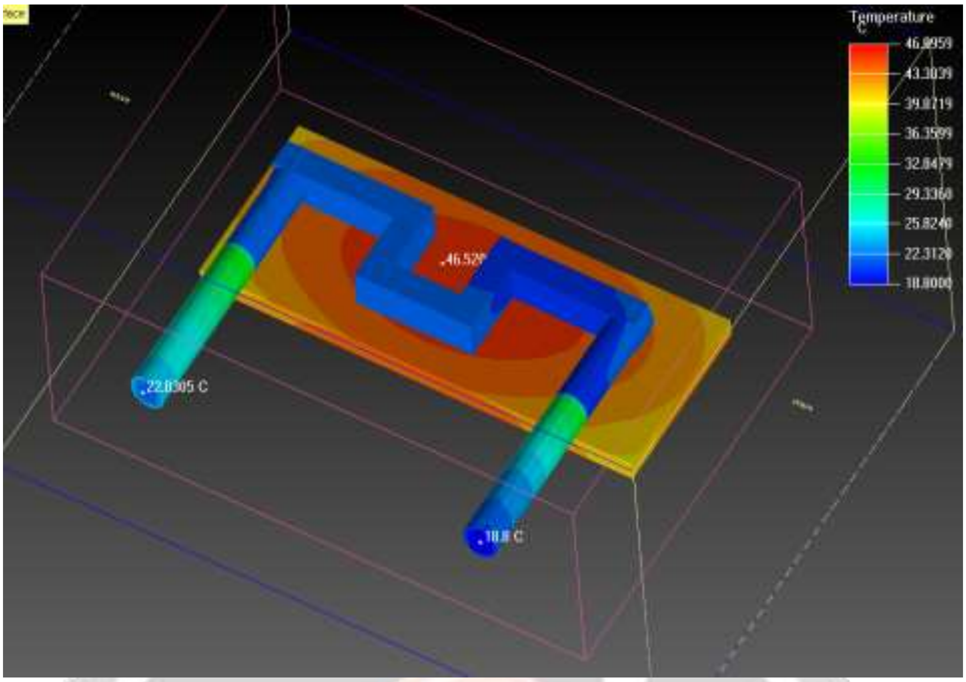


Figure 13: Temperatures result by using CFD for double pass ethylene glycol at the mass flow rate velocity 0.05 m/s.

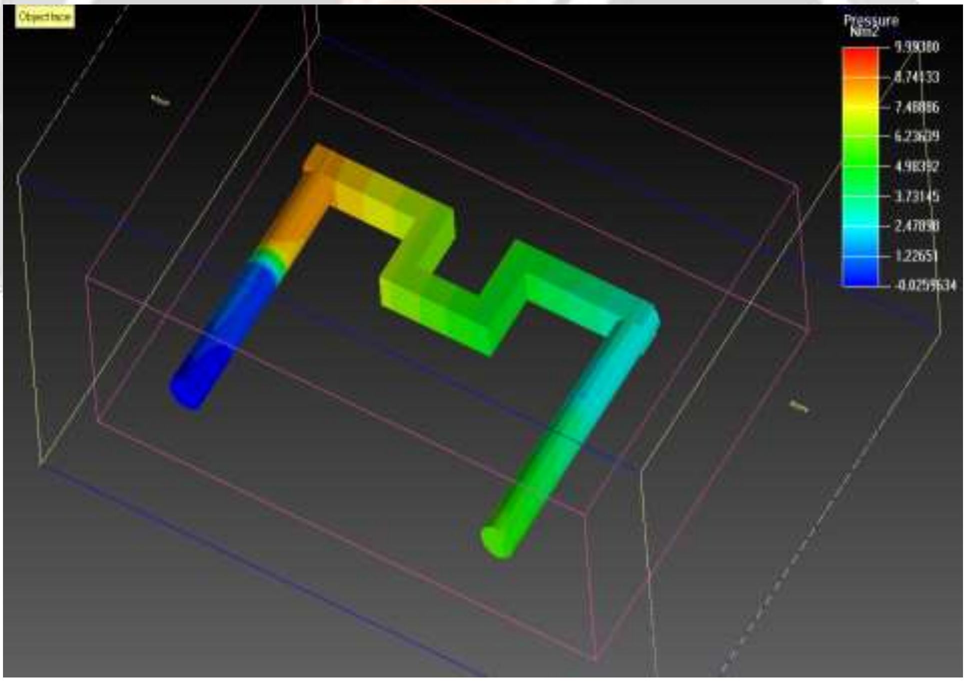


Figure 14: Pressure result by using CFD for double pass ethylene glycol at the mass flow rate velocity 0.05 m/s.

7.3 Comparative Study for Double Pass

The comparison of double pass of Liquid Cooling for different liquid at different mass flow rates as shown on table 6. The condition for safe design is the Maximum Pressure < Design Pressure (10 Pa) and The Maximum Temperature < Design Temperature (63 C). If this condition fails then design fail. The maximum temperature and the maximum pressure for water and ethylene glycol is under the limit mean the design is safe are shown in table 6. From table it’s clear that the lower temperature of cold plate is maintained for water at the mass flow rate 0.05 m/s as compare to the other fluid at different fluid.

	Water		**E.glycol**	
	0.01	**0.05**	**0.01**	**0.05**
Max. T	**57**	**44.6**	**58.9**	**46**
Max. P	**5.8**	**9.69**	**5.3**	**9.9**

Table 6: Results comparison of double pass of Liquid Cooling for different liquid at different mass flow rates.

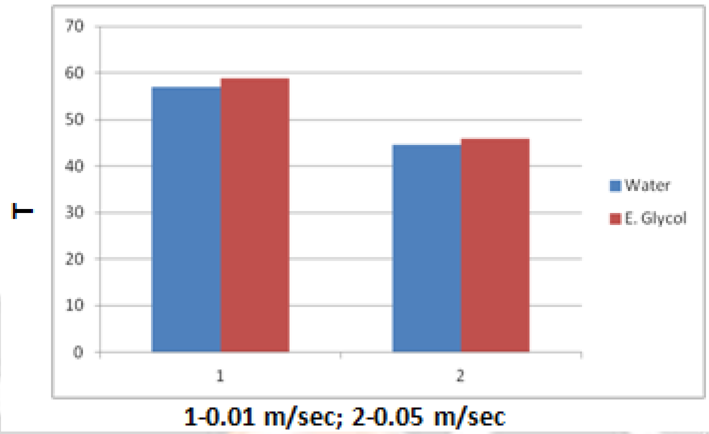


Figure 15: Temperature comparison of water and E. glycol for double pass

8) CONCLUSION

The liquid cooling is maintained at the lower temperature as compared to the air cooling. The various liquids are available but in this paper, water and ethylene glycol are considered. The design of cold plate of double pass for water and ethylene glycol was taken. The solution is obtained by using CFD. The solution is concluded that the lower temperature of cold plate is maintained by water at the mass flow rate 0.05 m/s as compared to the other fluids at different mass flow rates.

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