Experimental and Computational Study of a Closed Loop Cooling System for High Performance Electronics

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Abstract

This paper is on the experimental and numerical studies of a closed loop liquid cooling system for a high performance electronic device. The closed loop cooling system consists of a cold plate, a heat exchanger, a pump, a reservoir, and hoses connecting the components. Computational fluid dynamics (CFD) models of the cold plate and the heat exchanger have been developed to study the heat transfer and fluid flow in these devices. Experimental and CFD studies have been conducted to understand the heat transfer and fluid flow in the cold plate and the heat exchanger and their influence on the electronics device, and to study the effect of coolant flow rate on the dissipation of heat in the closed loop system.

Introduction

Increasing demand for smaller, more portable and higher performance devices increases power density in electronics devices. Thermal management is essential in high performance electronics to remove heat generated by the devices and thus improve reliability and enhances performances. The tremendous growth in electronic equipment demands innovative solutions to the new challenges of thermal management. Active cooling systems have been installed in the high performance electronics systems to remove the excessive heat. Traditionally fans and heat sink fans are used as means of air cooling systems, but fan noise level increases with high performances electronics. Liquid cooling can be more effective as compared to air cooled system due to its lower budget and quieter application. A Closed loop cooling system can easily meet the demands of high heat loads, low thermal resistance and reduced noise. Using liquid as a cooling method may to lead to vibration free and smooth operation system.

Experimental Study of a Closed Loop Cooling system

The current setup consists of a heat source representing a CPU processor, an aluminum cold plate, and a BXQINLENX 600L/H 19W DC12V CPU Cooling Heat Exchanger. The heat exchanger has four components, including a water tank, a pump, a water cooling radiator, and a radiator fan. The cold plate is placed on the heat source and its inlet is connected with the water tank and its outlet is connected with the radiator. Water running in the cold plate removes heat from the heat source and exits at an elevated temperature. The heated water is then cooled by the radiator. The water circulation in the system is driven by the pump.

The radiator has a fan attached to it to provide forced air flow through the radiator fins. Since the fan was broken at the time of experiment, a temporary fan was used to provide forced air flow. Water tank is filled to its full capacity and the pump is connected to a 12V DC supply source and the heat source is connected to a 30V DC supply source. Cold Plate is placed on top of a heat source which has a heating capacity of 450 F. DC supply source of 27.3V and 1.04A is provided to the heating source. Two K -type sensors are installed in the inner tubes of the inlet and outlet of the Cold Plate. The temperature reading is at an interval of 5 mins over a period of 2-hour time. The temperatures measured of water entering and exiting the Cold Plate is plot in Fig. 2. The heat source generates 23W of heat and is removed by the liquid cooling system. The initial temperature of water is 21.5oC and is gradually increase as it picks up heat at the heat source through the cool plate and dissipate heat through the heat exchanger. The temperature approaches a steady state after two hours.

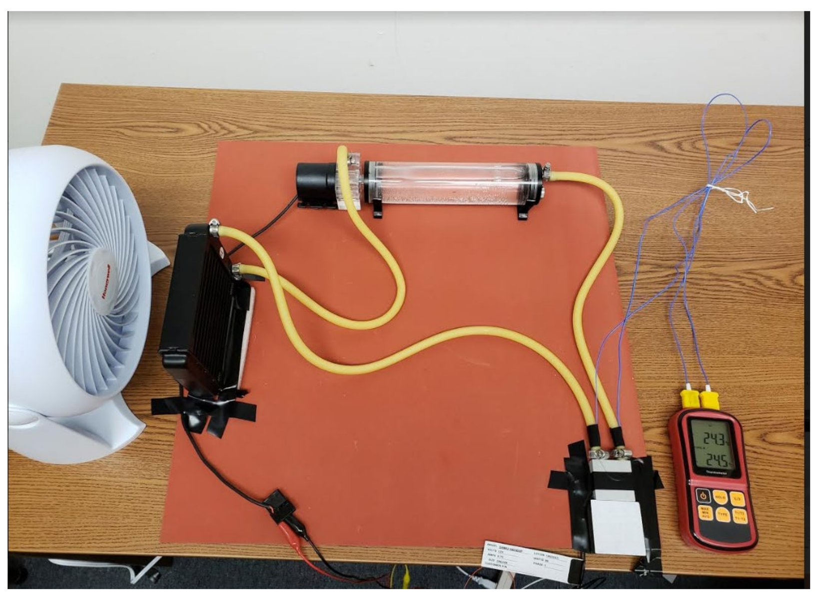

Fig. 1 Experimental setup

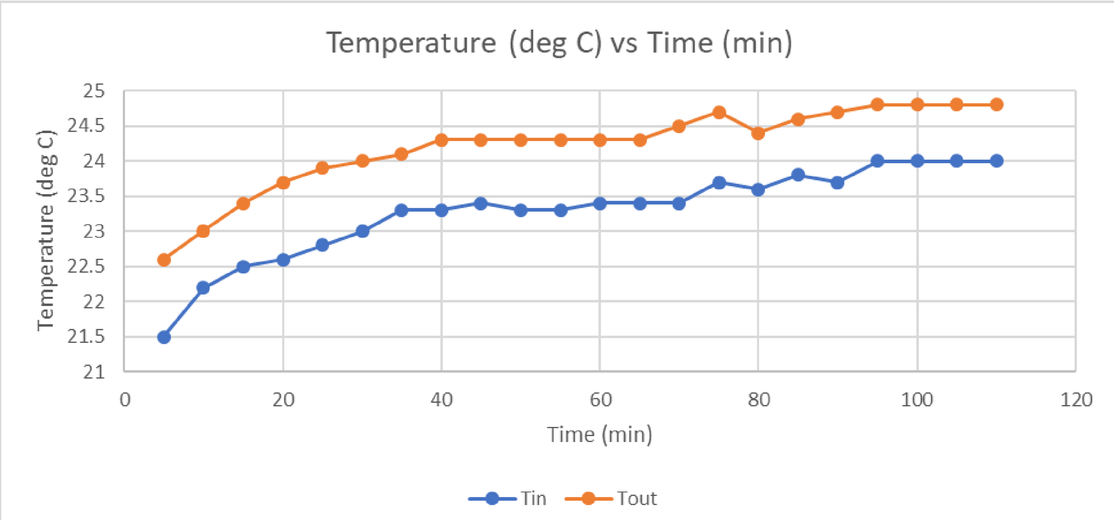

Fig. 2 Water temperatures measured at the inlet and outlet of the cold plate

Computational study of Cold Plate and Radiator

Computational fluid dynamics study is conducted on both a cold plate and a radiator with the similar design and dimensions in the experiment. As shown in Fig. 3, the cold plate is aluminum block with dimensions 40mm ×40 mm×11.8 mm and has M shaped circular flow channels of 6mm in diameter. The heat exchanger has 12 flat tubes with 0.31 in gap connected with manifolds at each end. The baffles in the manifolds direct the flow patter to be a M shape as well. Plate fins are stacked between the gaps of the flat tubes to enhance heat transfer.

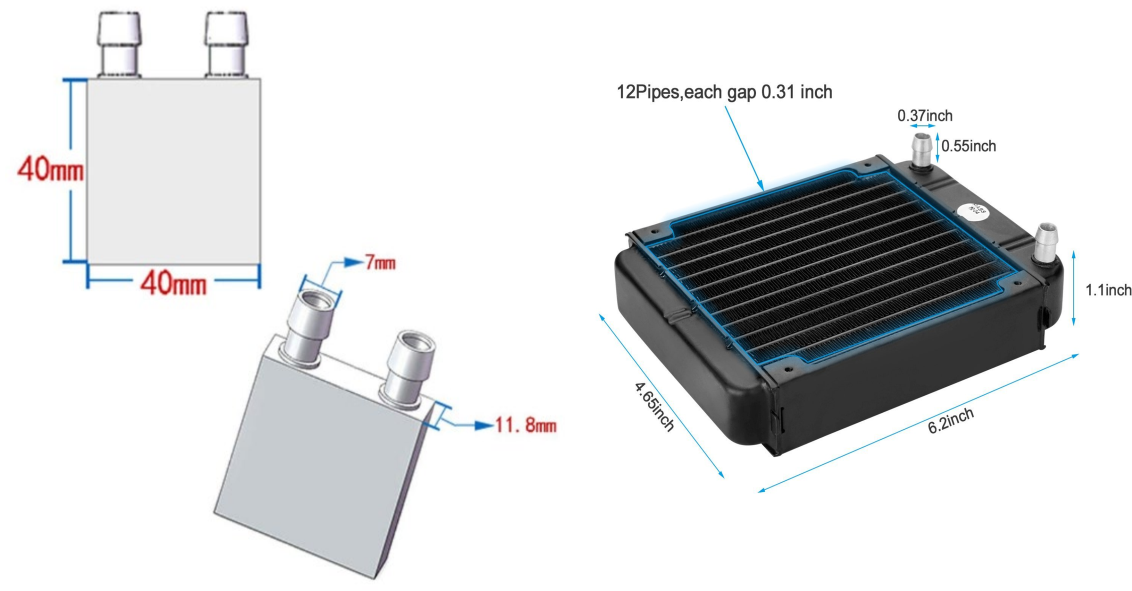

Fig. 3 Dimensions of the cold plate and the heat exchanger

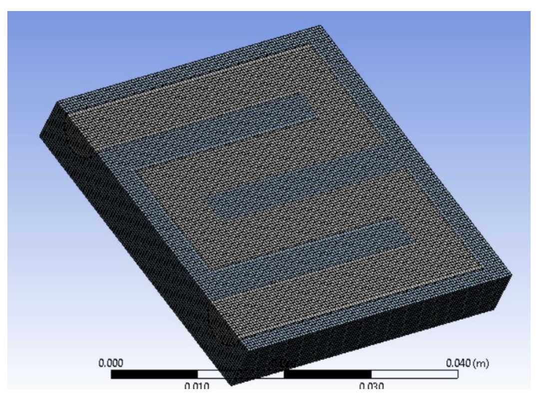

Fig. 4 Cut mesh of the cold plate

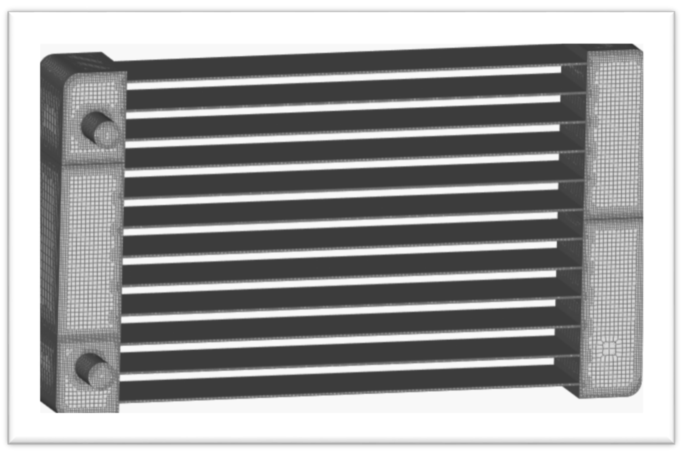

Fig. 5 Surface mesh of the heat exchanger

Table 1 Mesh Counts

	Cold plate	Radiator
Nodes	459155	4485185
Elements	427367	3350691

A conjugate heat transfer model of the cold plate model is developed in ANSYS Fluent. The model includes two domains and heat transfer in the solid and fluid flow and heat transfer in the liquid. A single fluid domain is developed in Simscale to study the heat transfer and fluid flow in the fluid channel. Due to the complex geometry of the heat exchanger, the finned thin flat tube walls are modeled as an external heat transfer coefficient. Figure 4 shows a cut section mesh of cold plate and Fig. 5 shows the surface mesh of the heat exchanger. The total mesh and node counts are listed in Table 1. These models are used to study the flow rate requirement in cooling an Intel® Xeon® Processor 5080, which has a Thermal Design Power of 130W and must maintain its case temperature below 78^{o}C.

Computational study of Cold Plate

Figures 6 and 7 show respectively the pressure contour and temperature contour at the middle cross section of the Cold Plate when the inlet velocity is 0.1 m/s. It shows water enters at higher gage pressure of 57.5 Pa and lower temperature of 300K and exits with lower gage pressure of 0 Pa and higher temperature of 355K. As it flows through the cold plate channels, it has a the pressure drop of 57.5 Pa and a temperature increase of 55K. The highest temperature at the cold plate surface is 99^{o}C, which exceeds the allowed case temperature of 78^{o}C. A parametric study is carried out and the results are plotted in Figs. 8 and 9.

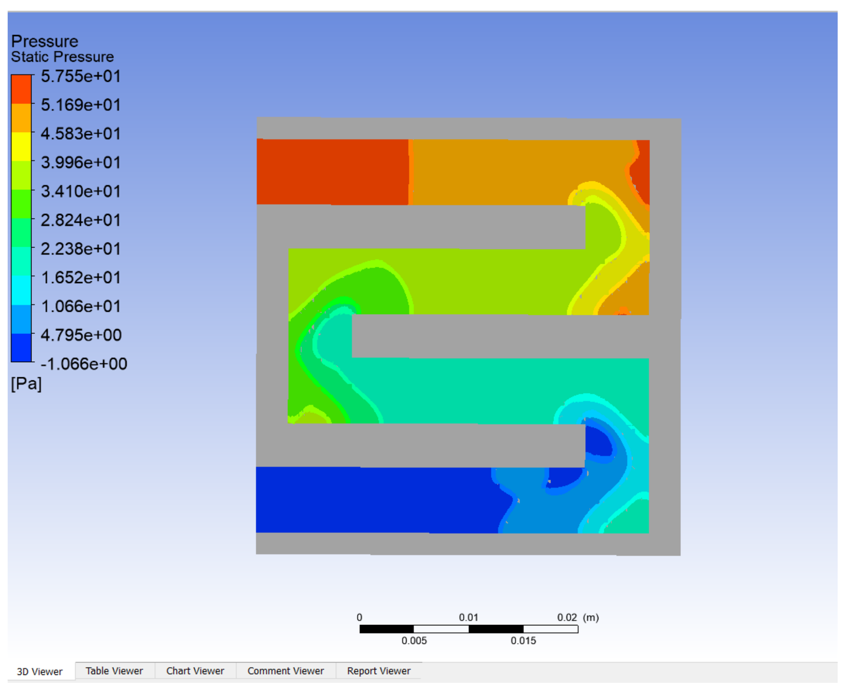

Fig. 6 Temperature contour of cold plate

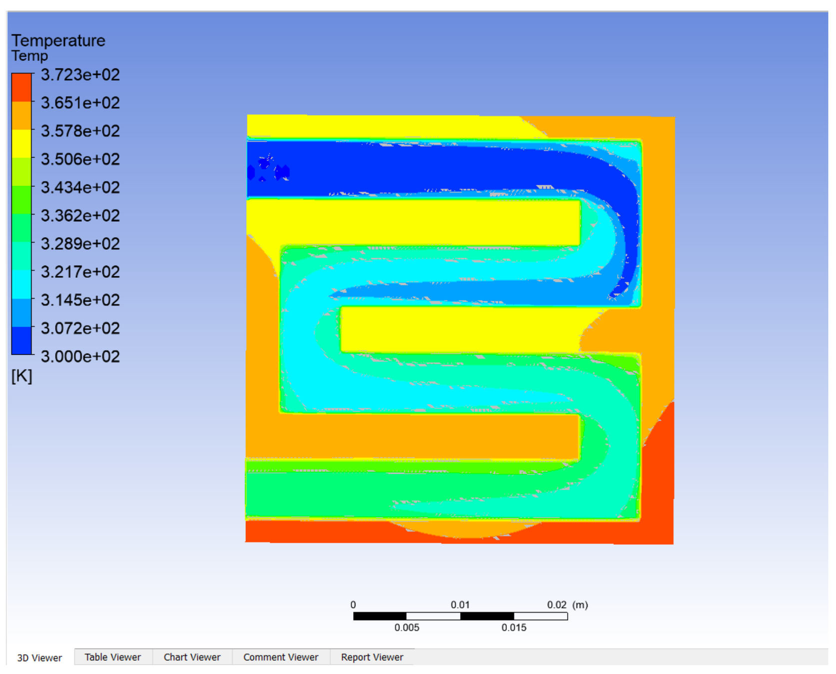

Fig. 7 Pressure Contour of cold plate

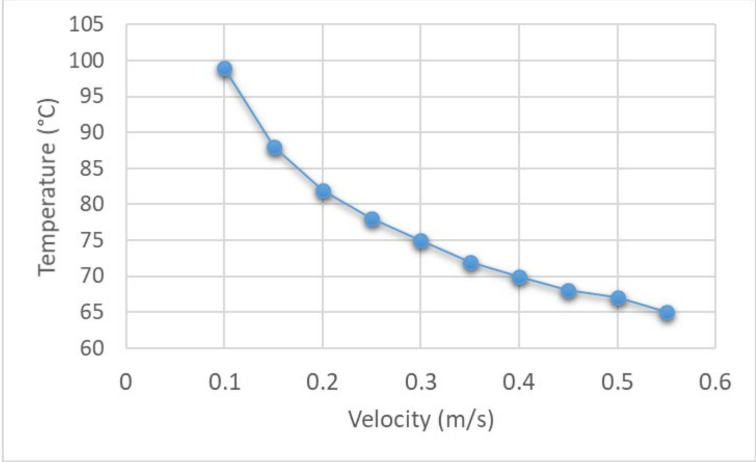

Fig. 8 Maximum surface temperature at various flow rate in the cold plate

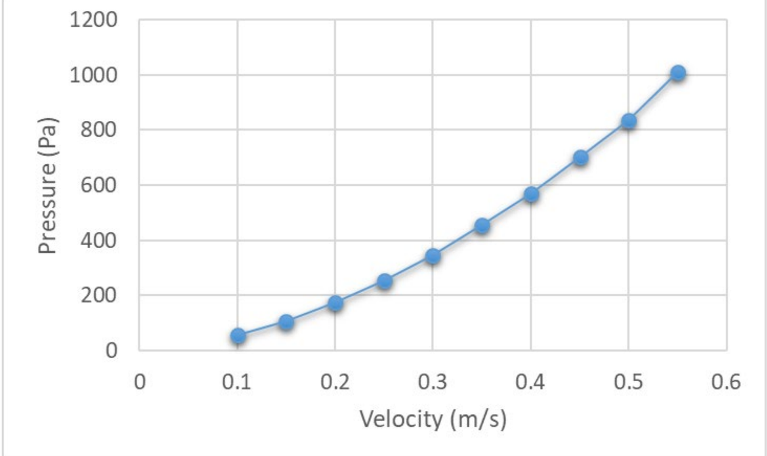

Fig. 9 Pressure drop at various flow rate in the cold plate

Computational study of Heat Exchanger

Figures 6 and 7 show respectively the temperature contour and pressure contour at the channel surface of the heat exchanger with the velocity of 0.5 m/s . It can be seen that water enters at higher temperature of 297.95K and exits at a lower temperature of 297.35K. As it flows through the heat exchanger channels, it has a temperature drop of 0.60K and a pressure drop of 42.3 kPa. The parametric study results are plotted in Figs. 12 and 13.

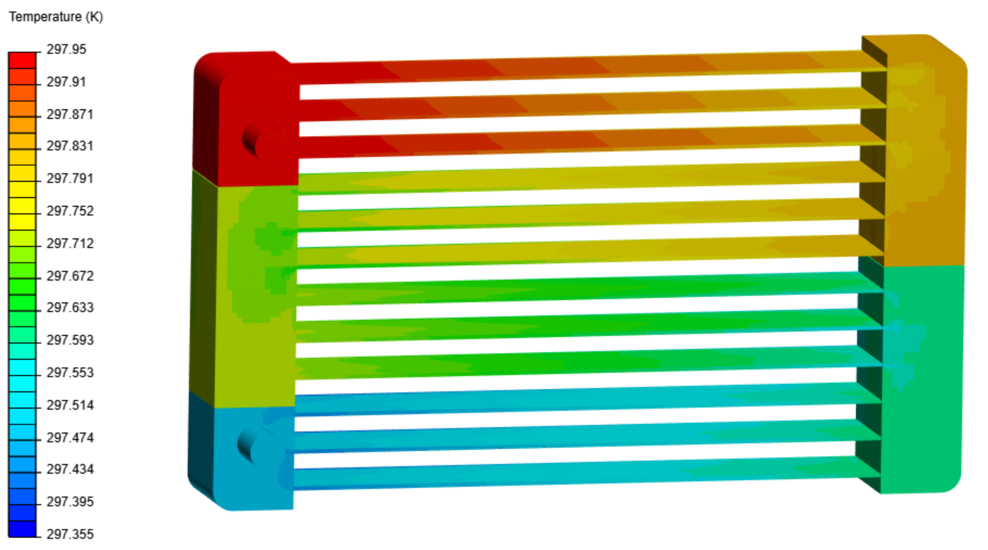

Fig. 10 Temperature contour in the heat exchanger

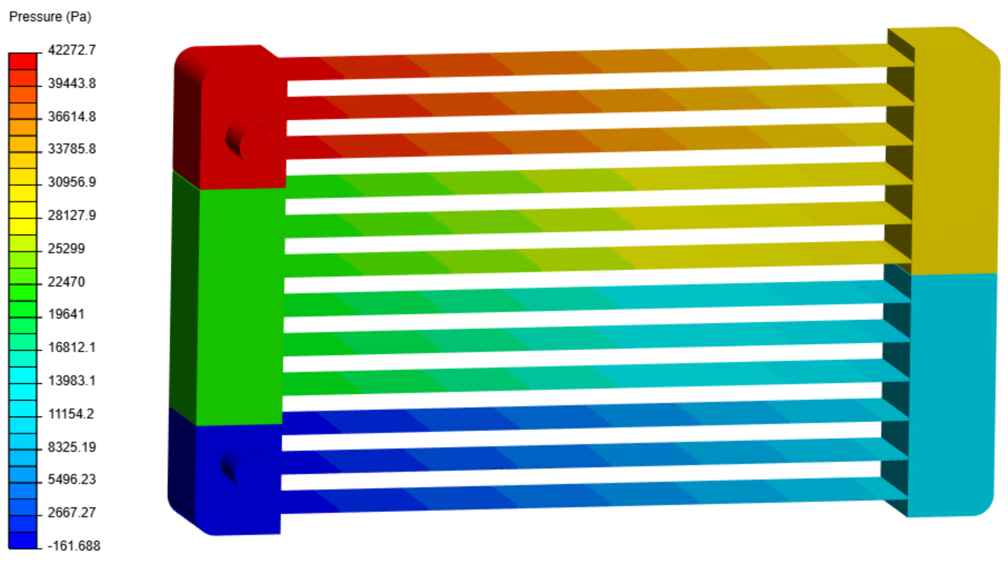

Fig. 11 Pressure contour in the heat exchanger

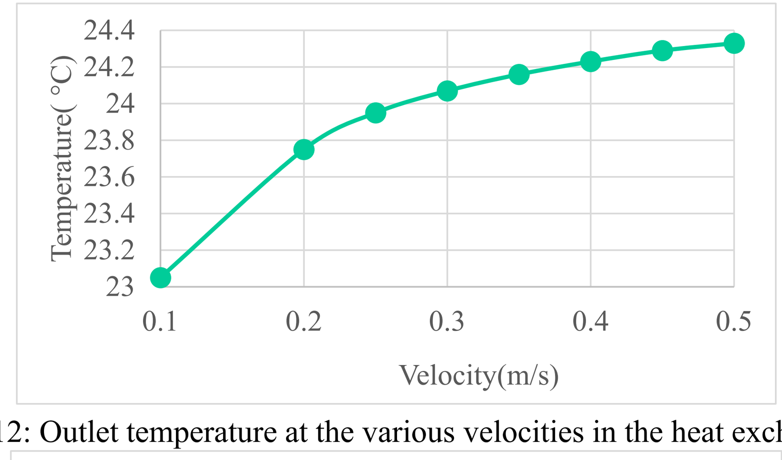

Fig. 12: Outlet temperature at the various velocities in the heat exchanger

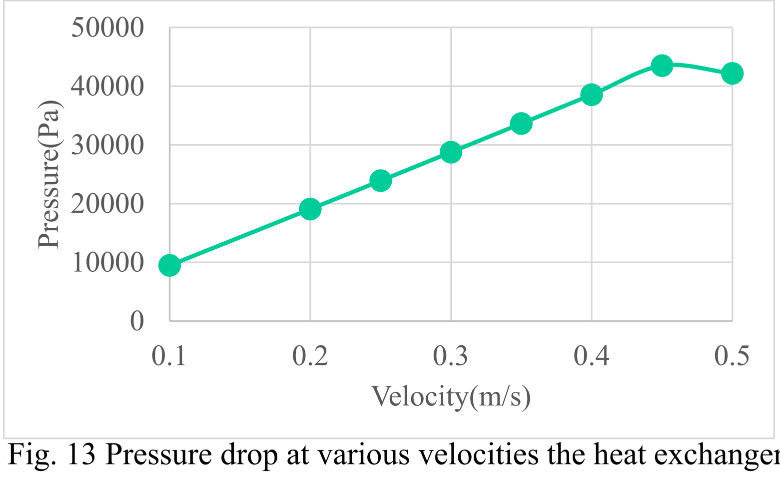

Fig. 13 Pressure drop at various velocities the heat exchanger

Conclusions and Future Work

Experimental results have shown the temperature history in a closed loop cooling system. CFD simulations has been carried out on two critical components in the system. The numerical simulations have provided insights on the heat transfer and fluid flow in the cold plate and the heat exchanger and their influence in the system. The parametric study results can be used to build 1D models for a system dynamics model in the future. These models can also be used to for cold plate and heat exchanger design and optimization. In this simulation water is used as coolant. Further work can involve exploring different fluids.