LIQUID COOLING

> Cold Plates Performance

radian
THERMAL PRODUCTS

WHITE PAPER
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This paper compares the predicted performance of two cold plate designs for a given liquid cooling system.

CFD simulation is used to visualise the temperature and pressure drop profiles in both designs and provide comparative predicted results.

1. THE NEED FOR LIQUID COOLING

Due to the increase in the thermal density of microchips, the conventional heatsink and fan solutions need to increase in size to remove the required amount of heat, for long term component operation. This increase in heatsink and fan size significantly reduce the available component PCB area.

Given that water has four times the specific heat capacity of air, a liquid cooling solution made up of a plate with internal water channels to take heat directly from the thermally dense components becomes a viable solution. Consequently, a Cold Plate has the capability to handle significantly higher power, in regions of ~ 6kW, compared with air cooling which would typically handle ~1-2kW with the aid of 2-phase passive cooling devices and high airflow.

The overall Liquid cooling system is made up of a Cold Plate, Pump & Heat Exchanger, as shown in Figure 1 below.

The Pump and Heat exchanger are matched to give the optimum Cold Plate performance. Of the three components the Heat Exchanger is of the largest physical size and as a result can dictate the overall space envelope for the system. Hence when designing the system, the heat exchanger should be assessed initially. If only a small Heat Exchanger can be accommodated a higher performing Pump and Cold Plate would need to be specified.

Water is then pumped through the pipe at a set flowrate, transferring the dissipated heat from the plate's surface into the water, where it is then dissipated via a heat exchanger further down the system.

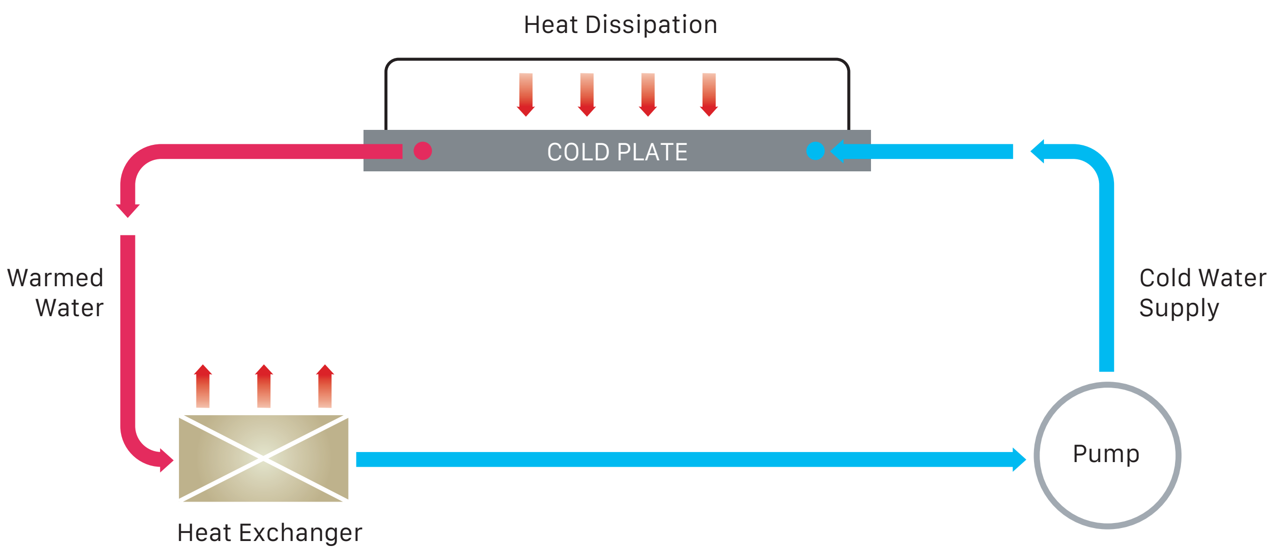

Figure 1 Cold Plate System Configuration with Heat Exchanger and Circulation Pump

2. COLD PLATES

2.1. BASIC COLD PLATE - PLATE & EMBEDDED PIPE

At its most basic, a Cold Plate is made up of the components shown in *Figure 2*. Piping (typically copper or stainless steel) is formed into several loops known as passes (four pass shown) and either interference fitted, or epoxy bonded into machined channels of a plate (typically aluminium). This type of Cold Plate design represents a cost-effective solution.

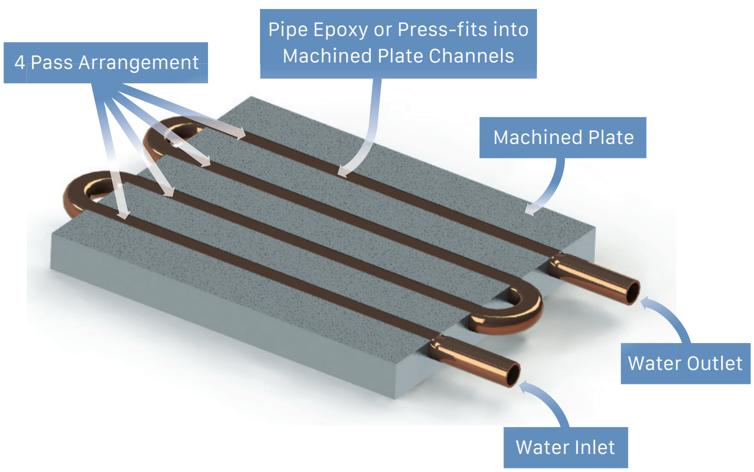

Figure 2 Four Pass Aluminium Plate with Copper Piping

2.2. ENHANCED COLD PLATE DESIGN – IMMERSED MICRO-FIN

Greater heat transfer can be achieved using a high-density fin array immersed in moving water to transfer the imbedded pipe design. The design shown below is a Radian custom solution to loop a number of Micro-Finned Cold Plates together. The high-density fin array is created by skiving a copper block (thermal conductivity 400 W/(mK)) which is then immersed in a water-tight enclosure.

Water is pumped through the enclosure to remove the dissipated heat and the heat is rejected via a heat exchanger further down the system.

The Micro Fin assembly is shown in *Figure 3*, where the high-density fin array is fixed to the plastic housing and sealed with the O-ring as shown. Components are mounted on the uppermost surface of the skived copper block.

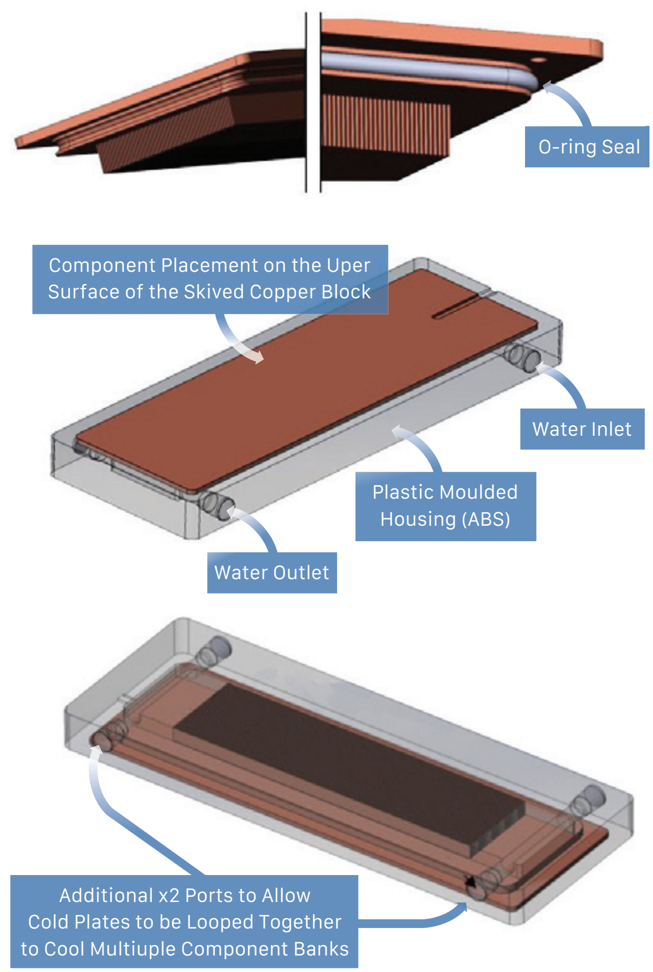

Figure 3 Radian Micro-Fin Cold Plate Design

While other types of cold plate design exist, this paper focuses on the two designs mentioned here.

3. COLD PERFORMANCE COMPARISON - FOUR PASS ALUMINIUM PLATE VERSUS MICRO-FIN PLATE

A simulation was undertaken to compare the performance of the two Cold Plate designs with an inlet water temperature of 20°C and volumetric flow of water at 2 (l/min).

For the Four Pass Aluminium Plate design an aluminium plate (thermal conductivity 200 W/(mK)) was used with copper pipes (thermal conductivity 400 W/(mK)) and a power dissipation of 400W applied to the upper plate surface, as shown in *Figure 4*.

Plate dimensions (152x127x15)mm.

The overall dimensions for the Micro-Fin plate are (220x95x17)mm, where the upper surface area of (220x95)mm is marginally greater than the Four Pass Aluminium Plate surface area of (152x127)mm. Hence an equivalent power per unit area was applied to the upper area of the Micro-Fin plate

Four Pass Aluminium Plate = 400W / (152 x 127)mm = 0.0207 W/(mm^2).

So 0.0207 x (220x95) = 433.1W applied to the upper surface of the Micro-Fin plate, shown in *Figure 5*.

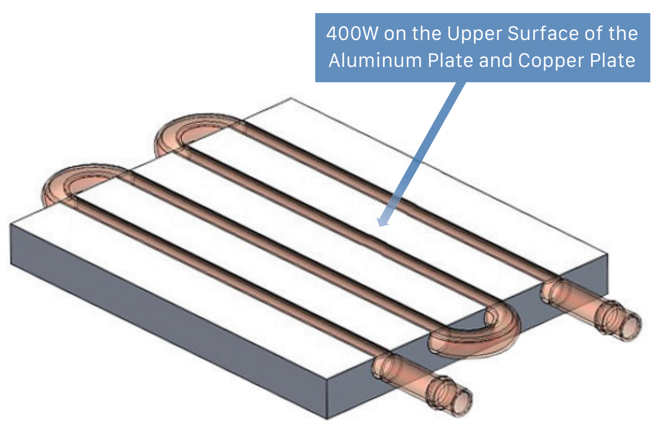

Figure 4 Four Pass Aluminium Cold Plate showing 400W Heat Load

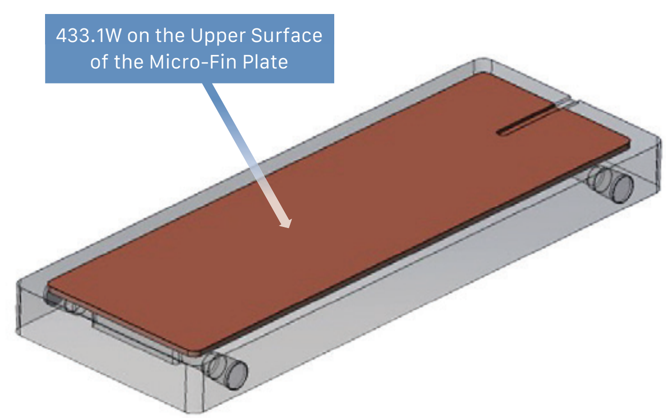

Figure 5 Micro-Fin Cold Plate showing 433.1W Heat Load

The critical dimensions for the Four Pass Aluminium Cold Plate are shown in *Figure 6*

The critical dimensions for the Micro-Fin Cold Plate are shown in *Figure 7*.

Note: The secondary inlet and outlet ports on the Micro-Fin Cold Plate were blocked for the purpose of the simulation comparison.

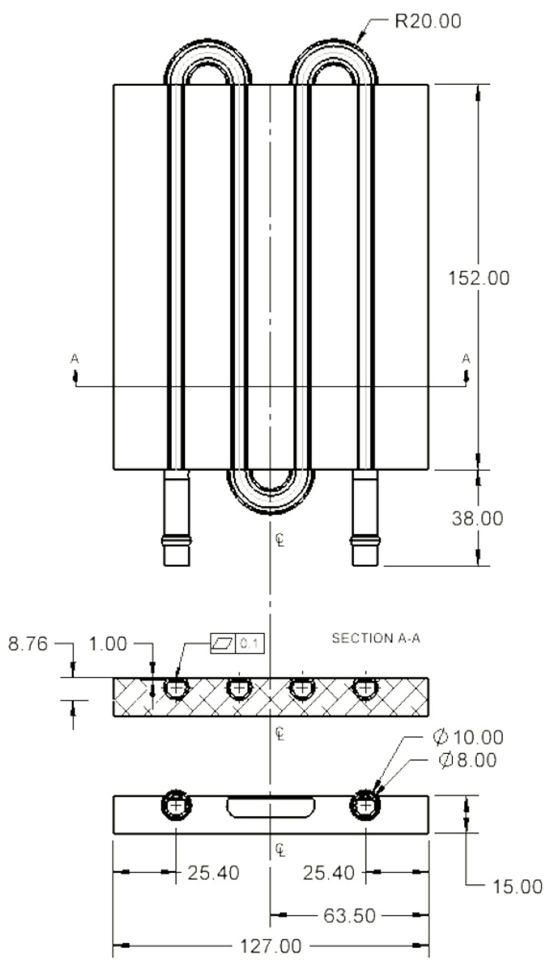

Figure 6 Critical Dimensions
Four Pass Aluminium Cold Plate

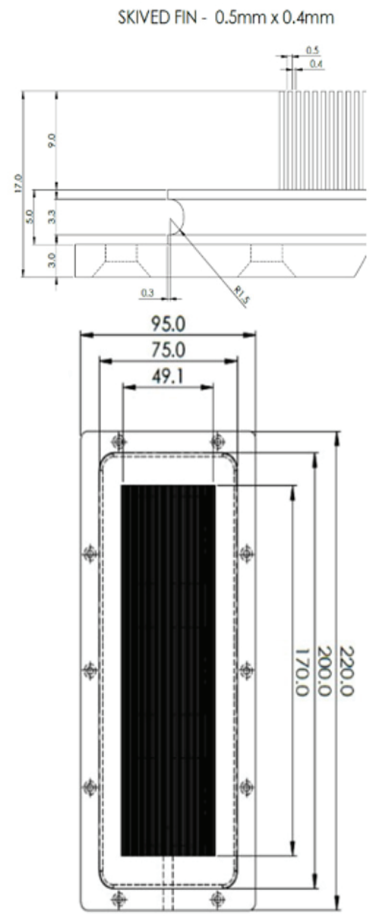

Figure 7 Critical Dimensions
Micro-Fin Cold Plate

3.1. SIMULATION RESULTS

3.1.1 THERMAL PROFILE

The Four Pass Aluminium Plate and Micro-Fin Cold Plate thermal profiles are shown in *Figure 8 & Figure 9*.

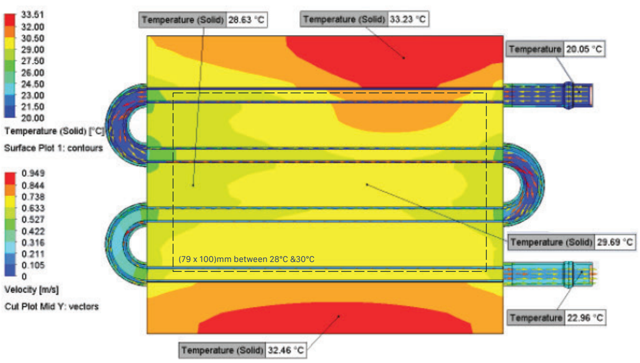

Figure 8 Four Pass Aluminium Cold Plate Thermal Profile

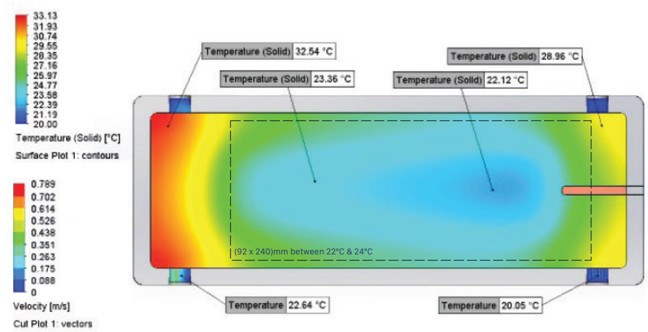

Figure 9 Micro-Fin Cold Plate Thermal Profile

As the same power per unit area is transferred into the water, there is a 3°C temperature rise between the inlet and exit water temperatures in both designs.

The Four Pass Aluminium Plate design maintained an area of (76 x 100)mm between (28°C & 30°C), shown as a dotted rectangle in Figure 8.

The Micro-Fin design maintained an area of (92 x 240)mm between 22°C & 24°C, shown as a dotted rectangle in Figure 9.

The combination of the Aluminium Plate and Embedded Copper Pipe provides a path of higher thermal resistance between the dissipated heat and the water, compared with the Copper Micro-Fin arrangement.

Cross-sectional views showing the thermal resistance profile are shown in Figure 10 & Figure 11 .

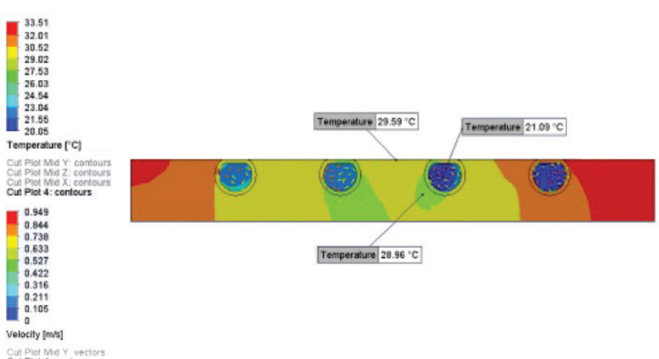

Figure 10 Four Pass Aluminium Cold Plate Thermal Resistance Profil

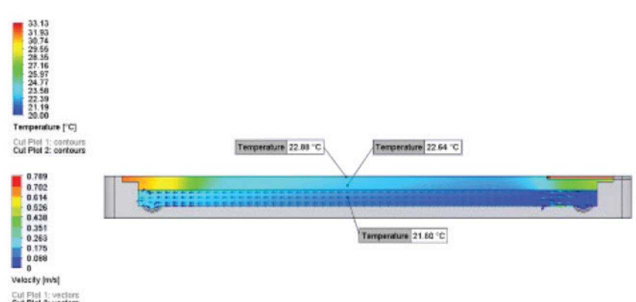

Figure 11 Micro-Fin Cold Plate Thermal Resistance Profile

From Figure 10 the Four Pass Aluminium Cold Plate gives a thermal resistance of (29.6-21.1)/400 = 0.021 (°C/W) between the top of the plate and the water.

From Figure 11 the Micro-Fin gives a thermal resistance of (22.9-21.6)/433 = 0.003 (°C/W) between the top of the plate and the water.

3.1. SIMULATION RESULTS

3.1.2 PRESSURE DROP

The micro finned channels for the Micro-Fin design result in a marginally higher pressure drop dP (102695 – 101225) = 1,470 Pa, *Figure 12*.

Compared with the Four Pass Aluminium Plate dP = (102482 – 101208) = 1,274 Pa, *Figure 13*.

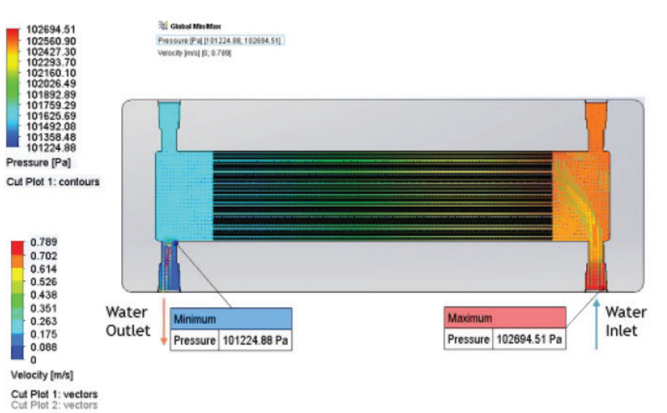

Figure 12 Micro-Fin Cold Plate Pressure Drop Profile

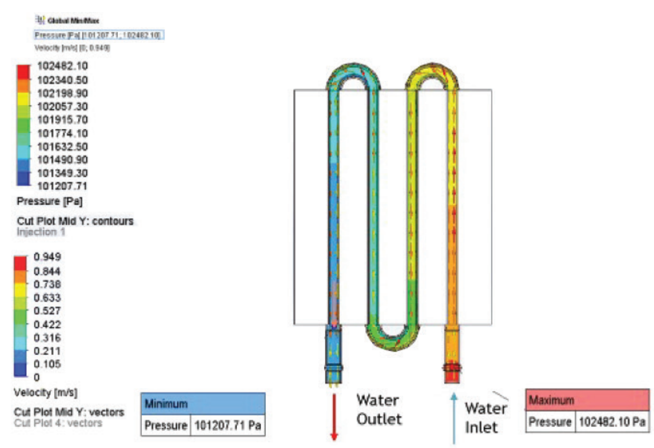

Figure 13 Four Pass Aluminium Cold Plate Pressure Drop Profile

The pressure drop between the two designs is closer than expected, as the four bends in the Embedded Copper Pipe (bend radius 20mm and Ø8) increase the pressure drop through the system. With the Copper Micro-Fin arrangement (0.4mm gap x 9mm high), the flow enters the housing and turns through 90° but a plenum area allows the flow to evenly distribute prior to the finned section, evening out the flow and reducing the pressure drop from the 90° inlet and outlet.

The pressure drop through the Cold Plate is an essential design consideration and will affect the choice of circulation pump in the system, where a more powerful, higher cost pump would be required to overcome increasing pressure drops.

Pressure drop increases as a square of the flow rate as shown in Figure 14, where a marginal difference in system pressure drop at lower flows would result in significantly higher pressure drops as the flow increases. The required flowrate and subsequent pressure drops should be evaluated prior to a specific Cold Plate design selection.

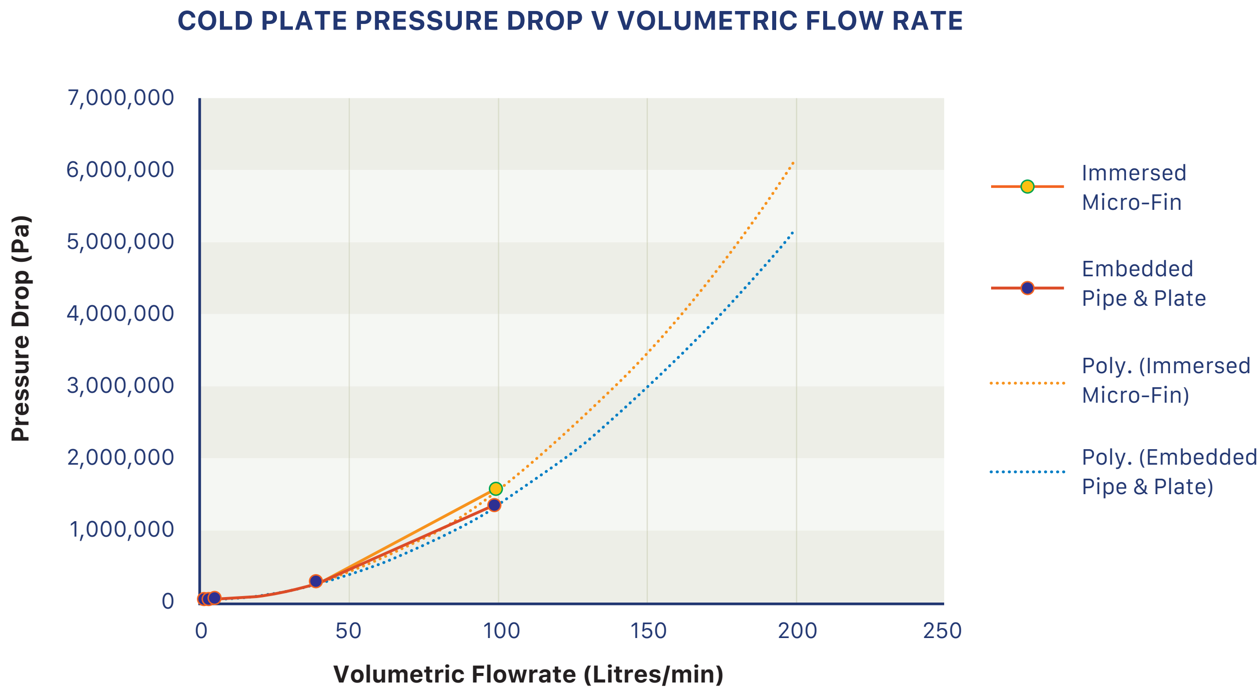

Figure 14 Cold Plate Pressure Drop v Volumetric Flow Rate

4. DISCUSSION

The purpose of this document is to compare a basic commercially available Four Pass Aluminium Plate design with a Radian custom designed Micro-Fin design. Table 1 below summarises the key data from the simulation comparison.

Cold Plate Design	Applied Power[1] (W)	Plate Working Surface Temperature (°C)	Pressur Drop (Pa)	Thermal Resistance (°C/W)	Plate Area (mm^2)
Four Pass Al Plate	400	28 to 30	1,274	0.021	(152x127) 19,304
Micro-Fin	433	22 to 24	1,470	0.003	(220x95) 20,900

Table 1: Aluminium Plate and Micro-Fin Cold Plate Simulation Results Summary

The Micro Fin design is a Radian custom design to meet a specific customer requirement and would allow multiple Housings to be coupled together to cool banks of components.

The improved heat transfer of the high-density copper skived fins allowed a significantly larger working surface area of the design to be maintained at a 6°C cooler temperature than the Four Pass Aluminium Plate arrangement.

The Aluminium Plate and Embedded Copper Pipe Cold Plate type design is ideal for lower cost applications where the Cold Plate's ability to maintain a tight temperature tolerance over the plate's working surface is not critical.

The higher thermal conductivity of the copper plate, twice that of aluminium, and the enhanced heat transfer coefficient of the high-density copper fins of the Micro-Finned Cold Plate, allow higher power dissipations to be managed with greater temperature control over the working surface of the plate. This improvement in performance is offset by higher part cost due to the material and machining costs.

A commercially available aluminium micro fin Cold Plate would be around three times the cost of the Aluminium Plate and Embedded Copper Pipe design discussed.

As demonstrated in this paper Radian have the capability to design and simulate Cold Plate solutions.

1. Equivalent power density in both cases is 0.0207W/mm2.