Chapter 4

EXPERIMENTAL WORK

Heat exchangers are normally used to carry away the heat generated in different types of equipment in industry. In the MEMs industry, electronic ICs and CPU chips have been developed to carry out operations at very high speeds. Such operations also result in lot of heat generation. The heat generated in such devices should be in real time removed or abstracted out of such systems as quickly as potential. Such Micro channel heat sinks, developed in our analysis work, use nanofluids and de-ionized water to require away the warmth generated within the device. This chapter describes the event, fabrication and instrumentation of a Copper rectangular high ratio small channel device assembly, which was used for activity of warmth transfer and pressure drop and analyzation the thermal and fluid flow performance of the liquid coolants through the Micro Channel Heat Sinks.

4.1 EXPERIMENTAL SETUP

The basic apparatus used in conducting the experiments is a three dimensional microchannel heat exchanger assembly made from Copper and Aluminium. The source of heat is a 900 W ceramic heater which simulates the heat generated from the CPU of a computer. Since liquids like water or nanofluids is used for taking away the heat, the hot liquid exited out, has to be circulated back after cooling at room temperature, hence a closed circuit system has been developed and installed. The measuring devices like flow meter, thermocouples, and U tube manometer are used for measuring flow, temperatures and pressure drops across the Micro Channel Heat Sinks. The Micro Channel Heat Sinks is a single inlet-outlet type heat exchanger assembly, because a single fluid is used as coolant and it is a single phase heat transfer.

4.1.1 MICRO CHANNEL ASSEMBLY

The assembly development is done based on the Micro Channel Heat Sinks material available, type of fabrication method used, the aspect ratio of each
micro channel and finally the number of channels. The assembly drawing of the Micro Channel Heat Sinks is shown as isometric solid in Figure 4.1.

![3D Sketch of the Micro channel Assembly](image)

**Figure 4.1** 3D Sketch of the Micro channel Assembly

![Dimensions of the micro channel assembly](image)

**Figure 4.2(a)** Dimensions of the micro channel assembly
Figure 4.2(b) Photograph of the micro channel assembly

The entire micro channel assembly is developed out of Copper plates. The overall size of the Micro Channel Heat Sinks assembly is $31 \times 36.75$ mm ($l \times w$). It is fabricated out of 3mm Copper plates above and below the Micro Channel Heat Sinks. The heat sink is connected to a plenum which enables nanofluids to enter inside the Micro Channel Heat Sinks. The single inlet and outlet to and from the Micro Channel Heat Sinks assembly is vertical. The details of the mounting plates are as shown in Figure 4.3. Aluminum was taken for the mounting plate because fabrication and assembly was easier and it was lightweight.
4.2 FABRICATION OF THE MICRO CHANNEL ASSEMBLY

The material used for fabrication of the micro channels is Copper. Copper has been chosen because it can be easily machined and has a good heat transfer capability. Copper when compared to Silicon is less costly. The individual channel width has been designed to be 150 μ. The height of the channel is kept at 7 mm. The total number of micro channels fabricated were 122 in number. Since the dimensions correspond to a micro channel, Wire-cut Electric Discharge Machining is used.
4.2.1 COPPER MATERIAL DETAILS

The thermo-physical property which decides the material required for the Micro Channel Heat Sinks is thermal conductivity. Since the thermal conductivity of the Micro Channel Heat Sinks influences the heat transfer process considerably, Copper has been selected. It has a high value of $k=387 \text{ W/mK}$. Metals like aluminium, silicon have $k=205 \text{ W/mK}$ and $60 \text{ W/mK}$.

The fabrication of small heat exchangers victimisation EDM method involves metal strength, malleability and sensible machinability. Therefore, supported the channel breadth, spacing between channels and also the sizable amount of channels, Copper is chosen for the EDM methodology of fabrication. Atomic number 13 has not been used for the Micro Channel Heat Sinks however it's been used for the quilt plates. it's conjointly been found that Copper is appropriate for micro-machining.

4.2.2 WIRE CUT EDM SETUP

In an EDM machine using wires (also called as wire cut EDMs), a thin single strand metal wire normally made of brass is fed through the work piece, submerged in a tank of dielectric liquid normally de-ionized water. The advantage of such EDMs is to cut plates up to thickness of 300 mm. Another application of EDM is to make punches, tools and dies from hard metals that are difficult to machine with traditional manufacturing methods.

The wire is feed from a spool and is controlled by holding it between two guides, one upper and the other lower diamond guide. The machine is a CNC operated one which moves the guides in x-y planes. The cutting width is greater than the width of the wire to prevent sparking from the sides of the wire onto the work piece. The wire cut process uses water as its dielectric fluid. The electrical properties are controlled using filters and de-ionizer units. The water takes away the cut debris away from the cutting zone. This helps in determining the maximum feed rate for a given material thickness. Also wire cutting EDMs are normally used where low residual stresses exist. This means that cutting forces, developed while machining, are not high. This also indicates that energy/power per pulse is low.
4.3 LAYOUT OF THE EXPERIMENTAL SETUP

Figure 4.4 Layout of the complete experimental setup

Figure 4.5 Photograph of the Experimental setup
4.3.1 SOURCE OF HEAT INPUT

The source of heat supply to the bottom wall of the micro channel assembly is a 900 W ceramic plate heater. This is controlled by a rheostat. The above serves as a constant heat flux source. This simulates the heat flux emanating from the CPU of a computer. The input power supply from the heater is monitored through an ammeter and a voltmeter. The voltage reduction is carried out using a step-down transformer.

4.3.2 PRESSURE MEASUREMENT

The pressure drop across the Micro Channel Heat Sinks assembly was measured by providing identical pressure taps at the inlet and exit of the Micro Channel Heat Sinks assembly. These pressure taps are connected to a U-tube manometer by means of plastic hoses. The pressure taps were located at the same heights. The inlet and outlet pressure taps were having similar fittings and tube connections. The manometer used in the experiment is a 1 mm Hg manometer. It is partially filled with Mercury. The range of the manometer was 750-0-750 mm. The U tube manometer is indicated in the photograph as shown in Figure 4.6.

![Image of ceramic heater with Micro Channel Heat Sinks assembly](image)

**Figure 4.6 The ceramic heater along with the Micro Channel Heat Sinks assembly**

The formula for measurement of the differential pressure is:

\[ \Delta P = h \times (d_m - d_f) \]  \hspace{1cm} (4.1)
Where $d_m$ indicates the fluid density of the fluid in the manometer (Hg) and $d_f$ indicates the density of the fluid above the manometer. The above is possible only if $d_f << d_m$.

4.3.3 FLOW MEASUREMENT

A H-10 pump, driven by an electric motor was used to circulate the de-ionized water as well as the nanofluids into the system. Though the pump generated very high flows, a manually adjustable flow control valve was used to moderate the flow rate to less than 5 litres per minute. The details of the flow measurement and flow control using a ball valve is given below. The return hot liquid is cooled by a fan type condenser before being re-circulated into the system, from the reservoir through the pump.

A differential flow meter for measuring very small flows was used, ranging from 300 millilitres per minute to 5 litres per minute. This flow meter was connected at the outlet of the Micro Channel Heat Sinks. Also the coolant flow rates were measured with a 1 litre volumetric flask and a stop watch. A valve is employed to control the flow of agent into the circuit. The valve is manually controlled, by means that of a spherical disc. The disc incorporates a hole or a gap (port) through the center. The outlet once in line with each the body of water and also the outlet of the valve, flow can occur. On closure of the valve, the port becomes perpendicular to the ends of the valve, and flow is blocked.

4.3.4 TEMPERATURE MEASUREMENT

K type thermocouples were used to measure the surface temperature of the Micro Channel Heat Sinks heat sink. Four thermocouples with 1 mm diameter beads were connected over the heat sink surface. Two more K type thermocouples were used to measure the temperatures at the inlet and the outlet of the micro channel. The working range of the thermocouple is from -90 to 150°C. Such thermocouples have been used in our experiment because of their good temperature span, good linearity, fair price but lesser accuracy, when compared to T-type thermocouples. The thermocouples were bonded to the bottom of the heat sink surface by soldering process. Initially grooves were indented onto the wall surface and then soldering was
performed. After completion of the solder, electrical tape was wrapped around the thermocouples to provide additional support and fixity. The temperature measurements at the wall of the Micro Channel Heat Sinks and the coolant inlet and outlet did not show drastic variations, and there was a good amount of repeatability in the readings.

4.3.4.1 Calibration

All the temperature sensors were calibrated using water bath. The thermobath container is filled with water. The water is initially heated to 30°C and the thermocouple is turned on. The thermocouple ends were connected to the multimeter leads accordingly. The multimeter recorded a voltage of 1 micro volt. In the next step, one end of the thermocouple is placed in the water allowing the voltage to stabilize. The voltage reading which was not fluctuating was recorded from the multimeter.

In the next stages the water temperature is increased to 35°C and in steps of 5°C the temperature of the water bath is made to go up to 46°C. The room temperature is measured and the corresponding voltage is observed in the multimeter at the room temperature. The voltage measured for a type K thermocouple at a temperature of 25°C is 1 mV.

The curve fitting method is used to find the best line that fits the recorded data. The increase in voltage, for each degree of temperature increase, is indicated by the slope of this line.
The bath and the calibration apparatus with the temperature sensors

Table 4.1 Temperature calibration

<table>
<thead>
<tr>
<th>Bath temperature fixed at 46 C</th>
<th>Thermocouple 1</th>
<th>Thermocouple 2</th>
<th>RTD 1</th>
<th>RTD 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature indicated by Thermocouples and RTDs</td>
<td>46.1°C</td>
<td>45.5°C</td>
<td>45°C</td>
<td>45.1°C</td>
</tr>
<tr>
<td>Error</td>
<td>+0.1°C</td>
<td>-0.5°C</td>
<td>-1°C</td>
<td>-0.9°C</td>
</tr>
</tbody>
</table>

The flow meters and pump were calibrated together. The pump was set for a specific flow rate, and the fluid was collected in a measuring flask and time was noted. Then, the mass of the fluid was measured on a calibrated balance for the same period of time. Many regions were taken over the various ranges of flows of the pump. A polynomial curve was fitted to get the calibration equation for the pump and flow meters.

4.4 EXPERIMENTAL PROCEDURE

4.4.1 DATA REDUCTION

The temperature measurements at the recess of the Micro Channel Heat Sinks and at the outlet of the Micro Channel Heat Sinks were performed. The temperature measurements were additionally performed close to the walls of the
Micro Channel Heat Sinks at the heater finish. Since it absolutely was much not possible to live the wall temperature directly, four thermocouples were strategically settled close to the wall, signifying mensuration of a median wall bulk temperature. Pressure drops mensuration across the recess and outlet of the Micro Channel Heat Sinks, indicated stratified friction flow. The measurements were taken so as to decipher it as helpful heat transfer and fluid flow parameters. This was done to enable evaluation of Nusselt and friction factors for performance analysis of the micro channel assembly. The heat transfer calculations were performed based on the difference in temperatures of the liquid at the inlet and outlet of the Micro Channel Heat Sinks as well as the difference between the measured wall temperature and the bulk coolant temperature. The temperatures have been measured axially. The hydraulic diameter of each channel $D_h$ is 294 $\mu$m.

4.4.2 HEAT TRANSFER

Temperatures were measured at four different points on the heater to approximate the average wall temperature. The inlet and outlet temperatures of the coolant were measured (as mentioned) using sensors. The wall temperatures were measured and their average value was calculated.

The heat removed by the coolant was calculated by the following equation:

$$Q = m \times c_p \ (T_{out} - T_{in})$$  \hspace{1cm} (4.2)

where ‘m’ is the mass flow rate, $c_p$ is the specific heat and $(T_{out}$ and $T_{in})$ happened to be the inlet and outlet temperatures of the fluid in the Micro Channel Heat Sinks.

The average heat transfer coefficient is an important parameter to be ascertained in micro heat exchanger analysis which is by the following equation:

$$h_{conv} = Q / (A_{eff} \times \Delta T_{m})$$  \hspace{1cm} (4.3)

Where, $Q$ is heat transfer, $A_{eff}$ is effective heat transfer area and $\Delta T_{eff}$ is log mean temperature difference.
Nusselt Number, a non dimensional number, the ratio of convection to conduction heat transfer, is a measure of heat transfer to the fluid and is calculated by:

\[ Nu = h \times \frac{D_h}{K_{nf}} \]  \hspace{1cm} (4.4)

4.4.3 ENERGY ABSORBED BY THE WORKING FLUIDS

In our experimental work, the energy generated by the heater (which is simulating the CPU) is considered for absorption by the working fluid, with the heat loss to the environment being assumed as negligible. The energy absorbed by the working liquid or nanofluid is given as follows:

\[ Q_{nf} = (\rho C_p)_{nf} V_{nf} (T_{nf0} - T_{nf1}) = (\rho C_p)_{nf} V_{nf} \Delta T_{nf} \] \hspace{1cm} (4.5)

The energy absorbed by the initial working fluid or the base fluid is given by the following equation:

\[ Q_f = (\rho C_p)_{f} V_{f} (T_{fo} - T_{fi}) = (\rho C_p)_{f} V_{f} \Delta T_f \] \hspace{1cm} (4.6)

Also the ability of the nanofluid to enhance heat transfer is judged by the following equation:

\[ (T_{nf0} - T_{nf1}) > (T_{fo} - T_{fi}) \] \hspace{1cm} (4.7)

where \( T_{nf} \) = \( T_f \) which means that the temperatures of the working fluid at inlet is same in both the cases. Also the flow rate is controlled.

4.4.4 THERMAL RESISTANCE

An important feature of small device performance is its semiconductive thermal resistance, that additionally is necessary. If the thermal resistance of the Micro Channel Heat Sinks is low, then heat transfer capability of the Micro Channel Heat Sinks is high. Therefore the thermal capability or performance might be evaluated supported by the calculation of thermal resistance across the Micro Channel Heat Sinks.
This is done with the help of the following equation:

$$ R_{sh} = (T_w - T_{in}) / Q \quad (4.8) $$

Where $T_w$ denotes the average of the measured wall temperatures and $T_{in}$ denotes the coolant inlet temperature.

4.4.5 HYDRO_DYNAMIC AND THERMAL ENTRANCE LENGTH

The laminar flow hydrodynamic length across the micro channel is calculated with the equation given below:

$$ L_h = 0.05 \times 100 \times R_e \times D_h \quad (4.9) $$

$$ = 0.05 \times 100 \times 294 \mu $$

$$ = 0.0147 \text{ m or } 1.47 \text{ mm which is less than } L_c \text{- the length of the channel} $$

The thermal boundary layer length across the micro channel is calculated by the following equation:

$$ L_h = 0.1 \times R_e \times P_r \times D_h \quad (4.10) $$

$$ = 0.1 \times 100 \times 4.33 \times 294 \mu $$

$$ = 0.0127 \text{ m or } 12.7 \text{ mm which is less than } L_c \text{- the length of the channel} $$

The fully developed flow assumption is valid because of above.

4.4.6 PRESSURE DROP

Pressure drop across the micro channels is given by

$$ \Delta p = \Delta p_m - (k_i - k_o) \times \rho u_n^2 / 2 \quad (4.11) $$

Where $k_i$ and $k_o$ are loss coefficients for the inlet contraction and outlet expansion and $p_m$ happens to be the pressure drop measured across the Micro Channel Heat Sinks with the help of a U-tube manometer.
Friction factor was also calculated by the formula related to the pressure drop across the Micro Channel Heat Sinks:

\[ f = \frac{(2 \times \Delta p \times D_h)}{L ((L \times \rho \times u_m^2)} \]  \hspace{1cm} (4.12)

4.4.7 FLOW RATE

The mean rate of fluid flow was calculated supported the rate of flow through the cross sectional space of the small channel. Additionally to spot the character of flow through the Micro Channel Heat Sinks, the painter range (a non-dimensional parameter) was calculated by the quality equation in fluid mechanics:

\[ R_e = \rho \times u_m \times D_h / \mu \]  \hspace{1cm} (4.13)

4.5 SUMMARY

This chapter describes the equipment for the experimental facility developed by us for our analysis and study. The layout, the sensors used for numerous measurements have conjointly been delineated shortly. The information reduction methodology aims to seek out the warmth transfer constant, Nusselt range, friction issue, pressure drops, flow rates, Reynolds range, thermal resistance etc. This analysis methodology forms the precursor for the experimental results, analysis and conclusion bestowed within the final chapters. Device and instrumentation errors are of an awfully low proportion. Therefore the measurements recorded are often thought of as fairly correct. In our current experimental work, a swish rectangular higher ratio small channel assembly was developed to review the convective heat transfer and fluid flow through it. The experimental results and testing methodology were validated by evaluating the warmth transfer rate, pressure drop etc. with numerical study of the fluid flow and warmth transfer characteristics through the Micro Channel Heat Sinks employed in the experimental work.