Experimental investigation of the heat transfer characterization of multiple microjet impingement cooler

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Abstract. In this paper, a new type microjet with a return channel was designed and constructed from plastics using 3-Dimensional print techniques. The array of 12 microjets with diameter 3mm was tested using high pressure (17.3KPa-275.8 KPa) air as coolant for jet diameter Reynolds number from $1.5 \times 10^3 - 6.75 \times 10^3$. The effects of the design parameters such as standoff that is the distance of the nozzle exit to the heated surface were analyzed under different input power and Reynolds number. The pressure drop and COP of the cooler were explored under different conditions in the present study.

1. Introduction

With the development of electronic industry, cooling of high-power electronics is becoming increasingly important to the whole world. Jet impingement is one of the most effective techniques to dissipating the high heat flux on electronic components surfaces [1]. Experimental and numerical researches have been conducted extensively in past decades due to its wide application in cooling the walls of electronic components systems and other industrial equipment. John E. Leland et al. [2] has set up a microjet impingement cooling device for high power electronics. Heat transfer and pressure drop data of the cooler were obtained for a range of mass rates extending up to the point of choked flow and also for variable heat fluxes. Sinan Caliskan and Senol Baskaya et al. [3] investigated the effect of jet geometry on the flow and the heat transfer characteristics using experimental and numerical method for elliptic and rectangular impinging jet arrays. They obtained that the Nusselt numbers for the elliptic jets in the impingement regions was larger than that for a circular jet. Dae Hee Lee et al [4] studied the effects of slot width on heat transfer performance for confined, laminar impinging slot jets of millimeter-scale. H.D. Haustein [5] set up an experiment with IR thermography and high-speed photography to investigate transient and steady heat transfer characteristics for both free and submerged-jets impingement. Aaron m. et al. [6] studied the effects of jet-jet spacing and spent air exits location on heat transfer performance of a $3 \times 3$ square arrays air jets impinging cooler. They found that the jet-jet spacing affects the convective coefficient and the addition of spent air exits increased the convective coefficient and influenced the location of the optimum separation distance.

The presented study investigated thermal performance under inline array-jets impingement which constructed from plastics using 3-Dimensional print techniques. The air flow rate, input power of the
heater and distance from the microjet exist to the heated surface have been found to significantly affect the heat transfer along the wall. Detailed temperature distribution over a heater surface by circle impinging jet arrays were obtained using thermal infrared camera.

2. Experimental apparatus and method

2.1. Apparatus

![Experimental set up and heater assembly](image)

An experimental setup such as the one shown in Figure 1 was used to conduct the microjet impingement experiments. The system basically consists of primarily of the microjet array cooler and the flow rate and pressure drop and temperature measurement equipment and a substrate coated with indium tin oxide (ITO), which was used as heating element to ensure constant heat flux conditions during microjet impingement. This was a 25 mm by 25mm square. Air was supplied to the jet orifices by a compressor. The heater system was shown in Figure 1(b). Temperatures were measured by using an IR camera located below the heater.

Figure 2 shows a schematic of the cooler. The cooler was consisted of plenum chamber, orifice plate and heater. The heater surface was held in tension by four bolts through a Teflon frame. The jet orifice plate and plenum were mounted on a stand which allowed vertical movement as showed in reference [8]. To change the separation distance (H), the locking bolts were loosened and the plenum and orifice plate moved upwards or downwards with a gasket for different thickness 2, 4 and 6mm. The orifices are round-edged with diameter of 3mm. The inlet of each orifice was slightly rounded to ensure similar entrance conditions for each orifice. The orifice plate was 8 mm thick and 441 mm square. For this study, 21×21 mm square isothermal jet arrays were used with H= 4mm, 6mm , 8mm and 10mm.
2.2. Data reduction
The area-averaged Nusselt numbers were calculated as in reference [9]:

\[ Nu = \frac{hd}{k} \]  

(1)

Where, \( d \) is the inner microjet diameter, and \( k \) is air conductivity using thermophysical properties at the average of jet inlet and heater surface temperatures. \( h \) is the average heat transfer coefficient, can be calculated from:

\[ h = \frac{Q_{\text{input}} - Q_{\text{loss}}}{A_{\text{surf}}(T_s - T_{\text{in}})} \]  

(2)

Where \( T_s \) is the heater surface average temperature, \( T_{\text{in}} \) is the microjet inlet air temperature. \( Q_{\text{loss}} \) is the heat transfer losses from free convection and radiation. In this research, heat losses were measured when no air impingement on the top part of the heater was taken place. Average surface temperatures on the backside of the heater were recorded after the surface temperature reached steady state. \( Q_{\text{input}} \) is the electrically generated heat flux which can be calculated with the following equation

\[ Q_{\text{input}} = IV \]  

(3)

In Equation (3), \( V \) is the voltage on the heater, \( I \) is the current through the heater.

The jet Reynolds number is defined as follows in reference [10],

\[ Re_{\text{ud}} = \frac{ud}{\nu} \]  

(4)

Where \( u \) is the average jet velocity at the jet exit and \( d \) is the inner jet diameter, \( \nu \) is the kinematic viscosity of air. Thermo physical properties were evaluated at the average of jet inlet and heater surface temperatures, except for the viscosity in the Reynolds number which was calculated at the jet inlet temperature.

The performance coefficient of the microjet cooler can be calculate from

\[ \text{COP} = \frac{Q_{\text{input}} - Q_{\text{loss}}}{P} = \frac{Q_{\text{input}} - Q_{\text{loss}}}{A_{\text{jet}}u\Delta p} \]  

(5)

The pumping power required to drive the fluid through the microjet cooler can be evaluated as follows in reference [11]

\[ P = A_{\omega}u\Delta p \]  

(6)

Where \( A_{\text{jet}} \) is the area of the microjet inlet surface, \( u \) is the average jet velocity at the jet exit, \( \Delta p \) is the pressure drop of the cooler which can be measure by a differential pressure transducer.
3. Results and discussions

Figure 3 shows surface mean temperature variations with input power at standoff 4mm (a) and 10mm (b) for different flow rate. It can be observed from Figure 3 that as the input power increases, the surface mean temperature of heater increases under a constant volume flow rate, as the volume flow rate increases the surface mean temperature decreases under the same input power. The surface mean temperature of heater at standoff 4mm was lower than standoff 10mm under almost same input power and volume flow rate.

![Figure 3](image_url)

**Figure 3.** Surface mean temperature variations with input power for different flow rate at stand off 4mm (a) and 10mm (b).

Figure 4 shows that convective heat transfer coefficients increase with increasing of volume flow rate at the same input power. As input power < 6.73W, convective heat transfer coefficients increase quickly with increase of input power after that keeping almost a constant at the same volume flow rate. It showed that convective heat transfer coefficients was more great at standoff 4mm than standoff 10mm, such as when volume flow rate was 0.0025m³/s, 1800 W/m²·K was obtained at standoff 4mm in the experiment, but under the same volume flow rate, convective heat transfer was only 1400 W/m²·K at standoff 10mm. All of these showed that standoff has an obviously effects on heat transfer performance of microjet cooler.

![Figure 4](image_url)

**Figure 4.** Convective heat transfer coefficient variations with input power for different flow rate at standoff 4mm (a) and 10mm (b).
Figure 5. Variations of the maximum temperature rise with input power for different standoff.

Figure 6. Nusselt number variations with jet Reynolds number for different stand off.

Figure 7. Pressure drop variations with jet Reynolds number for different stand off.

Figure 5 showed the experimental results for the maximum temperature rise ($\Delta T_{max}$) in the microjet cooler for various heat powers applied at heater surface at volume flow rate 0.0025m$^3$/s for different standoff 4, 6, 8, 10. It presented that the maximum temperature rise of the heater surface ($\Delta T_{max}$) increases monotonously with increasing of the input power for the same standoff at volume flow rate 0.0025m$^3$/s. The maximum temperature rise ($\Delta T_{max}$) increase with increasing of standoff under the constant input power. At higher values of $D/H$, the stagnation region facilitate convective heat transfer.
Figure 8. Thermal efficiency variations with jet Reynolds number for different stand off.

The heat transfer performance of the jet arrays is shown in Figure 6, 7 and 8. Figure 6 presents that in the microjet arrays with pressure air for different D/H, the Nusselt number increased monotonically with Reynolds number. Figure 7 shows pressure drop variations with jet Reynolds number for D/H=0.3-0.75. It presented that pressure drop increases monotonously with an increase in the Reynolds number. Obviously, D/H ratio has a negligible effect on pressure drop at the same Reynolds number. Figure 8 shows thermal efficiency variations with jet Reynolds number for different stand off 4-10. It can be seen that thermal efficiency decreased monotonically with jet Reynolds number increasing at same stand off. As Reynolds number <5000, thermal efficiency decreases quickly with increase of Reynolds number, and thermal efficiency at D/H=0.3 was lower than D/H=0.75 under same Reynolds number. As Reynolds number >5000, D/H ratio has a negligible effect on thermal efficiency at the same Reynolds number.

4. Conclusions
A new type multiple microjet cooler with a return channel was designed and constructed from plastics using 3-Dimensional print techniques. The heat transfer performance of the cooler has been studied by experimental method. The results are summarized as follows:

(1) Standoff has an obvious effects on heater surface mean temperature under the same working conditions. The surface mean temperature of heater increases with increasing of standoff from 4mm to 10mm for a same volume flow rate and input power. The maximum temperature rise (ΔTmax) increases with increasing of standoff under the constant input power. The maximum temperature rise of the heater surface increases monotonously with increasing of the input power for the same standoff and volume flow rate.

(2) Convective heat transfer coefficient was more great at standoff 4mm than at standoff 10mm under same volume flow rate. Convective heat transfer coefficients increase with increasing of volume flow rate at the same input power. The Nusselt number increased monotonically with Reynolds number at same standoff. The data obtained with D/H=0.75 showed much higher Nusselt numbers for a given Reynolds number than the data with D/H=0.3.

(3) Thermal efficiency decreased monotonically with jet Reynolds number increasing at same standoff. Thermal efficiency at D/H=0.3 was lower than D/H=0.75 under same Reynolds number. Pressure drop increases monotonously with an increase in the Reynolds number. But, D/H ratio has a negligible effect on pressure drop at the same Reynolds number.

Acknowledgments
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