International Journal of Engineering Science Invention (IJESI)
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 8 Issue 06 Series. II || June 2019 || PP 68-73

Single and Multiple Impinging Jet Arrays on Fluid and Heat Flow

Rajeswari Chaini[1], Abhaya Kumar Baliarsingh[2], Dr Biranchi Mishra[3]
[1,2]*Assistant Professor, Department of Mechanical Engineering, Gandhi Institute For Technology (GIFT), Bhubaneswar*
[3] *Assistant Professor, Department of Mechanical Engineering, Gandhi Engineering College, Bhubaneswar*

Abstract. *The hydrodynamics and heat transfer of micro array jet impingement cooling of a steel plate was investigated. The steel plate was taken stationary during the experimentation. K-type thermocouples were embedded at the bot- tom surface of the plate for transient temperature measurement and the jet array was applied on the upper surface. Experimental results were generated by using CHINO DAS and were analyzed by using the application software ZAILA and in MS-Excel environments. The experiments were conducted on an electrically heated steel plate of dimension 200 mm x200mm x 6mm. Array of jets were generated by the help of different types of headers consisted of metallic plates with small orifices arranged in arrays. Two such headers of different character- istics were used for cooling experiments and were compared in terms of their efficiencies. Effect of the controlling parameters, such as coolant pressure, mass impingement density, mass flow rate and ratio of header to plate spacing and jet diameter on cooling rate were investigated. The experimental results showed a dramatic improvement of heat transfer rate from the surface and the results es- tablished good optimal cooling strategies and the developed cooling system was found efficient in removing more heat from the steel surface with less time.*
Keywords: *Multiple Impinging jet array, Fluid properties, Mass flux densi- ty,Heat transfer characrecteristics*

I. Introduction

Array of impinging jets is generally preferred when high and uniform heat transfer is required. Enhancement of heat transfer from metal surface through impingement of multiple jet arrays was investigated. The jet arrays were generated by using the con- ventional shower heads of different configurations. Although many researchers [Peng Xu et al. (2012), Nuntadusit et al. (2012), Shyy Woei Chang et al. (2007), Robinson

and Schnitzler (2007)] identified the multiple jet array cooling method as one of the tool to enhance the heat transfer from the metal surfaces, but the information available in the open literature is not enough to understand the physical nature of impingement cooling and complexity of solid-fluid interaction during impaction. Some of the im- portant literatures are cited here.

The influence of jet to jet distance and jet to plate distance on heat transfer charac- teristics of round impinging jets with inline arrangements has been investigated by Katti and Prabhu (2008). Investigations carried out by Chiu et al. (2009) on influence of jet geometries revealed that optimum heat transfer was obtained for aspect ratio (AR) of 1. Pil Jong Lee et al. (2003) studied the effect of ambient air condition on heat transfer during jet impingement cooling of a hot steel plate. Whelan and Robin- son (2008) analysed the effect of inlet and outlet nozzle geometries on thermal – hy- draulics of jet impingement heat transfer.

In this paper the experimentation on jet array impingement cooling of a hot steel plate is described. Of particular interest here is to experimentally investigate effect of various fluid properties like water pressure, mass flux density, flow rate and velocity on heat transfer characteristics. The test piece consists of a square plate of side 200mm and 4mm thick. The plate is electrically heated and array of jet generated by commercially used bath showers is made to impinge on test plate. The time – temper- ature data is acquired by CHINO DAS and analyzed by generating plots in MS Excel environment.

II. Experimental Set Up:

The experimental test setup consists of several sections. These include the water supply section, heating section, impingement jet plate and target plate. Figure 1 shows the schematic of the whole experimental setup.
The jet arrays are created by using bathing shower plates of different sized holes and different holes arrays. The diameter of each jet was assumed as equal to the hole diameter in this investigation and were different for different jet headers.

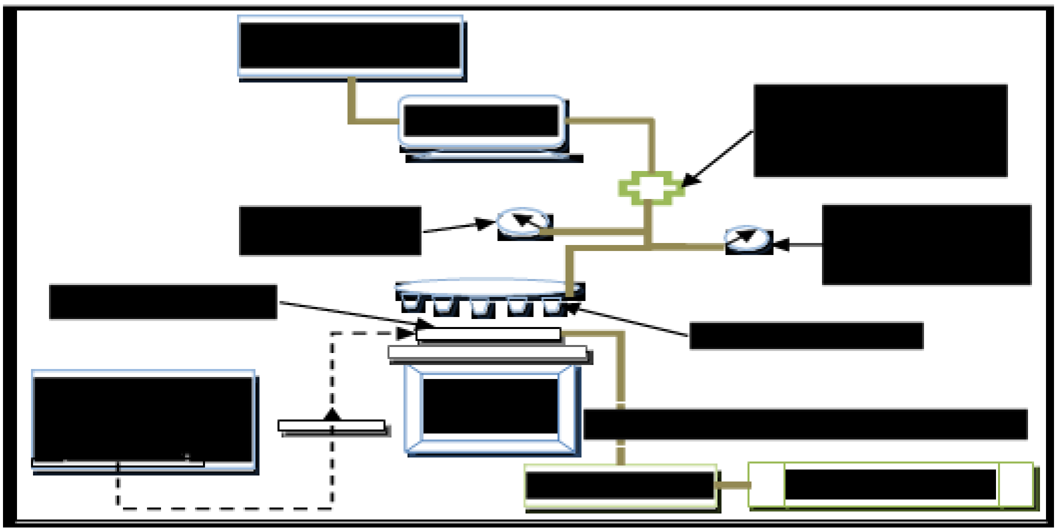
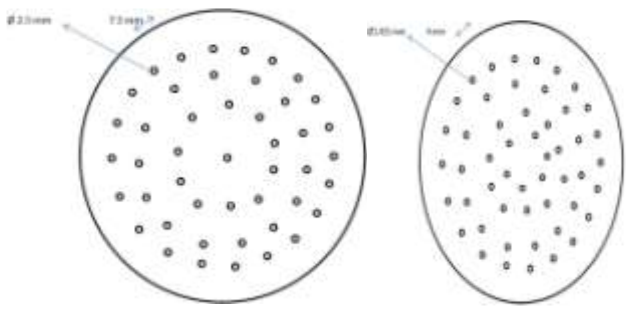


Fig. 1. Schematic of experimental set up

Table 1. Salient features of the jet headers

Salient Features	Jet Diameter (D)	Number of Holes	Jet to Jet Spacing	Number of Arrays	Shape
Jet Header 1	2.5 mm	80	7.5 mm	4	Circular
Jet Header 2	1.425 mm	80	4.0 mm	6	Circular

The commercially available heating coils having capacity of 3.5 kW were placed over ceramic base plates. Inorder to ensure uniform heating a proper gap was main- tained between the upper surface of the heater and the lower surface of the steel plate. The bed was made to move vertically over the test stand with help of a pulley and hand wheel assembly arrangement. This was done to vary the shower exit to plate distance as per requirement. The total height of the test bed assembly was 7 ft. Square steel plate of 200 mm side and 6 mm thickness was used in the current research. Five K – type thermocouples having accuracy of ±2.10C were spot welded at suitable loca- tions on the bottom surface of the plate to measure the temperature. The thermocouple data were accessed by CHINO – DAS with an accuracy rating of ±0.1%±1digit and using Zaila software the obtained data were processed.



Jet Header 1 Jet Header 2

Fig. 2. Jet Headers used in the study

III. Experimental Procedure

The steel plate was heated to a temperature slightly higher than the test temperature to compensate for the heat loss during transfer of the steel plate from the heater to test bed (underneath the jet array system). When the temperature of the steel plate reached the required temperature the jet array was impinged on the hot steel surface and tem- perature - time data was generated with aid of CHINO - DAS. The initial temperature of the steel plate was varied between 750^0C to 950^0C and the jet to surface distance

(H) was varied as 70mm, 135mm and 255mm.The mass flow rate was taken for dif- ferent values between 0.5 to 9.56 lt./min. The mass flux density for different shower exit to surface gap was measured by means of a mechanical patternator. These were the same locations where the heat transfer experiments were subsequently conducted.

IV. Results And Discussion

The variations of temperature with respect to time were measured at various key loca- tions on the steel plate. From these data, the rate of heat transfer from the plate were calculated. This research mainly illustrates the relationships between the rate of heat transfer and the primary parameters: water pressure, mass flow rate, mass impinge- ment density and shower exit to surface distance.

Transient Temperature Profiles

The non-dimensional temperature difference against non-dimensional time for water pressure range of 2 - 4 bar is plotted in Figure 2. The non-dimensional temperature difference is taken as the ratio of the measured temperature difference to the cooling water temperature as shown in equation 1. The non-dimensional cooling time is calcu- lated by using equation 2.

$$\Delta T^* = \frac{\Delta T}{T_c} \quad (1)$$

$$t^* = \frac{l^2}{\alpha} t \quad (2)$$

Where ΔT represents the temperature difference, T_c represents cooling water tem- perature, l is the length of the plate, α represents thermal diffusivity and t is time of spray. From the figure 3 (a) and (b) it is seen that with increase in pressure, the fall in non-dimensional temperature difference becomes steep. But as the pressure is in- creased from 3.5 bar to 4 bar, the steepness reduces. The possible explanation to this might be as the pressure increases so does the atomization of water particles which results in blow off there by not contributing significantly to the cooling process.

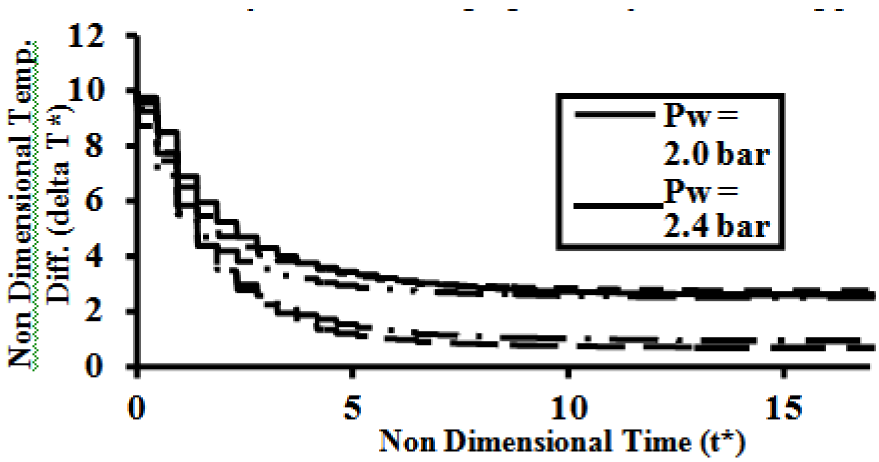


Fig. 3. (a): Temperature Profile for Different Water Pressure (Jet Header 1)

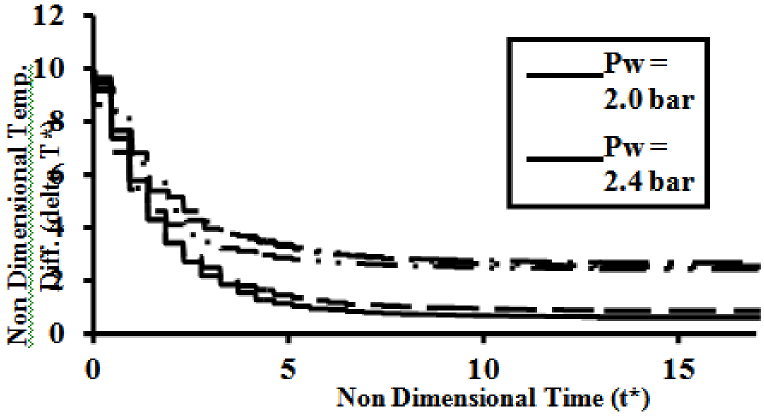


Fig. 4. (b): Temperature Profile for Different Water Pressure (Jet Header 2)

Effect of Reynolds Number

Reynolds Number defined as the ratio of inertia force to that of viscous force. Hence an increase in velocity leads to increased Reynolds number. Nusselt number is expressed as the ratio of convective heat transfer to heat transfer by conduction. The following correlations were used to calculate the Nusselt numbers:

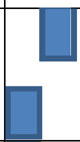
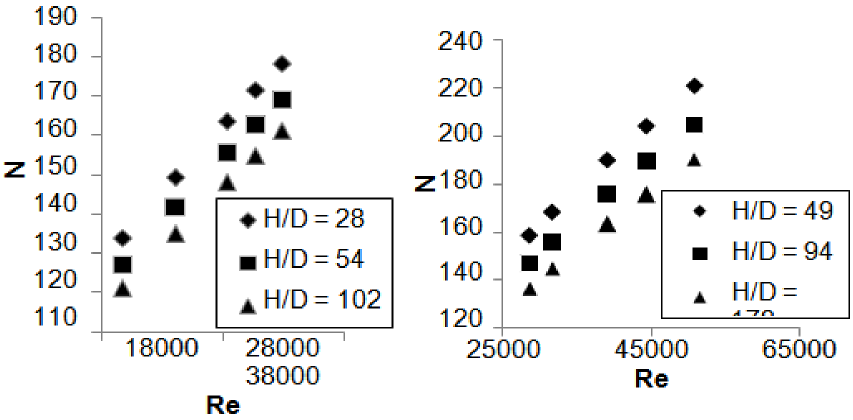
	Hole Shape	Correlation	
Jet Header 1		Nu = 0.641*Re^0.566*(H/D)^-0.078	Lee and Lee (2000)
Jet Header 2		Nu = 0.698*Re^0.573*(H/D)^-0.116	Lee and Lee (2000)

Figure 4 (a) and (b) illustrates the effect of Reynolds number on the Nusselt num- ber for different H/D ratio. From the figures it is clearly indicated that the Nusselt number increases gradually with the increase of Reynolds number. Also the Nusselt number varies inversely with the H/D ratio. It could be predicted that with the increase in distance, a less amount of water jet hit to the surface. Thus there could be continuous dry-wet situation over the plate. Most of the jets blown off outside the plate surface. This could be confirmed from the measurements of mass impingement density.



(a) (b)

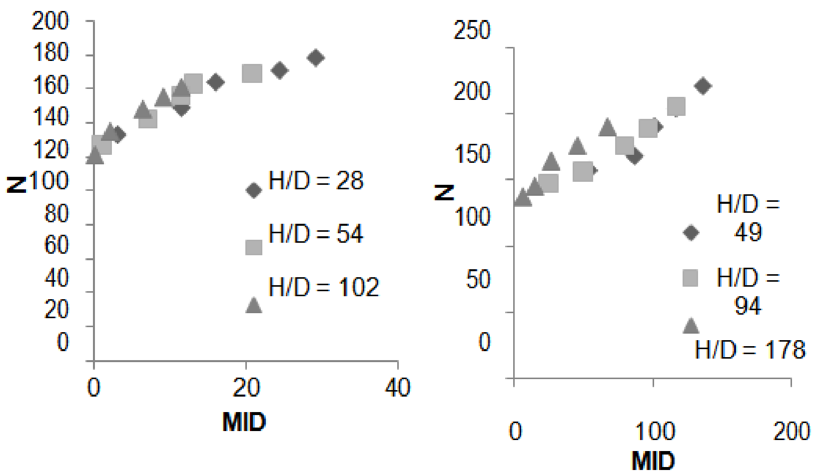
Fig. 5. (a) and (b): Nusselt Number vs Reynolds Number for Jet Header 1 and 2

Effect of Mass Impingement Density (MID)

By using a simple mechanical patternator, the average and local liquid mass flux (or liquid impingement density) was measured at various water pressures/ water flow rates by using the following equation.

$$\dot{m}_s = \frac{4.M_w}{\pi.d_t^2.\Delta t} \quad (3)$$

The tubes collect the water mass M_W from the spray over a period of Δt. The water impingement density ' $\dot{m}_s$ ' was calculated, where „d_t" is the tube diameter. The varia- tion of Nusselt number with mass impingement density is shown in figure 5 (a) and (b). The increase of Nusselt number indicates that there is an increase in heat transfer from the plate surface as the mass impingement density increases.



(a) **(b)**

Fig. 6. (a) and (b): Nusselt number vs. MID for jet header 1 and 2

V. Conclusion

Investigation on heat transfer characteristics of jet array cooling was performed in a simple experimental setup that consisted of two jet headers of different configura- tions. The fluid flow and heat transfer characteristics of these headers were compared through experimental results and presented. The following conclusions were drawn from the experimental work:

- The observation revealed that the header orifice arrangement and design of jet header has great influence on the cooling rate.
- Nusselt number varies directly with the Reynolds number
- With increase in the shower tip to target space the local impingement density dis- tribution decreases.

From the data generated it was observed that jet header 2 showed maximum heat transfer rate with maximum value of Nusselt reaching upto 221.128 compared to
177.95 for header 1.

References

[1]. Peng Xu, Shuxia Qiu, MingZhou Yu, Xianwu Qiao, Arun S. Mujumdar "A study on the heat and mass transfer properties of multiple pulsating impinging jets" In- ternational Communications in Heat and Mass Transfer 39 (2012) 378–382

[2]. C. Nuntadusit, M. Wae-hayee, P. Tekasakul, S. Eiamsa-ard "Local heat transfer characteristics of array impinging jets from elongated orifices" International Communications in Heat and Mass Transfer 39 (2012) 1154–1164

[3]. Shyy Woei Chang, Shyr Fuu Chiou, Shuen Fei Chang "Heat Transfer of Imping- ing Jet Array Over Concave-Dimpled Surface with Apllications to Cooling of Electronic Chipsets" Experimental Thermal and Fluid Science 31 (2007) 625–640

[4]. A.J. Robinson and E. Schnitzler "An experimental investigation of free and sub- merged miniature liquid jet array impingement heat transfer" Experimental Thermal and Fluid Science 32 (2007) 1–13

[5]. V. Katti, S.V. Prabhu, "Influence of spanwise pitch local heat transfer distribution for in-line arrays of circular jets with air flow in two opposite" Experimental Thermal and Fluid Science 33 (2008) 84–95.

[6]. H.C. Chiu, J.H. Jang, W.M. Yan, "Experimental study on the heat transfer under impinging elliptic jet array along a film hole

surface using liquid crystal thermo- graph" International Journal of Heat and Mass Transfer 52 (2009) 4435–4448.

[7]. Pil – Jong Lee, Hae – Won Choi, Sung Hong Lee, (2003) " The effect of ambient air condition on heat transfer hot steel plate cooled by an impinging water jet" KSME International Journal, Vol. 17 No. 5 , pp. 740 – 750.

[8]. B.P. Whelan, A.J. Robinson, "Nozzle geometry effects in liquid jet array im- pingement" Applied Thermal Engineering (2008), doi:10.1016/j.applthermaleng.2008.11.003.

[9]. Lee, J. and Lee, S. J. (2000). "The effect of nozzle configuration on stagnation region heat transfer enhancement of axisymmetric jet impingement". Int. J. Heat Mass Transfer, 43: 3497–3509.