Experimental Investigations on Influences of Nozzle Dimension on Thermal Characteristics with Impinging Water Jets

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ABSTRACT *The research workdemonstrates the experimental investigations on the heat transfer performance of an axisymmetric water jet impinging on a heated plate. Several influencing parameters relating to the thermalbehavior of the water jet impingement are identified and their effects on heat transfer characteristics are also studied. The parameter considered is nozzle diameter (3-6 mm). Furthermore, the studies are limited to a constant heat flux situation. The careful observations of the results divulge that the performance of water jet can be optimized with regard to thiskey parameter. However, with the current experimental conditions, the nozzle diameter of 5 mm offers reasonableheat transfer behaviorand is the finest one.*

Keywords:Heat Transfer; axisymmetric;Water jet; Target plate;Nozzle diameter.

I. Introduction

The increasingdesires for faster and smaller electronic components in the electronic industry has resulted in the development of compact electronic equipments with high power densities. Conventional air cooling is insufficient in most cases to help sustain and safeguard the electronics components from the thermal failure. Sanyal *et al*. [1] numerically studied on heat transfer from pin-fin heat sink using steady and pulsated impinging air jets. Saha and Dutta [2] developed heat transfer correlations for PCM-based heat sinks with plate fins. Chaudhari*et al*. [3] examined heat transfer characteristics of synthetic air jet impingement cooling. Narasimhan*et al*. [4] investigated on thermal management using the bi-disperse porous medium approach. Yu *et al*. [5] compared a series of double chamber model with various hole angles for enhancing cooling effectiveness by air jets. Besides, Yu *et al*. [6] also carried out numerical simulation on the effect of turbulence models on impingement cooling of double chamber model. Cheng *et al*. [7] numerically studied air/mist impinging jets cooling effectiveness under various curvature models. Nguyen *et al*. [8] investigated cooling effect by sub-zero cold air jet in the grinding of a cylindrical component. Gould *et al*. [9] studied jet impingement cooling of a silicon carbide module. Zhao *et al*. [10] also investigated the effect of guide wall on jet impingement cooling.

II.Objectives of Present Research Work

Cautiousevaluation and investigation of the already stated relevant literature reveals no clear cut and prior theoretical and experimental investigation on the local heat transfer under an obliquely impinging, axisymmetric free surface water jet flow for Reynolds number of range 800-3200. In addition, to the best of the authors' knowledge, there is not a single comprehensive experimental study pertaining to the effects of the jet velocity rate and the nozzle diameter on the heat transfer behavior over the heated target plate previously maintained at a uniform heat flux of 6.25 W/cm^2 for investigating the relative importance of the key parameters involved. With this viewpoint, the current paper demonstrates experimental investigations relating to the influence and role of the jet diameter (3-6 mm) on the local heat transfer characteristics over a flat plate heated from the underneath and maintained at a uniform flux of 6.25 W/cm^2, for free surface axisymmetric water jet impingements. Additionally, the results thus obtained are analyzed and compared, so as to realize deeply, the heat transfer behavior over the target plate for achieving better cooling effect.

III. Test Apparatus and Practices

Figure1 represents the photograph of the complete assembly of the experimental setup. It consists of a heater kept in a rectangular Plexiglas box, a nozzle connected to a rotameter via a flexible pipe and a copper target plate mounted on the heater. The heater consisting of tungsten filament (with heater wire diameter of 0.576 mm and heater element resistance of 4.3 Ω) is connected to a dual supply D.C. power source. For particular values of current and voltage the heat flux to the heater remains constant. A digital multimeter (Keithley 2700 model) is used to measure the voltage, whereas, current is directly measured from the display unit of power supply.The rotameter is connected to a water supply tap by means of a flexible pipe with brass ball valve arrangement for regulating water flow. The copper plate mounted on the heater have got grooves underside in order to accommodate thermocouples connected to data acquisition system. The surface of the copper plate is polished with sand paper and then is cleaned with acetone before conducting experiments. The nozzle is kept perpendicular or inclined to the target plate by means of a vertical stand with clamp arrangement. The test fluid (water) discharges out through the outlet of the test chamber after impinging on the target plate.

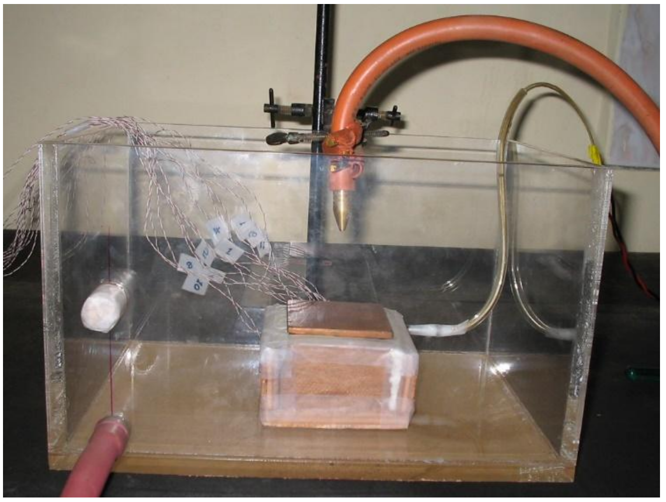

Fig 1. Photograph of the experimental setup.

The temperature variation on the plate is assumed to be a step function. The assumption is only used for calculating the average heat transfer coefficient or the average Nusselt number for the normal jet impingement.

Here, local heat transfer coefficient, $$h_i = \frac{Q_{out}}{A_h (T_{si} - T_j)}\ ;\ Q_{out} = VI \quad \textbf{(1)}$$

So, average heat transfer coefficient, $$\bar{h} = \frac{\sum h_i A_i}{\sum A_i} \quad \textbf{(2)}$$

Average heat transfer coefficient, $$\bar{h} = \left[\frac{Q_{out}}{A_h^2}\right] \sum \left(\frac{A_i}{T_{si} - T_j}\right) \quad \textbf{(3)}$$

Hence, local Nusselt number, $$\mathrm{Nu}_i = \frac{h_i d}{k} \quad \textbf{(4)}$$

Now, average Nusselt number, $$\overline{\mathrm{Nu}} = \frac{\bar{h} d}{k} \quad (5)$$

IV. Results and Discussions

Rigorous experiments are performed to study the effects of nozzle diameter (d) on the heat transfer behavior over the heated target plate subjected to a uniform heat flux. At the outset, a base case of nozzle diameter 5 mm and a normal water jet of flow rate 30 lph corresponding to Reynolds number of 2400 is considered. The heat flux of 6.25 W/cm^2 (corresponding to 30 V and 2 A of D. C. power source associated with copper target plate of size 31 mm × 31 mm) is applied in all investigations. The results thus obtained in line with the stated base case experimental conditions are analyzed to investigate further the role and effect of the said key process parameters involved.

Influences of Nozzle Dimension

Apart from the stated base case involving nozzle diameter of 5 mm, in this study three more nozzle diameters of 3, 4 and 6 mm are taken into account with the said experimental conditions. The results thus obtained are compared to investigate the role and effect of the nozzle diameter. Figs. 2-3illustrate the variation of both stagnation and average Nusselt numbers with the nozzle diameter.

Figure2 shows the variation of both stagnation and average Nusselt numbers with the nozzle diameter at different jet Reynolds numbers.

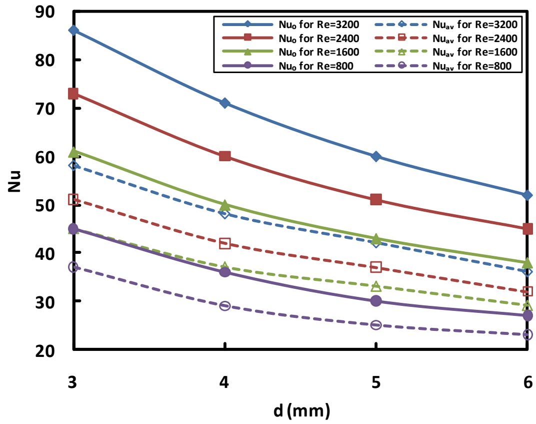

Fig 2. Nu vs. d at different Re.

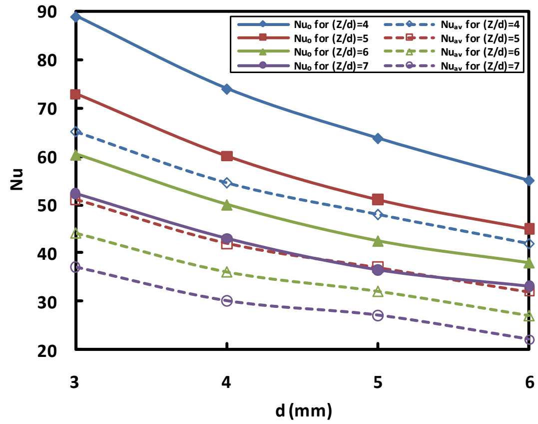

Fig 3. Nu vs. d at different (Z/d).

Figure3 shows the variation of both stagnation and average Nusselt numbers with the nozzle diameter at different nozzle to plate spacings.

From the quoted figures, it is quite obvious that both stagnation and average Nusselt numbers decrease with increase in nozzle diameter. This can be owing to the fact that for same jet flow rate the higher nozzle diameter causes the lower jet velocity/jet Reynolds number and hence gives rise to the carrying away of heat from the target plate at relatively slower rate. In addition, for a particular nozzle diameter, both stagnation and average Nusselt numbers increase with Reynolds number (Fig. 2). Similarly, for a particular nozzle diameter, both stagnation and average Nusselt numbers decrease with increase in Reynolds number(Fig. 3). And also, from Fig. 2 and Fig 3, it is evident that the variation of both stagnation and average Nusselt numbers with nozzle diameter is almost linear.

VI. Conclusion

For investigations on the heat transferperformance, complete experiments are performed and accordingly measurements are taken for different combinations of interconnected and interdependent parameters concerned with a water jet impinging on a heated plate. Exhaustive experimental studies on the effects of the nozzle diameter are conducted as it highly influence the thermal performance of the water jet impingement. In accordance with the measurements taken and the data obtained, the trends of the results pertaining to the parameters are found to be along expected lines. Besides, the appropriate combinations of the influential and interrelated parameters for which enhancement in the averaged heat transfer from the plate can be expected is also identified. Direct comparison with other experimental/numerical results is not possible due to non-availability of such experimental conditions in the literature. Additionally, comparison with a numerical model pertaining to the present experimental conditions is planned for the future. However, the current study also neglects target plate side heat losses because of lesser thickness comparable to length/breadth. Nevertheless, with the current experimental condition the nozzle diameter of 5 mm provides reasonableheat transfer performanceand is the finest one. Therefore, the currentarrangement can be applied straightway in production houses to augment heat transfer useful for cooling of electronic structures.

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