Experimental Research on Impacts of Nozzle to Plate Gap on Thermal Features with Water Jet Impingements

Dr. Nirmal Kumar Kund

Associate Professor, Department of Production Engineering

Veer Surendra Sai University of Technology, Burla, Odisha, India
nirmalkund@gmail.com

Abstract

The research work describes the experimental investigations on the thermal performances of an axisymmetric water jet striking on a heated target plate. Different key process parameters on the subject of the heat transfer behaviors of the water jet impingement are traced out and their influences on thermal performances involving nozzle to plate gap (20-35 mm) are studied. Furthermore, the investigations are constrained to a uniform heat flux circumstance. The cautious observations of the results divulge that the performance of water jet can be optimized in connection with these important parameters. Additionally, with the present experimental settings, the nozzle to plate gap of 25 mm provides reasonable thermal performance and is the optimal one.

Keywords: Heat transfer, Water jet, Target plate, Nozzle to plate gap.

1. Introduction

Traditional air cooling is lacking 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.

2. Objectives of Present Research Work

Cautious review and examination 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. In addition, to the best of the authors' knowledge, there is not a single comprehensive experimental study pertaining to the effects of the nozzle to target plate spacing and the nozzle inclination 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 nozzle to plate gap (20-35 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.

3. Test Apparatus and Procedures

Figure 1 illustrates 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.

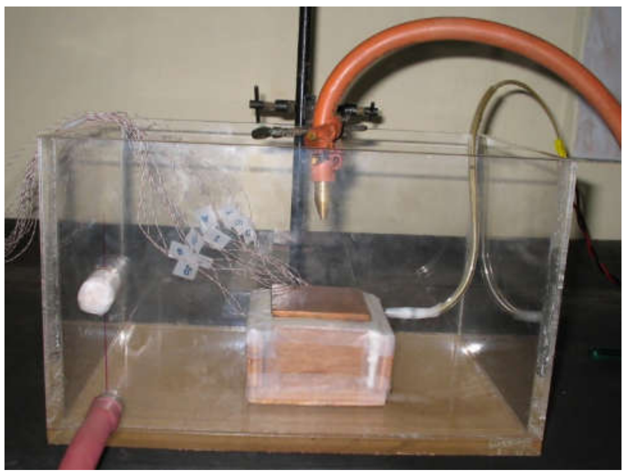

Figure 1. Photograph of Experimental Setup.

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, $$h_i = \frac{Q_{out}}{A_h(T_{si} - T_j)};\ Q_{out} = VI \quad (1)$$

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

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

Hence, local Nusselt number, $$Nu_i = \frac{h_i d}{k} \quad (4)$$

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

4. Results and Discussions

Thorough experiments are performed to study the effects of nozzle-to-target plate gap 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 with the nozzle to target plate spacing of 25 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.

Influences of Nozzle to Plate Gap

Despite the said base case involving nozzle to target plate gap of 5 times the nozzle diameter, in the present study three more nozzle to plate gaps of 4, 6 and 7 times the nozzle diameter are taken into consideration with the stated experimental conditions. The results so observed are compared to investigate the role and effect of the nozzle to plate spacing. Fig. 8 depicts the variation of both stagnation and average Nusselt numbers with the nozzle to plate spacing.

Figure 2 shows the variation of both stagnation and average Nusselt numbers with the nozzle to target plate gap at different jet Reynolds numbers.

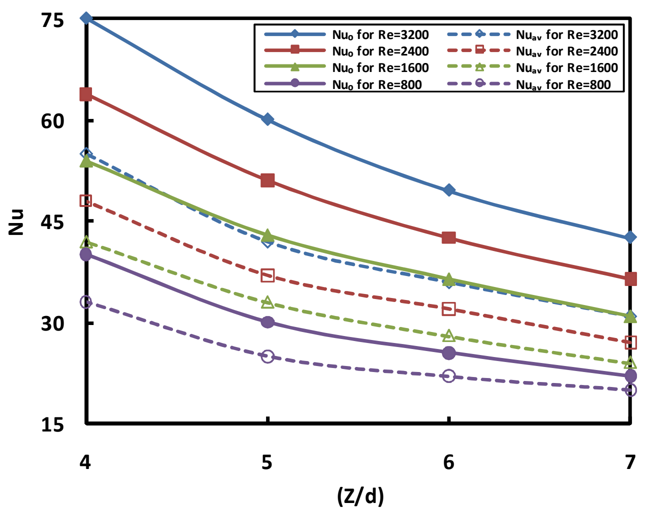

Figure 2. Nu vs. (Z/d) at different Re.

Figure 3 shows the variation of both stagnation and average Nusselt numbers with the nozzle to target plate gap at different nozzle diameters.

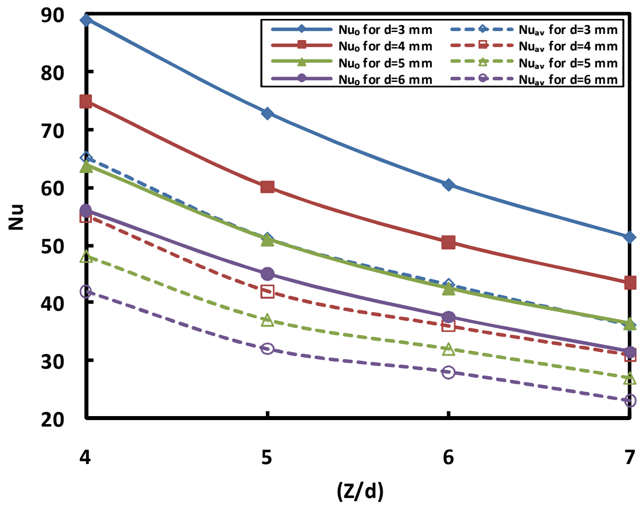

Figure 3. Nu vs. (Z/d) at different d.

From the cited figures, it is evident that both stagnation and average Nusselt numbers decrease with increase in nozzle to plate gap. This result as expected can be on account of the higher nozzle to plate spacing causing the carrying away of heat from the target plate at relatively slower rate. Additionally, for a particular nozzle to plate gap, both stagnation and average Nusselt numbers increase with Reynolds number as depicted in Figure 2. Likewise, for a particular nozzle to plate spacing, both stagnation and average Nusselt numbers decrease with increase in nozzle diameter as depicted in Figure 3. Here also, from Figures, 2 and 3, it is apparent that the variation of both stagnation and average Nusselt numbers with nozzle to plate gap is nearly linear.

5. Conclusion

To investigate the heat transfer performance, broad experiments are conducted 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 to plate gap are conducted as they highly influence the thermal behavior of the water jet impingement. In accordance with the measurements taken and the data obtained, the trends of the results pertaining to various 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. Furthermore, comparison with a numerical model pertaining to the present experimental conditions is planned for the future. In addition, the present study also neglects target plate side heat losses because of lesser thickness comparable to length/breadth. Nevertheless, with the present experimental conditions, the nozzle to plate gap of 25 mm (at nozzle diameter of 5 mm and jet Reynolds number of 2400) provides reasonable heat transfer performance and is the finest one. Hence, the current combination can be used right away in industries to improve heat transfer useful for cooling of electronic devices.

Acknowledgments

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