Experimental Examinations on Sways of Jet Angle on Heat Transfer Characteristics by Impinging Water Jets

Dr. Nirmal Kumar Kund

Associate Professor, Department of Production Engineering

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

Abstract

This article elucidates the experimental studies on the heat transfer behavior of an axisymmetric water jet impinging on a heated plate. Various influencing parameters pertaining to the thermal performance of the water jet impingement are identified and their effects on heat transfer characteristics involving jet angle (30-90°) are studied. Additionally, the studies are limited to a constant heat flux situation. The careful observations of the results reveal that the performance of water jet can be optimized with regard to these key parameters. However, with the current experimental conditions, the jet angle of 60º gives moderate heat transfer characteristics and is the optimum.

Keywords: Heat transfer, Water jet, Target plate, Jet angle.

1. Introduction

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.

2. Objectives of Present Research Work

Careful 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 gap and the nozzle angle 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 angle (30-90°) 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 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.

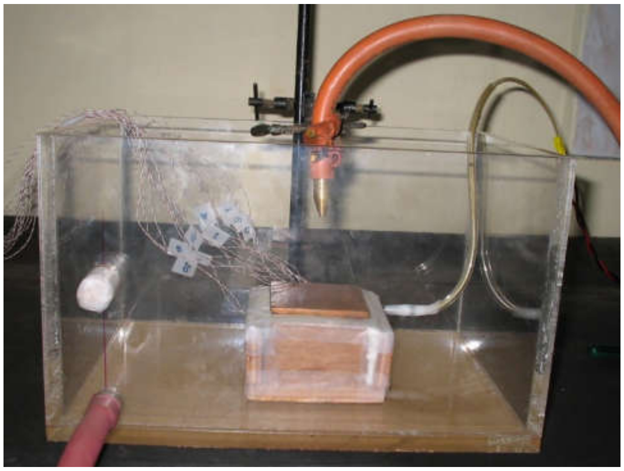

Figure 1. Photograph of Experimental Setup.

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

Rigorous experiments are performed to study the effects of jet angle 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 gap 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 Jet Angle

Besides the said base case involving jet angle of 90°, in this investigation four more jet angles of 30, 45, 60 and 75° are carefully considered with the stated experimental conditions. The corresponding results are analyzed and compared to study the role and effect of the jet angle. Figures 2-4 describes the variation both stagnation and average Nusselt numbers with the jet angle.

Figure 2 shows the variation of both stagnation and average Nusselt numbers with the nozzle angle at different jet Reynolds numbers.

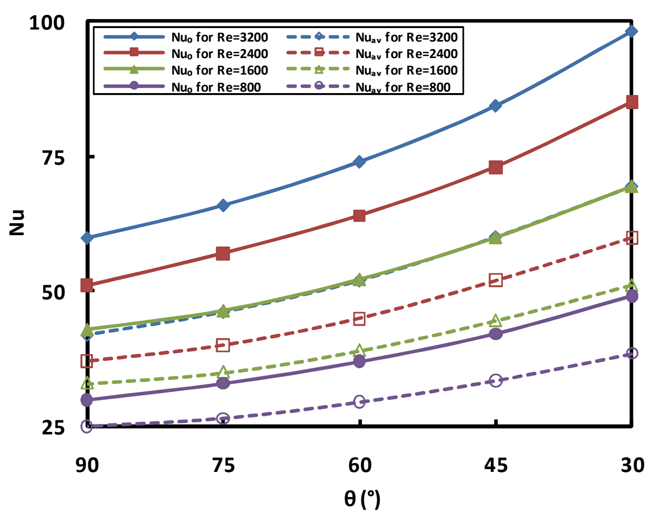

Figure 2. Nu vs. θ at different Re.

Figure 3 shows the variation of both stagnation and average Nusselt numbers with the nozzle angle at different nozzle diameters.

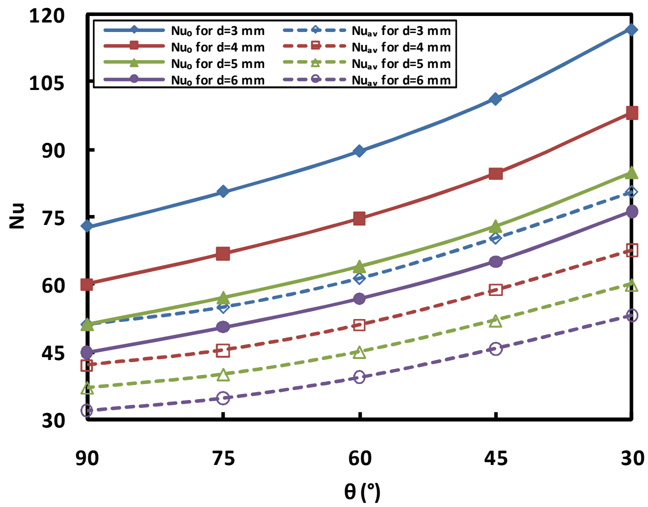

Figure 3. Nu vs. θ at different d.

Figure 4 shows the variation of both stagnation and average Nusselt numbers with the nozzle angle at different nozzle to target plate gaps.

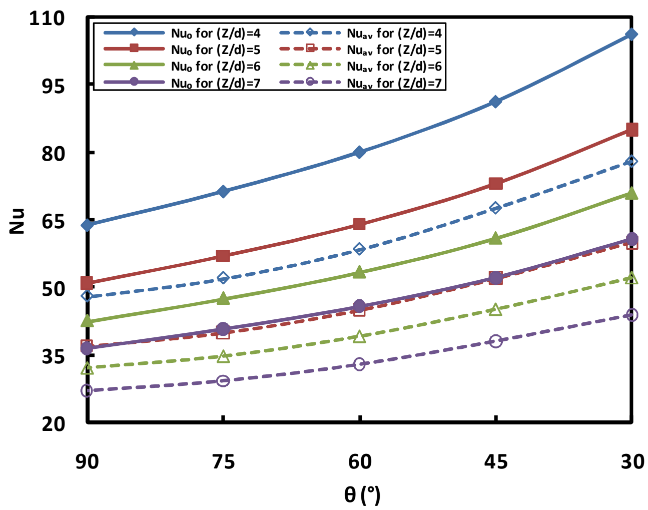

Figure 4. Nu vs. θ at different (Z/d).

From the stated figures, it is apparent that both stagnation and average Nusselt numbers increase with decrease in jet angle. It may be due to the higher local water flow rates on the downstream side for the oblique jet impingement resulting in the taking away of heat from the target plate at faster rate. This result is to be expected in view of the positive dependence of the heat transfer rate on the local water flow rates. Also, for a particular jet angle, both stagnation and average Nusselt numbers increase with increase in Reynolds number as illustrated in Figure 2. Furthermore, for a particular jet angle, both stagnation and average Nusselt numbers decrease with increase in nozzle diameter/nozzle to plate gap/jet angle as demonstrated in Figures 2-4. Moreover, from Figures 2-4, it is quite evident that the variation of both stagnation and average Nusselt numbers with jet angle is approximately linear.

5. Conclusion

To study the heat transfer behavior, comprehensive experiments are carried out 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 investigations on the effects of the jet angle and the nozzle to plate gap are conducted as they 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 various parameters are found to be along expected lines. However, the enhancement in the averaged heat transfer characteristics with water jet angle is newly identified. 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 jet angle of 60º at nozzle diameter of 5 mm, nozzle to plate gap of 25 mm and the jet Reynolds number of 2400 gives moderate heat transfer behavior and is the optimum. Hence, the present combination can be used directly in industries to enhance heat transfer and for cooling of electronic gadgets.

Acknowledgments

The author would like to thank the editor and the reviewers for their kind considerations and valuable time together with the thorough and insightful efforts for reviewing the manuscript.

References

[1] Sanyal A, Srinivasan K, Dutta P. “Numerical study of heat transfer from pin-fin heat sink using steady and pulsated impinging jets”. IEEE Transactions on Components and Packaging Technology. 2009; 32(4): pp. 859-867.

[2] Saha SK, Dutta P. “Heat transfer correlations for PCM-based heat sinks with plate fins”. Applied Thermal Eng. 2010; 30: pp. 2485-2491.

[3] Chaudhari M, Puranik B, Agrawal A. “Heat transfer characteristics of synthetic jet impingement cooling”. Int J Heat Mass Transfer. 2010; 53(5-6): pp. 1057-1069.

[4] Narasimhan A, Reddy BVK, Dutta P. “Thermal management using the bi-disperse porous medium approach”. Int J Heat Mass Transfer. 2012; 55(4): pp. 538-546.

[5] Yu Z, Xu T, Li J, Ma L, Xu T. “Comparison of a series of double chamber model with various hole angles for enhancing cooling effectiveness”. Int Comm Heat Mass Transfer. 2013; 44: pp. 38–44.

[6] Yu Z, Xu T, Li J, Xiu H, Li Y. “Numerical simulation on the effect of turbulence models on impingement cooling of double chamber model”. Mathematical Problems in Eng. 2013; Article ID 170317: pp. 1-8.

[7] Cheng P, Yao G, Chen W, Li B, Li J, Xu T, Yu Z, Ma L. “Computational study of air/mist impinging jets cooling effectiveness under various curvature models”. Advances in Mechanical Eng. 2014; Article ID 569243: pp. 1-9.

[8] Nguyen T, Liu M, Zhang LC. “Cooling by sub-zero cold air jet in the grinding of a cylindrical component”. Int J Adv Manuf Technol. 2014; 73(1-4): pp. 341-52.

[9] Gould K, Cai SQ, Neft C, Bhunia A. "Liquid jet impingement cooling of a silicon carbide power conversion module for vehicle applications". IEEE Trans Power Electronics. 2015; 30(6): pp. 2975-2984.

[10] Zhao QY, Chung H, Choi SM, Cho HH. "Effect of guide wall on jet impingement cooling in blade leading edge channel". J Mech Sci Technol. 2016; 30(2): pp. 525-531.