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EXPERIMENTAL INVESTIGATIONS ON EFFECTS OF NOZZLE TILT ANGLE IN LIQUID JET IMPINGEMENT COOLING

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Abstract*— The current research encompasses the experimental studies of the heat transfer performance of axisymmetric water jet impinging on a heated plate. Several parameters affecting the thermal behaviour of axisymmetric water jet are identified and their effects on heat transfer characteristics are also studied. The key parameters considered is nozzle tilt angle (30-90°). Besides, all the studies here are limited to a constant heat flux condition. Results show that the water jet performance can be optimized pertaining to these key parameters. Nonetheless, with the present experimental conditions, the jet tilt angle of 60º provides reasonable heat transfer characteristics and is the optimum one.

***Keywords*— Water Jet, Nozzle, Plate, Tilt angle.**

I. INTRODUCTION

The constant increase in requirements 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. Garimella and Nenaydykh [1] have experimentally investigated the effect of nozzle geometry on the local heat transfer of FC-77 per-fluorinated dielectric liquid for normal jet impingement. Chakraborty and Dutta [2] found analytical solutions for heat transfer during cyclic melting and freezing of a phase change material used in electronic and electrical packaging. Nayak *et al*. [3] developed a numerical model for heat sinks with phase change materials and thermal conductivity enhancers. Pavlova and Amitay [4] studied on the heat transfer behavior of electronics with synthetic normal jet impingement.

Besides, Adoni *et al*. [5] developed a thermo-hydraulic model for capillary pumped loop and loop heat pipe used for cooling of electronics. Saha *et al*. [6] investigated on optimum distribution of fins in heat sinks filled with phase change materials. Sanyal *et al*. [7] numerically studied on heat transfer from pin-fin heat sink using steady and pulsated impinging air jets. Chaudhari *et al*. [8] examined heat transfer characteristics of synthetic air jet impingement cooling. Yu *et al*. [9] compared a series of double chamber model with various hole angles for enhancing cooling effectiveness by air jets. Besides, Cheng *et al*. [10] numerically studied air/mist impinging jets cooling effectiveness under various curvature models.

Cautious analysis 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 tilt 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 tilt 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.

II. DESCRIPTION OF EXPERIMENTAL SETUP

Figure 1 represents the photograph of the complete assembly of the experimental setup consisting 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.

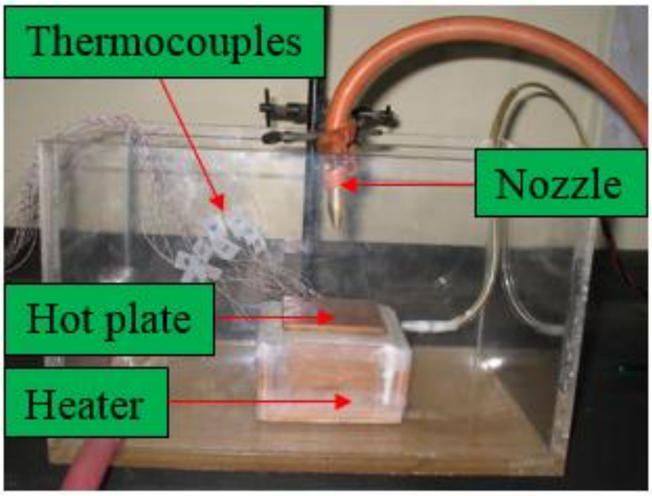

Fig 1. Photograph of experimental setup

III. RESULTS AND DISCUSSIONS

Thorough experiments are performed to investigate the effects of nozzle to-target plate spacing, nozzle diameter, jet velocity and jet tilt angle on the heat transfer distribution over the heated target plate subjected to a uniform heat flux. To begin with, a nozzle of diameter 5 mm with the nozzle to target plate spacing of 25 mm and a normal water jet of flow rate 30 lph. 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.

Effect of jet tilt angle

Apart from the stated case involving jet tilt angle of 90°, in this investigation four more jet tilt angles of 30, 45, 60 and 75° are carefully considered with the said experimental conditions. The results observed are analyzed and compared to study the role and effect of the jet tilt angle.

Figure 2 shows the variation of local Nusselt number with radial distance from the stagnation point for the said jet tilt angles altogether for the comparative investigation. For the axisymmetric water jet with 30° jet tilt angle, the local Nusselt number varies from 13 at the upstream edge (left side) to 43 at the downstream edge (right side) through 85 at the stagnation point (centre) of the target plate. Likewise, for the axisymmetric water jets with 45, 60 and 75° jet tilt angles, the local Nusselt numbers vary from 16, 20 and 23 at the upstream edge to 37, 33 and 29 at the downstream edge through 73, 64 and 57 at the stagnation point of the target plate, respectively. It is observed that the decrease in the jet tilt angle causes notable asymmetry in the local Nusselt number profile resulting in the sharpening of the peak in the Nusselt number profile (leading to the significant increase of the stagnation Nusselt number). In other words, with decreasing tilt angle, the local Nusselt number profiles exhibited an increasing asymmetry around the point of maximum heat transfer (i.e. the stagnation point), with the upstream side of the profile dropping off relatively more sharply compared to the downstream side. This result is to be expected in view of the positive dependence of the heat transfer coefficient on the Reynolds number, as there are higher local flow rates on the downstream side of the profile for oblique impingement.

Figure 3 depicts both stagnation and average Nusselt number variations with the jet tilt angles. The stagnation Nusselt numbers are 51, 57, 64, 73 and 85 for the jet tilt angles of 90, 75, 60, 45 and 30°, respectively. Likewise, the average Nusselt numbers are 37, 40, 45, 52 and 60 for the jet tilt angles of 90, 75, 60, 45 and 30°, respectively. Furthermore, both stagnation and average Nusselt numbers increase with the decrease of jet tilt angle (i.e. with the increase of obliquity). It is also apparent that the variations of both stagnation and average Nusselt numbers with jet tilt angles are nearly linear.

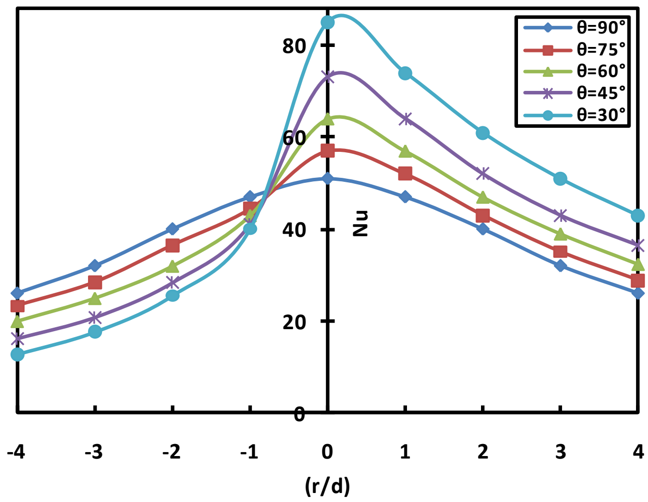

Fig 2. Variation of local Nusselt number with radial distance

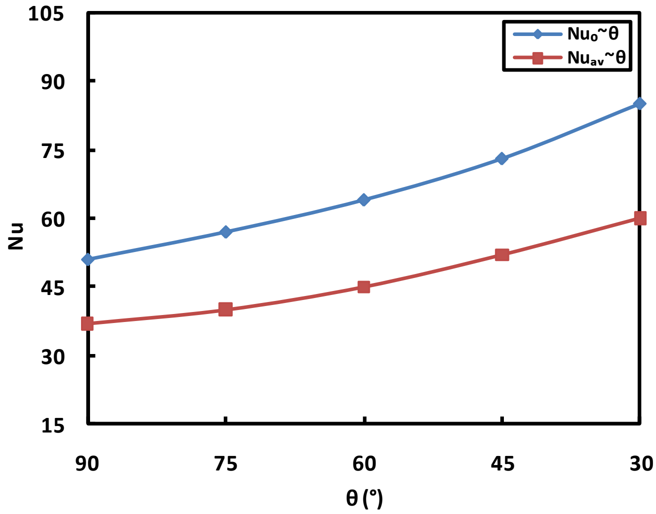

Fig 3. Variation of Nusselt number with jet tilt angle

IV. CONCLUSIONS

Comprehensive experiments are conducted for several combinations of interdependent and interrelated parameters involved with the water jet impingement on a heated plate to study the heat transfer characteristics. Broad experimental studies on the effects of the jet tilt angle are carried out as they greatly influence the thermal performance of the impinging water jets. Based on the measurements and the data derived, the trends of the results with regard to various parameters are observed to be along expected lines. However, the enhancement in the stagnation and averaged heat transfer characteristics with water jet tilt angle is newly identified. In addition, the appropriate combinations of the key interdependent and interconnected 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. However, comparison with a numerical model pertaining to the present experimental conditions is planned for the future. Furthermore, the present study also neglects target plate side heat losses. However, with the present experimental conditions the jet tilt angle of 60° provides reasonable heat transfer behaviour and is the optimum. Hence, the current combination can be utilized unswervingly in industries to enrich heat transfer and for cooling of electronic devices.

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