

# Experimental Examination on Impacts of Jet Inclination on Cooling Performances using Striking Water Jets

N. K. Kund

**Abstract:** Onerous experimentations stay continued for examining influences of jet inclination on heat dispersal over flat plate concerning constant thermal value 6 W/cm<sup>2</sup>. This paper presents the experimental studies on cooling behavior with water jet impingement. Several influencing parameters pertaining to cooling behaviors of striking jets got recognized for investigating impacts over heat transfer characteristics. The parameters taken into account are nozzle diameter (3, 4, 5 and 6 mm), Reynolds number (800, 1600, 2400 and 3200), nozzle to plate spacing (20, 25, 30 and 35 mm) and jet inclination (30°, 45°, 60°, 75° and 90°). Additionally, the studies are limited to a constant heat flux situation. The chary interpretations of results tell that performance remains boosted with regard to these key parameters. However, for present experimental settings, jet inclination of 60° brings plenty cooling badges and is remarkably ultimate.

**Index Terms:** Jet Inclination, Water Jet, Flat Plate, Thermal, Cooling Behavior.

## I. INTRODUCTION

The whisper of firmness of electronic fragments implicate abnormally elevated power densities. Accordingly, electronics cooling desires have grown at enormous rapidity from the development of ICT. Orthodox cooling means used before, like free/forced convection of air are deficient for huge heat energies. Alternating cooling exercise arresting boundless effort is fluid jet impingement. It engulfs strain of tall heat confrontation accompanying the aforesaid methods.

Equally, the nanofluid cooling is bluntly effervescent as air cooling is weak to convey the strength. Both numerical and experimental investigations of heat spreading on flat plate is prominent in the texts [1-10]. Computational enumerations as well as simulations are completely amazing in sorts [11-35].

Thoughtful valuation of the aforesaid relatable writings discloses no up-front experimental exploration on thermal characteristics about impacting water jet. No such experimentation on influences of jet inclination on cooling behaviors with striking water jet. With this outlook, the contemporaneous research institutes experimental studies for the influences of jet inclination (30°, 45°, 60°, 75° and 90°) on cooling behaviors of striking water jet over flat plate concerning constant thermal value 6 W/cm<sup>2</sup>. Additionally, the witnessed results are evaluated/matched for escalating the prominence of nozzle size in accomplishing the sought after cooling.

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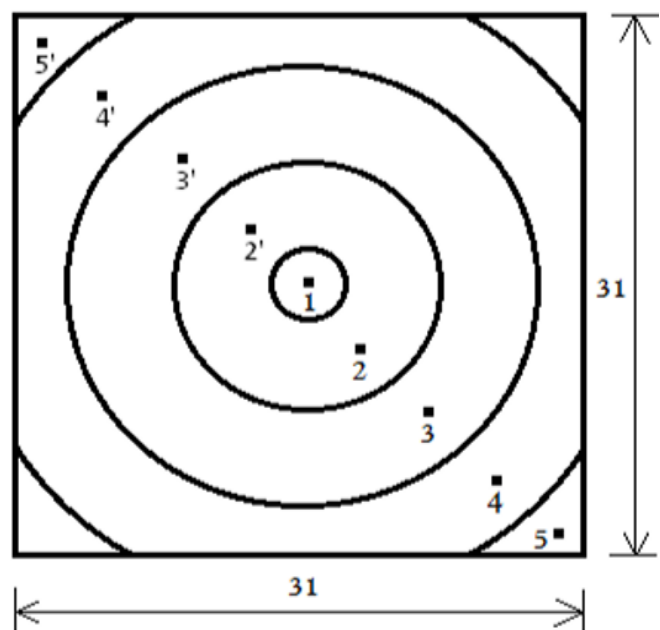
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## II. TEST ARRANGEMENT

It expounds expansively about the particulars of contemporary physical model along with experimental setup.

### A. Demonstration of Physical Problem

Fig. 1 displays the depiction of physical model. It includes a channeled copper flat plate of dimension 31×2×31 mm beneath which T-type thermocouples (with spaces 5 mm) are accommodated along diagonal route. Flat plate is fixed to a heater. Thermocouples got joined with data recording device to store thermal data successively during the experiments.



**Figure 1. Schematic of physical model divided into annuli**

The flat plate is delineated with several annuli vis-à-vis many thermocouples to estimate heat transfer coefficient (h) as well as Nusselt number (Nu) for impacting water jet. The under-mentioned equations 1-5, are used to figure the same.

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

$$\bar{h} = \frac{\sum h_i A_i}{\sum A_i} \quad (2)$$



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

$$Nu_i = \frac{h_i d}{k} \quad (4)$$

$$\bar{Nu} = \frac{\bar{h} d}{k} \quad (5)$$

## B. Illustration of Experimental Setup

Fig. 2 elucidates the unabridged assembly of experimental preparation. It implicates heater housing inside trial compartment, nozzle with stretchy tube, flat plate in addition to thermocouples. Heater with tungsten thread is connected to D.C. drive vis-à-vis both voltage and current. The rotameter is fixed to stretchy tube. Flat plate is having channels beneath to hold thermocouples connected to data acquisition system. The nozzle stays normal to flat plate using upright stand plus lock. Water discharges from outlet of Plexiglas box when impinging on flat plate.

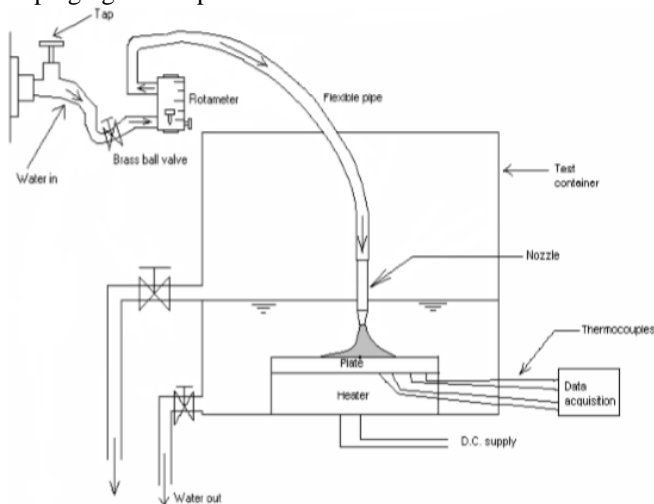


Figure 2. Schematic of experimental setup

## III. EXPERIMENTAL TECHNIQUES

It embroils the measurements of below mentioned variables.

### A. Liquid Flow Measurement

The flow rate of impacting water jet is noted expending a rotameter having measuring limit up to 120 lph (with uncertainty of  $\pm 0.01$ lph). Above and beyond, the adjustment of rotameter is done for killing fluctuations. The jet velocity is calculated from flow rate. The related jet Reynolds number is calculated from said velocity as well.

### B. Temperature Measurement

Polytetrafluoroethylene (PTFE) coated thermocouples (having response time of 0.8 sec) are used for measuring temperature at several plugs on flat plate during the water jet impinging. Particulars of the specifications of thermocouples are stated in Table 1. Thermocouples are calibrated using Pt opposition thermometer. Julabo FH40-MH flow path remains aimed at current effort. Thermal facts got chronicled unceasingly through a PC with storing device. It includes a 40-channel thermocouple plug-in card to observe temperature growth.

Table 1. Thermocouple information

Composition	Type	Dimension (mm)	Thermal limit (°C)
Cu -Constantan	T	0.2	0-200

## IV. RESULTS AND DISCUSSION

Broad experimentations got effectuated to elucidate the appurtenances of Reynolds number on thermal diffusion on flat plate with constant thermal value 6 W/cm<sup>2</sup>. Primarily picked nozzle size, stream rate and jet Reynolds number are 5 mm, 30 lph as well as 2400, one-to-one.

### Influences of Jet Inclination on Cooling Behaviors

Furthermore, 4 additional jet inclinations of 30°, 45°, 60° and 75° are picked for comparative appraisal of results as well.

#### A. Changes in Nusselt Number with Jet Inclination for Varying Reynolds Numbers

Fig. 3 unveils changes in average/stagnation Nusselt numbers with jet inclination for different Reynolds numbers of 3200, 2400, 1600 and 800. As anticipated, it displays, Nusselt number declines for increasing jet inclination. Furthermore, Nusselt number rises through Reynolds number.

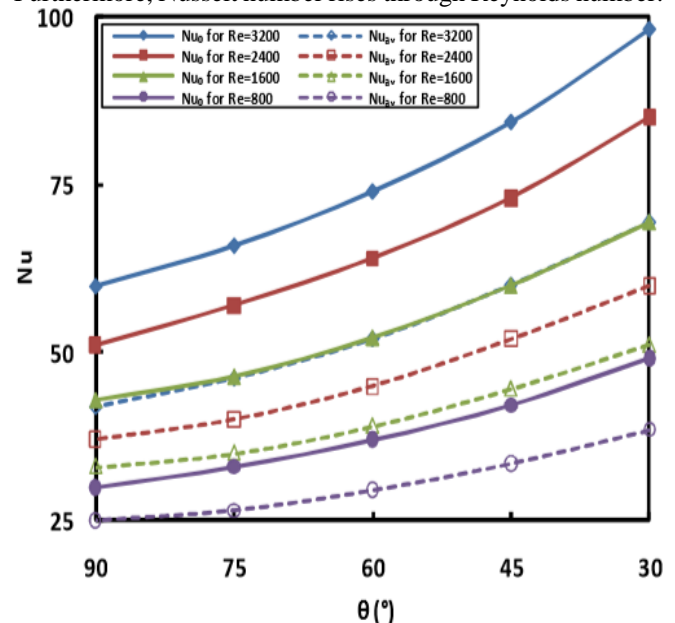


Figure 3. Changes in Nusselt number with jet inclination for varying Reynolds numbers

#### B. Changes in Nusselt Number with Jet Inclination for Varying Nozzle Diameters

Fig. 4 unveils changes in average/stagnation Nusselt numbers with jet inclination for different nozzle diameters of 6, 5, 4 and 3 mm. As anticipated, it displays, Nusselt number declines for increasing jet inclination. Furthermore, Nusselt number declines for increasing nozzle diameter.

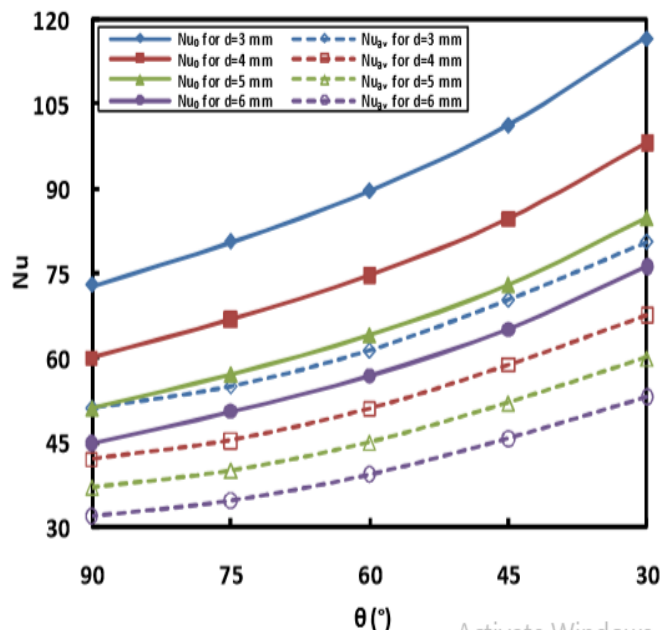


Figure 4. Changes in Nusselt number with jet inclination for varying nozzle diameters

### C. Changes in Nusselt Number with Jet Inclination for Varying Nozzle to Plate Spacings

Fig. 5 unveils changes in average/stagnation Nusselt numbers with jet inclination for different nozzle to plate spacings. As anticipated, it displays, Nusselt number declines for increasing jet inclination. Furthermore, Nusselt number declines for increasing nozzle to plate spacing.

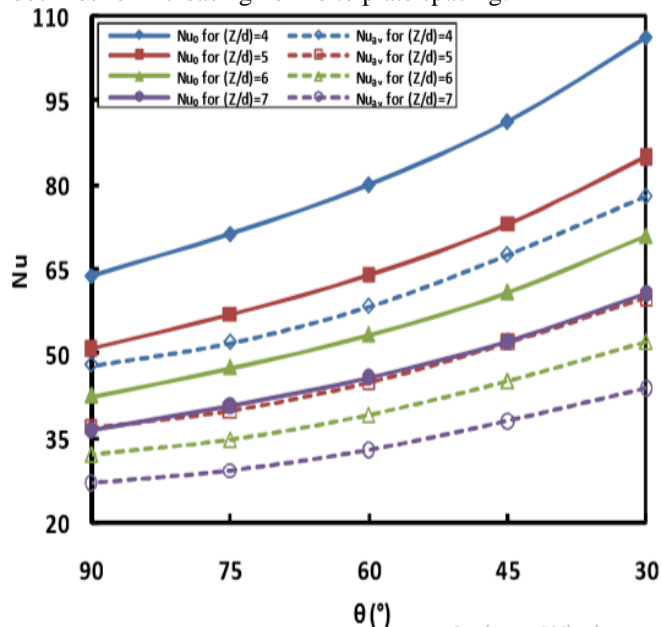


Figure 5. Changes in Nusselt number with jet inclination for varying nozzle to plate spacings

### V. CONCLUSION

Planned experiments remain fortified for examining the impacts of jet inclination on thermal dispersal over flat plate concerning constant thermal value 6 W/cm<sup>2</sup>. For that five different jet inclinations 30°, 45°, 60°, 75° and 90° are preferred, above and beyond, volume level and nozzle size of 30 lph and 5 mm, respectively. As anticipated, it is witnessed that the temperature rises in radial route. Additionally, the witnessed temperature distribution is axisymmetric.

Furthermore, it also discloses that the temperature declines with Reynolds number. Further, the witnessed temperature variation is more or less linear. Similarly, it also displays that the Nusselt number drops along radial course. The witnessed Nusselt number distribution is axisymmetric on top. Besides, it also divulges, Nusselt number grows with Reynolds number. Nusselt number variation stays almost linear. However, the jet inclination of 60° delivers congenial and significant thermal behaviors.

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