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Research Article

Experimental Studies on Heat Transfer Augmentation of Water Jet Impingement on a Horizontal Plate

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Abstract

Impinging jets have received considerable attention during the last decade. The reason is mainly due to their inherent characteristics of high rates of heat transfer besides having simple geometry. Thus most practical applications of jet impingement occur in industries where the heat transfer requirements have exceeded capacity of ordinary heating and cooling techniques. This work presents and discusses the results of an experimental investigation of heat transfer between the horizontal smooth and rough plate of impinged jets. The round jets are used. The experiment is focused on the verification of the jet effect on the distribution of local heat transfer coefficient on the impinged target surface. The effect of flow in jet to test plate distance are also examined at fixed intersect spacing (S/D).It is revealed that flow of the jet improves the radial uniformity of the heat transfer significantly. The heat transfer deteriorates in the stagnation region but gets enhanced in wall jet region.

***Keywords**: Water Jet, Horizontal plate, Plate heater, Nozzle*

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1. Introduction

Jet impingement involves a jet flow of fluid from a nozzle of a given configuration to a target surface. It is a common method for heating or cooling solid surfaces. Heat transfer for impinging jet is generally higher than that achieving with conventional methods. Heat transfer rates in case of impinging jets are affected by various parameters like Reynolds number, nozzle plate spacing, radial distance from stagnation point, Prandtl number, and target plate inclination confinement of the jet, nozzle geometry, and roughness of the target plate.

Industrial Applications of jet impingement

The following industrial applications of jet impingement are:

1. Drying of textiles and films
2. Metal sheet manufacturing
3. Gas-turbine cooling
4. Electronic Component cooling
5. Chip temperature under 115 C
6. Annealing of metal

Classification of Augmentation Techniques

1. Passive Techniques
2. Active Techniques
3. Compound Techniques

1. Passive Techniques: These techniques do not require any direct input of external power; rather they use it from the system itself which ultimately leads to an increase in fluid pressure drop. They generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficients by disturbing or altering the existing flow behaviour except for extended surfaces. Heat transfer augmentation by these techniques can be achieved by using;

- Treated Surfaces: Such surfaces have a fine scale alteration to their finish or coating which may be continuous or discontinuous. They are primarily used for boiling and condensing duties.
- Rough surfaces: These are the surface modifications that promote turbulence in the flow field in the wall region, primarily in single phase flows, without increase in heat transfer surface area.

2. Active Techniques: In these cases, external power is used to facilitate the desired flow modification and the concomitant improvement in the rate of heat transfer. Augmentation of heat transfer by this method can be achieved by 5

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- Mechanical Aids: Such instruments stir the fluid by mechanical means or by rotating the surface. These include rotating tube heat exchangers and scrapped surface heat and mass exchangers.
- Surface vibration: They have been applied in single phase flows to obtain higher heat transfer coefficients.
- Fluid vibration: These are primarily used in single phase flows and are considered to be perhaps the most practical type of vibration enhancement technique.

3. Compound Techniques: When any two or more of these techniques are employed simultaneously to obtain enhancement in heat transfer that is greater than that produced by either of them when used individually, is termed as compound enhancement. This technique involves complex design and hence has limited applications.

2. Literature survey

Luis A. Brignoni and Suresh V. Garimella(1999) presented study seeks to understand the effects of the governing variables in confined air jet impingement on enhanced surfaces including nozzle diameter, flow rate, nozzle-to-target spacing and number of nozzles, in an effort to optimize the impingement configuration for a given pin-fin heat sink. Pressure-drop measurements were also obtained in order to optimize thermal performance with respect to pumping power single, highly effective copper pin-fin heat sink was chosen for this study; jet parameters were varied while the heat sink remained the same for all experiments.

Robert Gardon (1965) data on the variation of local heat-transfer coefficients produced by impinging jets have been re-examined in the light of measurements of the velocity and turbulence distributions in submerged jets and in the context of other work on the influence of turbulence on heat transfer. It has been shown that the heat-transfer characteristics of impinging jets cannot be explained in terms of velocity- and position-dependent boundary-layer thicknesses alone. They can be explained when one also takes into account the influence of turbulence, which may manifest itself by a transition from laminar to turbulent boundary-layer flow or by a purely local enhancement of the rate of heat transfer across the boundary layer.

Herbert Martin Hofmann *et al*. (2007) they explain the experiments on flow structure and heat transfer in the impinging jet have been performed, which show the complex interaction of nozzle-to-plate spacing, radial distance from the stagnation point and the Reynolds number. The influence of Reynolds number and radial distance from the stagnation point on heat transfer coefficient was described by a correlation, which is valid for predicting local and surface-averaged values of heat transfer coefficients. The correlation is in good agreement with experimental data of several authors.

M. Hudina (1979) proposed a new method for the transformation of turbulent Stanton numbers measured in the annular channel geometry. The method was based on the solution of the simplified differential energy transport equation of the turbulent flow. To test this method, different heat-transfer calculations in the channels with smooth and rough surfaces are carried out. For comparison some other transformation procedures are also applied. The thermal performances of a particular roughness evaluated from the single rod experimental investigation, was used in a computer code to calculate the temperature distribution of a 37 rod bundle. The analytical predictions were compared with the experimental results

C. Gau (1992) has study impingement cooling flow structure and wall heat transfer along triangular ribbed walls. Both flow visualization and local Nusselt number measurements along the ribbed wall are made. Formation of air bubbles enclosing cavities in the region around the stagnation point were found in triangular ribbed wall, which can reduce the heat transfer and make it even lower than in the case of the flat plate. However, as the impinging or the wall jet becomes turbulent, it can readily penetrate the air bubble, impinge on the wall and significantly enhance the heat transfer. However, the cavity is wide open which makes the impinging or the wall jet more readily penetrate into the cavity and impinge on the wall than in the case along the rectangular ribbed wall. The strong momentum exchange between the cavity flow and the wall jet makes the recirculation cell scarce in the cavity. In this way, the heat transfer along the triangular ribbed wall is better. However, the smaller surface area of the triangular rib has limited the enhancement. In addition, the geometric shape of the triangular rib is favorable for rebounding the wall jet away from the wall. This can significantly reduce heat transfer

L. G. Hansen (1993) experiments were performed to characterize heat transfer to a normally impinging air jet from surfaces modified with fin-type extensions. Six fin geometries were investigated. Heat transfer enhancement was evaluated by comparison with results from a smooth, flat surface. Average Nusselt numbers and system effectiveness have been reported as functions of fin type, jet Reynolds number, nozzle-to-plate spacing, and jet nozzle diameter. The magnitude of the enhancement, as represented by the system effectiveness, was strongly dependent on fin type. The Reynolds number dependence was also significant. To a lesser extent, the system effectiveness exhibited both z/d and Rid dependence. Fin type dependence in the average Nusselt number resulted from variations in (1) the level of turbulence, (2) the fluid velocity at the surface, and (3) the percentages of total fin surface area exposed to normal impingement, oblique impingement, and parallel flow. Unlike jet impingement heat transfer from smooth surfaces, the average Nusselt number for the modified surfaces decreased monotonically with increasing z/d.

Cong Tam Nguyenn *et al*. (2009) experimentally investigated the heat transfer behaviour of a confined and submerged impinging jet using a nanofluid that is composed of distilled water and 36 nm average diameters Al2O3 nanoparticle in suspension. The tests were performed for three different nozzle-to-heated-surface distances, using water and two particular particle volume fractions; the Reynolds and Prandtl numbers are ranging respectively from 3800 to 88000, and from 5 to 10. Experimental data, obtained for both laminar and turbulent regime, have revealed that depending upon the combination of the nozzle-to-heated surface distance and the particle volume fraction, the use of nano- fluids can provide a clear heat transfer enhancement in some cases, while for others combinations, it may even result in an adverse effect on the surface heat transfer coefficient. Within the range of experimental parameters considered, it has been found that highest surface heat transfer coefficients can be achieved using an intermediate nozzle to surface distance of 5 mm and the 2.8% particle volume fraction nano-fluid. It has also been found that nano-fluids with high particle fractions seem not to be appropriate for the heat transfer enhancement purpose under the configuration of a confined and submerged impinging jet. Finally, for the cases with a very small or a large nozzle-to-surface distance, the present experimental data have revealed that the use of nano-fluids does not provide any heat transfer enhancement; for some worse cases, a clear decrease of the surface heat transfer coefficient was even found.

3. Experimental setup

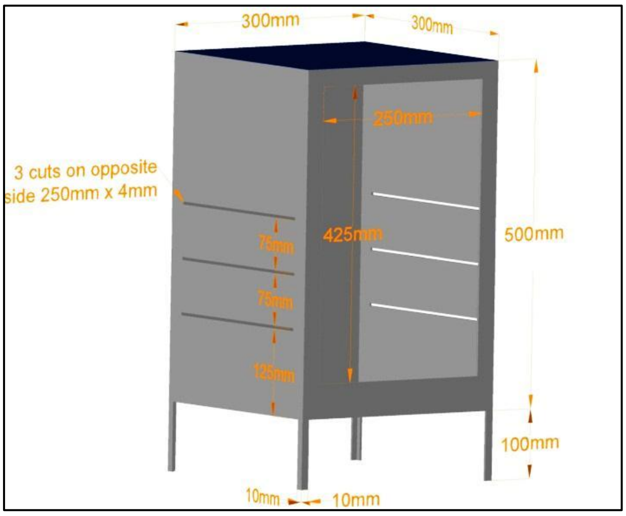

Fig.1 Experimental setup

The plate type of heater is assembled to the horizontal plates. The four thermocouples are attached to test piece at different holes in axial direction. The heater provides heat to the plate at different capacity i.e. 120 W, 100 W and 80 W. After heating the plates at different height of slots, which may be rough or smooth, water jet flow through the round nozzle is impinged on the plate for 2 seconds. The steady state temperatures of the test piece are measured by J-type thermocouple which is placed at four positions of the plate. The readings of thermocouple were recorded using a computer interfaced data scanner.

By varying the heat inputs from 80W, 100W and 120W, measurement of temperature at four positions were made for smooth plate and rough plate. The position of the plate with respect to round nozzle was also changed in order to study the effect of distance between plate and nozzle on heat transfer rates

Main Component of Experimental setup is:

1. Tank
2. Water Pump
3. Round jet
4. Plate heater
5. Rough Plate and Smooth Plate
6. Thermocouple
7. Wattmeter
8. Variac
9. Digital recorder

Methodology

In this experiment a cuboid shape set-up is used which is made up of mild steel. The dimensions of container are 600 mm X 300 mm and height of bottom stand is 100 mm . There are three slots provided at a distance of 5 inch, 8 inch and 11 inch respectively, leading to movement of the horizontal plate at three different heights. The thickness of all these three slots is 4mm and in these three slots the horizontal rough plates or smooth plates are placed according to the experiment. The bottom portion of the cuboid shape container has a water reservoir. The pump is placed in water tank which is used to lift the water and impinged on the flat plate. Fig. shows the schematic diagram of experimental set up. The round nozzle is placed in pump

4. Results and discussions

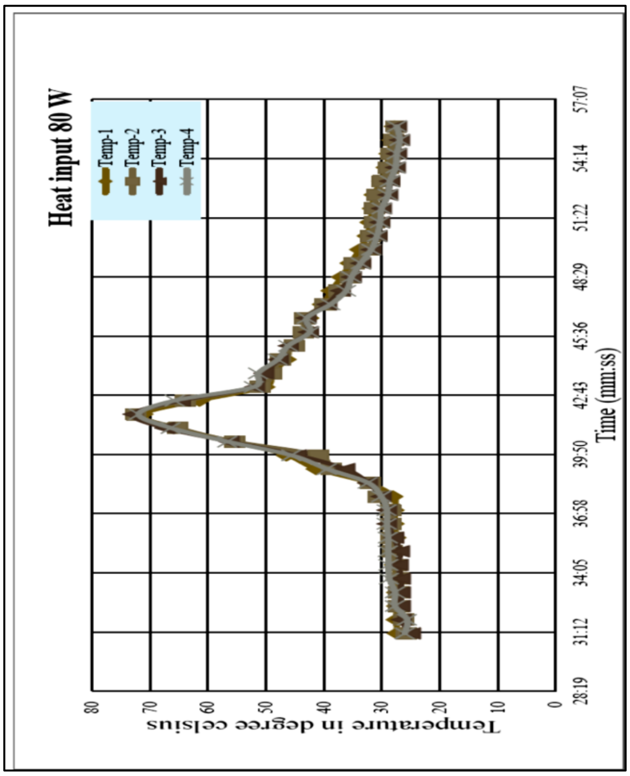

Fig.2 Variation of temperature w.r.t. time for heat input of 80 W

Fig. 2 shows the variation of temperature at all the four positions of the smooth plate, with respect to time. The distance between the nozzle and the plate was maintained as 11 inches. A constant heat input of 80 W was supplied to the plate. It was observed before the jet of water was impinged on the plate, the temperature of the plate increased uniformly from 28^0C to 76^0C, and then when an unconfined water jet was impinged for 2 seconds on the plate. The temperature suddenly drops from 76^0C to 49^0C within 30 seconds and become uniform at 28^0C after 10 minutes.

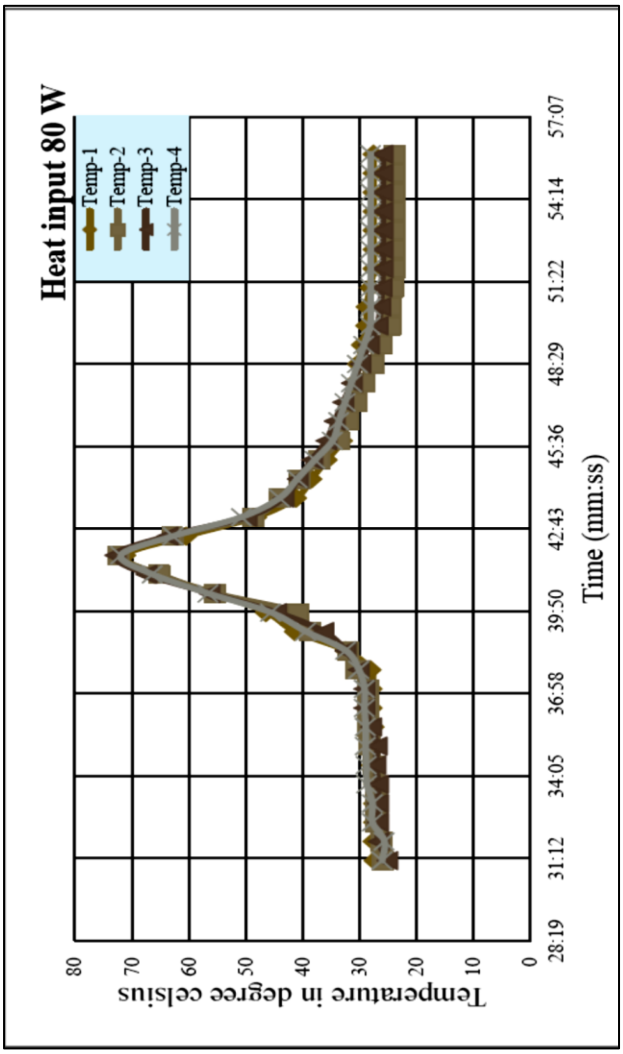

Fig.3 Variation of temperature w.r.t. time for heat input of 80 W

Fig. 3 shows the variation of temperature at all the four positions of the smooth plate, with respect to time. The distance between the nozzle and the plate was maintained as 8 inches. A constant heat input of 80 W was supplied to the plate. It was observed before the jet of water was impinged on the plate, the temperature of the plate increased uniformly from 28^0C to 76^0C, and then when an unconfined water jet was impinged for 2 seconds on the plate. The temperature suddenly drops from 76^0C to 41^0C within 94 seconds and become uniform at 26^0C after 10 minutes

Conclusion and future scope

The Experimental analysis was made to gain a fundamental understanding and comparing the heat transfer rate for a rough and smooth plate, when an unconfined jet of water is impinged on it. The following conclusions were made throughout the experimentation:

- It was observed that the rate of heat transfer was more for a rough plate as compare to smooth plate.
- The percentage drop of temperature in case of rough plate as compare to smooth plate was 6.7% and a constant heat input of 80 W. “Heat transfer behaviours of a confined slot jet impingement
- The effect of distance of the plate and nozzle play an important role w.r.t. heat transfer.
- As the plate is closely placed near to the nozzle, better is the heat transfer rate. An optimum selection of position of the plate w.r.t nozzle is to be made depending upon the industrial application.

Similar trends were also observed for various heat inputs of 80 W, 100 W and 120 W.

Future Scope

- Present experimental set up may be extended by varying the roughness of the plate. The profile of the roughness cut can have different heat transfer effects.
- Present study deals with heat transfer when temperature was measured at four positions, Temperature can be measured at other positions also.
- The effect of different kind of materials of plates on heat transfer rate can be studied
- The present works can be extended for the computational analysis for future study

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