PERFORMANCE ANALYSIS OF JET IMPINGEMENT COOLING ON COPPER SQUARE PLATE

Pallavi C. Chaudhari[1*], Ashish N. Sarode[2]
[1]Asst. Professor in Mechanical Engineering department, Rajarambapu Institute of Technology Polytechnic, Lohgaon, Pune
[2]Asst. Professor in Mechanical Engineering department, G.H. Raisoni Institute of Engineering and Management, Jalgaon.

ABSTRACT

The attempt was made in this Experimentation on the Jet impingement cooling on Square Copper plate. Jet impingement is very rapid effective convective heat enhancement technique is used in various thermal applications. In this experimentation, optimizing the parameters like the velocity of the jet 3 LPM, 5 LPM, 8 LPM, nozzle diameters is 6 mm and 8 mm and main parameter is distance between jet to target positioning selected 10 cm (h/d) with water as a coolant. Experimental data is analyzed as per requirement. The results obtained by experimentation for different input conditions are authenticated by using CFD simulation. This study shows that with decreasing temperature of heated copper square plate increases in Reynolds number. At the same time average Nusselt number is increases as the flow rate increases & heat transfer coefficient is also increases for 6 & 8 mm nozzle diameter. Form this analysis, obtained optimum cooling range with 6 & 8 mm nozzle diameters when distance between jet to target space is 10 cm with various flow rates. The results shows maximum average Nusselt no. and maximum Reynold no. is at 6 mm nozzle diameter as compared to 8 mm nozzle diameter. There is good consequences covenant in between CFD simulation and investigation.

KEYWORDS: Copper Square plate**;** Jet Impingement; CFD simulation; Nusselt number. Reynolds Number

I. INTRODUCTION

There are number of conventional cooling techniques and they are using successfully, major traditional techniques are heat sink, heat sink with fan, heat exchanger, heat pipes etc. These conventional methods have a lot of limitations such as low heat rejection rate, space constraints in very small electronic equipments. Jet impingement cooling is one of the very efficient method for cooling of hot objects in industrial processes. Now a day's Jet impingement heat transfer is extensively used such as cooling of gas turbine, cooling of rocket launcher, cooling of high-density electrical equipment and abundant industrial processes in order to remove large amount of heat. Many times it is necessary to avoid hot spot because of high thermal stresses by maintain low temperature of components. Therefore it is need an effective and efficient method for removing heat. The purpose of this experimentation is to analyzed the heat transfer characteristics of impinging water jets under constant distance between jet diameters to target surface.

Figure 1. Jet Impingement

Dushyant Singh et. Al. [1] In this experimental work more focused on parameter like nozzle diameter, ratio of nozzle diameter to the diameter of the heated target cylinder d/D of the circular cylinder and distance between nozzle exit, h/d. The result shows that when h/d ratio decreases, the inaction Nusselt number increases and the effects of d/D and distance between jet to target space are considerable only in the jet impinging region. On the made of experimental results, a new correlation for the Nusselt number has been developed.

Kyo Sung Choo et. Al. [2] the effect of various nozzle diameters are analyzed. This works shows that the hydraulic jump radius is independent on the nozzle diameter under secured impingement control conditions, while hydraulic jump radius increases with decreasing nozzle diameter under secured jet Reynolds number.

K. Jambunathan et.al [3] had considered single geometry circular jet impinging orthogonally onto a plane surface for nozzle-to-plate distances from 1.2-16 nozzle diameters and have flow region up to six nozzle diameters from stagnation point. Reynolds numbers in the range of 5,000–124,000 have been ordered and critically reviewed. However, the available empirical data suggest that this exponent should be a function of nozzle-to-plate spacing and of the radial displacement from the stagnation point. A correlation for Nusselt number has been derived using a selection of the data. The reviewer also suggest that the Nusselt number is independent of nozzle to plate spacing up to a value of 12 nozzle diameters at radii greater than six nozzle diameters from the stagnation point.

Qiang Guo et. al.[4] In this experimental investigation, the results shows that when the air jet began its impingement then the local Nusselt number hastily increases while considering 6 mm nozzle diameter. Range varied from 14,000 to 53,000 of Reynolds number with distance between jet to target space is varied from 4 to 8.

Liu and Lienhard et. al. [5] The effects of jet Reynolds number, jump Weber number, and jet Froude number on the dimensionless hydraulic jump radius were investigated for a nozzle diameter of 4.96 mm.

E. Baydar et. al. [6] the effects of distance between jet to target spacing on the flow structure and Reynold number are examined. The results are documented as per requirements. The numerical outcomes obtained using the customary k–e turbulence model are in good agreement with the experimental results.

Yi et al. [7] performed experimentation on transient temperature field and heat transfer of oblique jet impingement. The result shows that the heat transfer coefficient is maximum at the stagnation point. The 1-D semi-infinite solid model is used to obtain the heat transfer coefficient and data is validated with experimental results.

Rahman et al. [8] A numerical investigation is performed for nozzle diameters to the dimensionless plate (copper, silicon & constantan) thickness ratio having range from 0.083 to 1.5 on the transient heat transfer of a free liquid jet impinging on a hemispherical plate and Reynold no. range from 500–1500.

II. EXPERIMENTATION

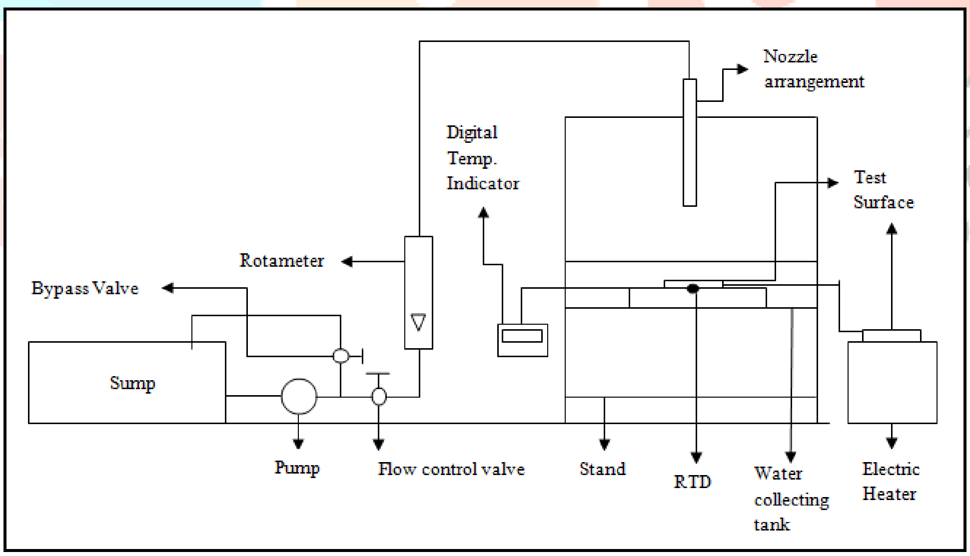

Figure 2. Experimental set up

The line diagram of experimental set up for impinging water jets is shown in Figure 2. The square plate is used in this set up is made up of copper material. The water jet vertically impinges on square plate. With considering the nozzles diameter of 6 and 8 mm made of brass material. The water is supplied from a water tank and Rotameter flow meter (1 to 30 LPM) is used to measure water flow rate. The distance between nozzle diameters to target surface is fixed 10 cm through the all experimentation. At the nozzle exit water temperature is kept constant at 32 ^{0}C for all reading. The copper square plate is heated by heater and thermocouple is used for measuring different point temperatures of plate for accurate reading. On glass plate, initially heated copper plate at 247 ^{0}C is placed in water collecting tank. At the base of the tank, glass plate is provided. The aim of providing glass plate is the only for insulation purpose. The date is recorded as per the requirement.

Figure 3. Heated copper Square Plate with arrangement of thermocouple

Figure 4. Actual Experimental setup

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Reynolds's Number:-

$$Re = \frac{\rho V d}{\mu} = \frac{Vd}{\vartheta}$$

Nusselt Number:-

$$Nu = \frac{hd}{k}$$

$$Nu_{avg} = 1.51\, Re^{0.44} Pr^{0.4} \left(\frac{h}{d}\right)^{-0.11}$$ -------------------- [9]

III. COMPUTATIONAL FLUID DYNAMICS SIMULATION

First using design software we developed 3D model of Copper square plate as per the dimension. This was introduced for CFD simulation workbench with .igs/step file saved in design software. Specification for square plate is 155 × 155 mm and 3 mm thickness.

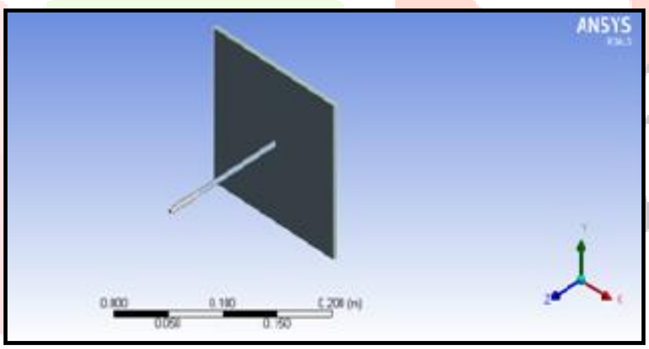

Figure 5. Catia Model of Square plate

- **Generation of Grid for copper plate**

In the generation of grid, square plate and flow of nozzle is the major importance for provides better replication results. For more accuracy of results more suitable grid and step sizes should use while simulation. All the fixed parameters considered for simulation were solved at centers of these discrete cells. So the accuracy in the meshing offers good results at the increased computational time. Hence in the domain, size of the mesh should be greater. If any changes is takes place in the number of control volumes then it will not effect on the results because of proper meshing size.

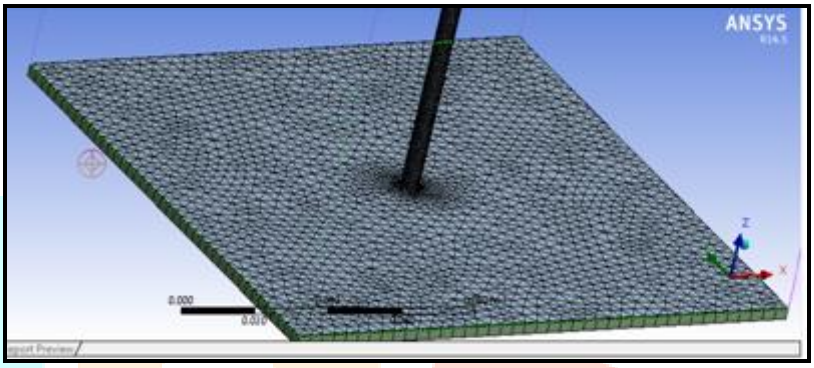

Figure 6. Mesh generation of nozzle flow and square copper plate

- **Boundary Conditions**

Boundary conditions are the prime consideration used according to the necessitate of the model. This conditions used at inlet and exit for temperature of water and nozzle flow velocity. At the outlet static pressure is applied. 'No Slip Condition' is used for Domain surface as a wall.

- **Steady state Analysis**

In this work the simulation results obtained from CFD of a basic model for a nozzle and test plate. Figure 7 shows that by fitting boundary conditions to the model, results is obtained as per requirements. It shows temperature of heated surface is rapidly cool down using jet impingement as compared to the conventional methods.

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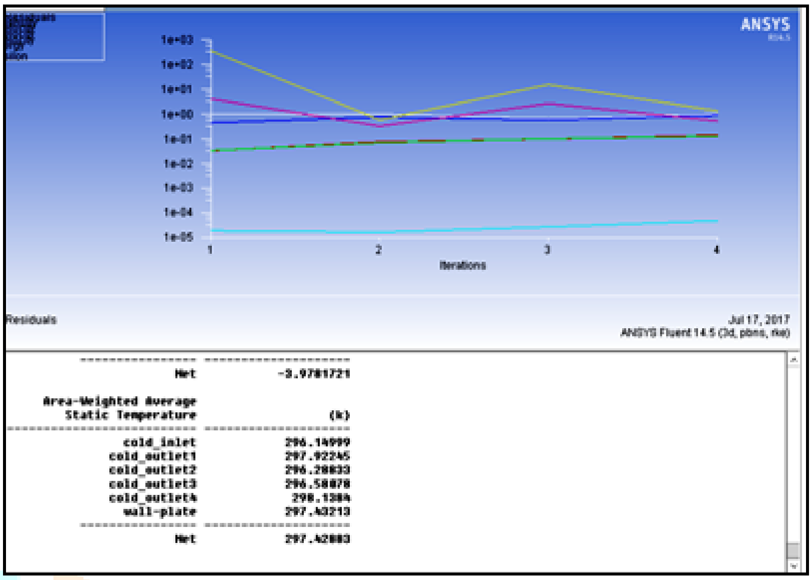

Figure 7.Temperature Result of Copper Square plate for 8 mm diameter of nozzle using CFD simulation.

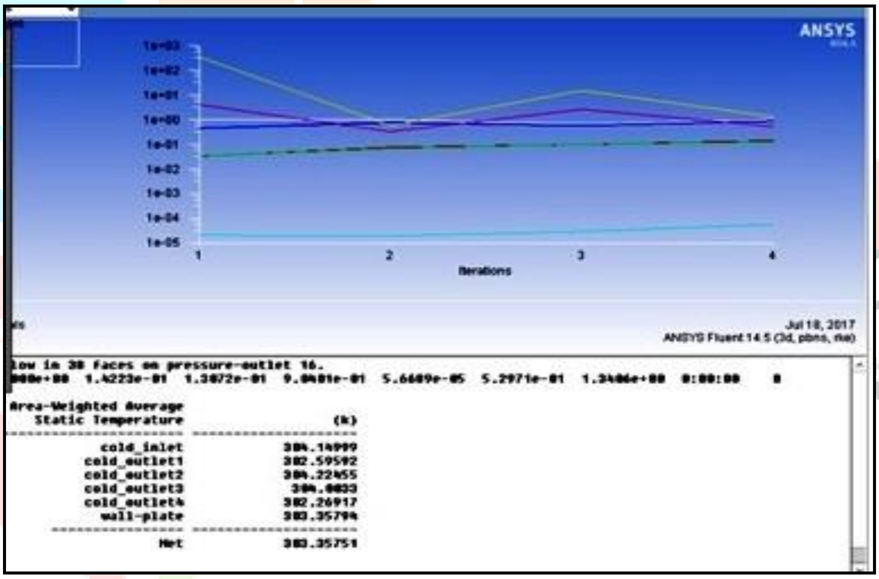

Figure 8.Temperature Result of Copper Square plate for 6 mm diameter of nozzle using CFD simulation.

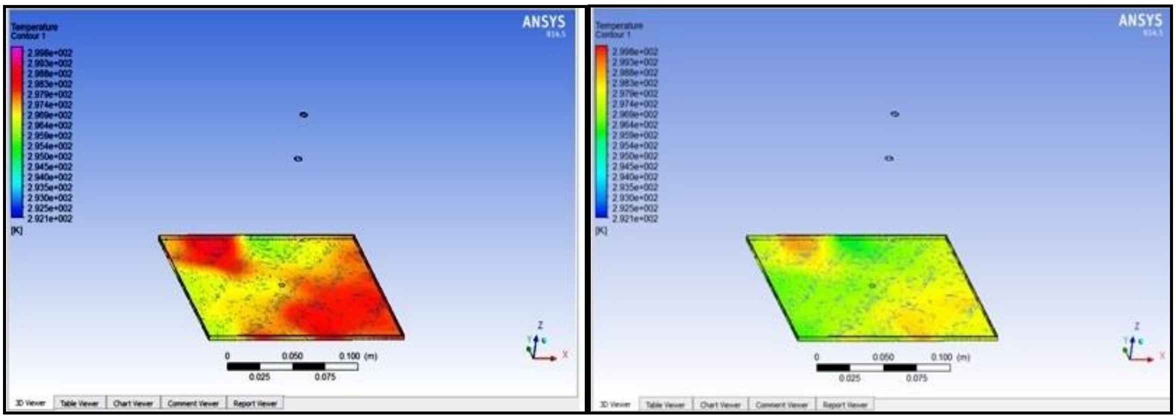

Figure 9. Temperature distribution on heated square copper plate by Jet impingement.

IV. RESULTS AND DISCUSSIONS

Here more effective parameter considerd like 6 mm and 8 mm nozzle diameter, 10 cm distance between nozzle exit and target plate and different mass flow rate 3, 5 and 8 lpm.

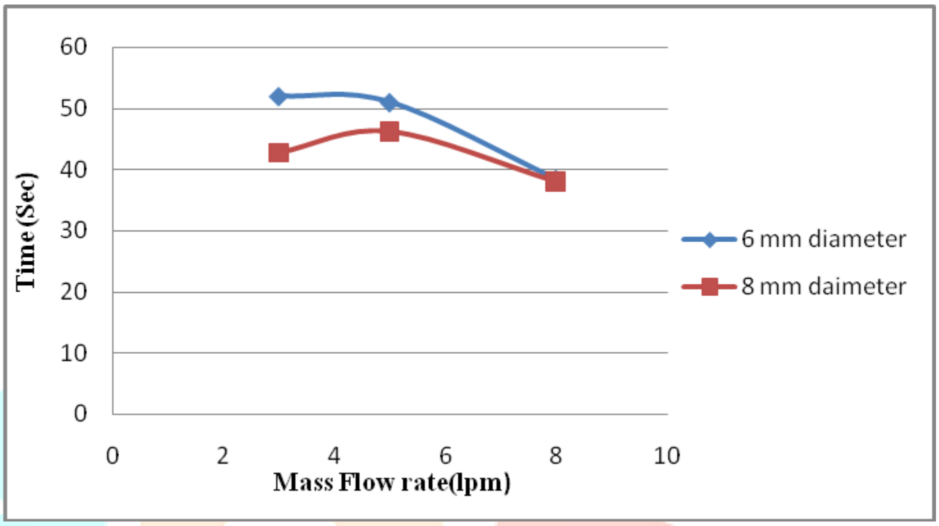

Figure 10. Mass flow rate v/s Time(Sec)

Above figure shows that mass flow rate verses time at 3, 5 and 8 lpm of mass flow rate for 6 and 8 mm nozzle diameter. Colling Time decreases with increasing mass flow rate. For 6 mm nozzle diameter at 3 lpm of mass flow rate, time required to cool plate is approximately 52 sec at normat ambient temperature. For 5 lpm, approximately 51sec. and at 8 lpm it is 38.36 sec. For 8 mm nozzle diameter at 3 lpm, 5 lpm and 8 lpm of flow rate is plotted on graph. Nozzle Diameters of 8 mm shows good result as compared to 6 mm diameter to cool down the hot surface.

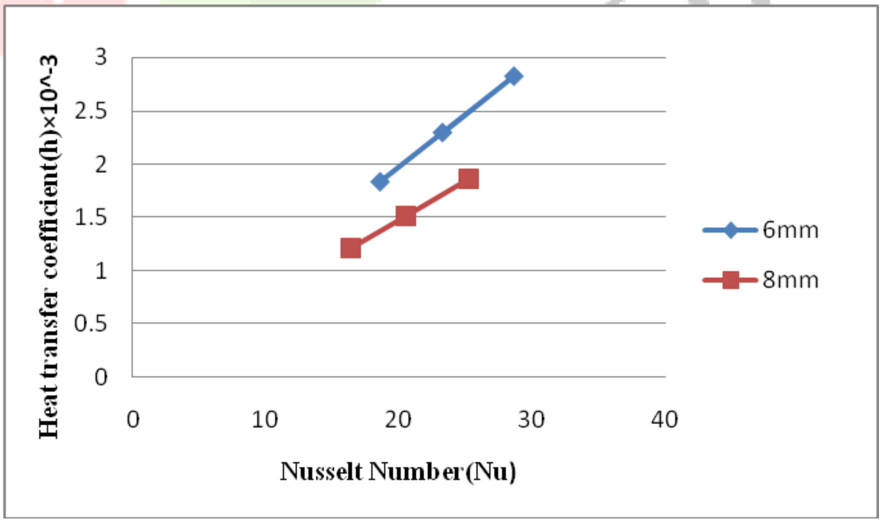

Figure 11. Nusselt Number v/s Heat transfer coefficient for test plate

Figure 11 shows that when nusselt number is increases with increasing heat transfer coefficient, for 6 mm nozzle diameter. Graph shows better results for 6 mm nozzle diameter as compared to 8 mm nozzle diameter.

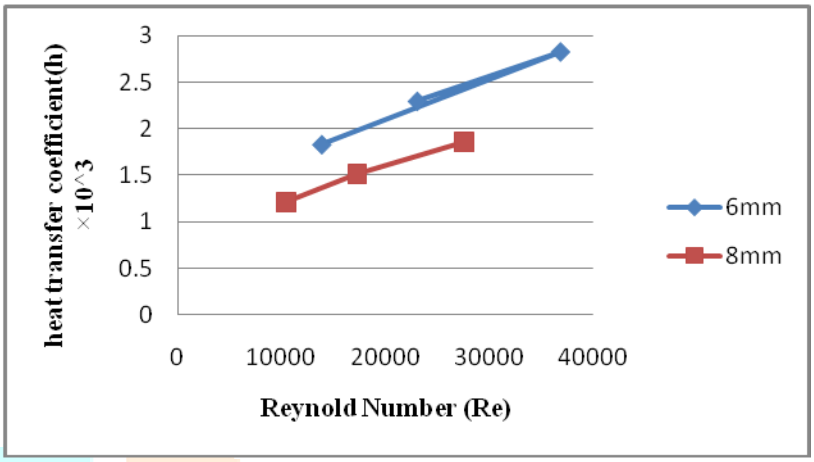

Figure 12. Reynold Number v/s Heat transfer coefficient

Figure 12 shows the comparison between Reynold number and heat transfer coefficient for 6 mm and 8 mm diameter of nozzle. It shows when Reynold number is at 36831.03 for 3 lpm, 13813.59 for 5 lpm and 23022.91 for 8 lpm then heat transfer coefficient is 1.2110×10^3, 1.8643×10^3 and 1.5159×10^3 respectively for 6 mm nozzle diameter. For 8 mm nozzle diameter Reynold number is 10358.76 for 3 lpm, 17255.92 for 5 lpm and 27617.8 for 8 lpm. At the same time heat transfer coefficient is 1.833×10^3, 2.2946×10^3 and 2.8216×10^3 respectively.

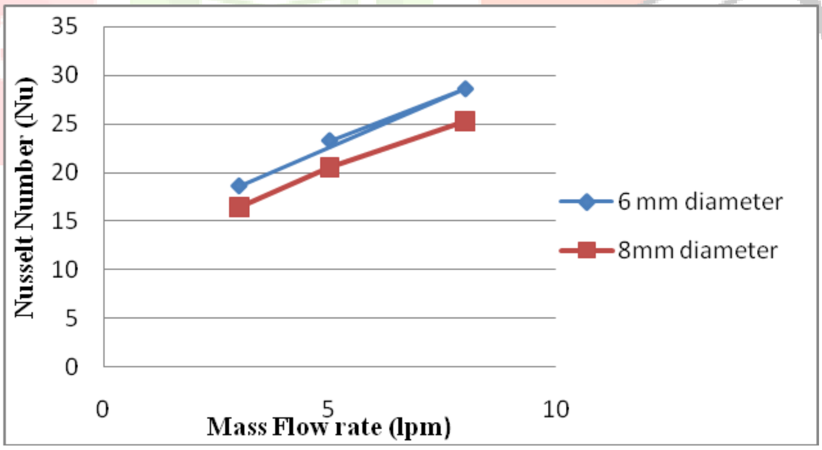

Figure 13. Mass flow rate v/s Nusselt number

Figure 13 shows when mass flow rate is at 3 lpm Nusselt number is 18.61 and 5 lpm and 8 lpm 23.296 and 28.646 respectively for 6 mm nozzle diameter. For 8 mm nozzle diameter mass flow rate 3, 5 and 8 lpm , Nusselt number is 16.39, 20.52 and 25.23 respectively.

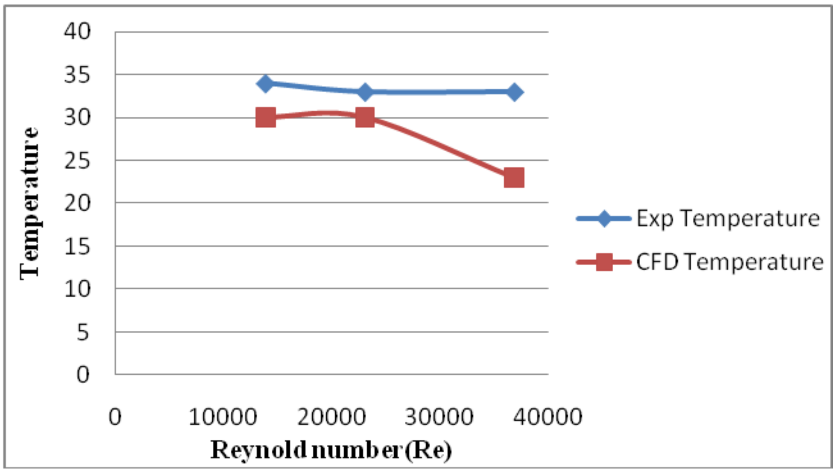

Figure 14. Reynold Number v/s Temperature for 6 mm nozzle diameter

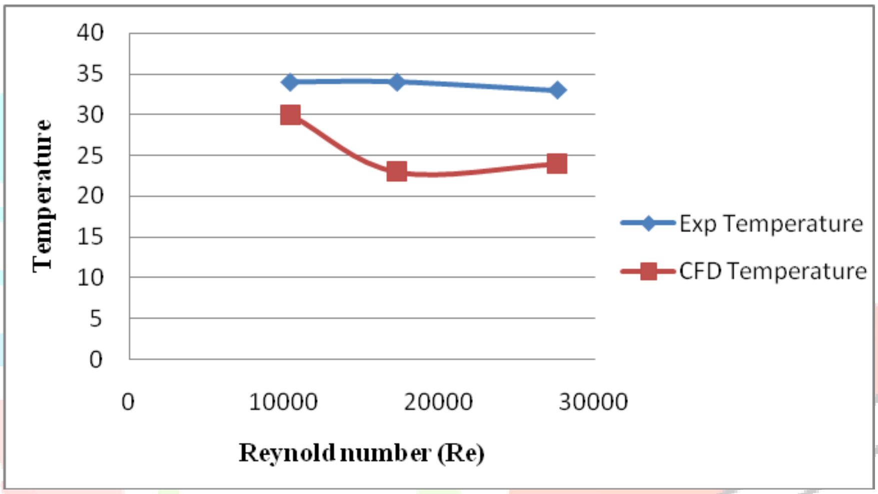

Figure 15. Reynold Number v/s Temperature for 8 mm nozzle diameter

Figure 14 shows that fine conformity between Experimental results and CFD simulation of copper square plate for 6 mm nozzle diameter. Figure shows at 13813.59, 23022.91 and 36831.03 range of Reynold number at mass flow rate 3, 5 and 8 lpm respectively for experimentation the temperature is as 34 ^{0}C, 33 ^{0}C, 33 ^{0}C and by CFD simulation it is 30 ^{0}C, 30^{0}C, 30 ^{0}C respectively. At the same time for 8 mm nozzle diameter as shwon in figure 15, temperature achived 34 ^{0}C, 34 ^{0}C, 33 ^{0}C respectively for 10358.76, 17255.92, 27617.8 range of Reynold number by experimentation for 3, 5 and 8 lpm respectively and by simulation it is 30 ^{0}C, 24 ^{0}C, 23 ^{0}C shows in figure 15.

CONCLUSIONS

Experimentation and CFD simulation was made to achieve an elementary perceptive. The heat transfer characteristics for copper square plate with nozzle diameter are 6 and 8 mm, when a jet of water is impinged on it for varying mass flow rate. We observed that, heat transfer improvement is takes place by varying the parameters like nozzle diameters, h/d ratio and flow rate of water. In the present experimental work we used correlation developed by Stevens and Webb correlation for average Nusselt number for this method. Reynolds numbers varies between 10,000 to 50,000.

1. Temperature of heated copper square plate diminishes rapidly with increasing Reynold number for 6 and 8 mm nozzle diameter at 3, 5 and 8 lpm mass flow rate.
2. At the mass flow rate 3, 5 and 8 lpm, It is found that as a flow rate is increases, the performance of heat transfer is also increases foe 6 and 8 mm diameter of nozzle.
3. For 6 mm nozzle diameter Reynold number (Re) is highest as compared to 8 mm nozzle diameter.

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