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EXPERIMENTAL AND CFD ANALYSIS OF JET IMPINGEMENT COOLING ON COPPER CIRCULAR PLATE

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ABSTRACT

This study presents the Experimental and Computational Fluid Dynamics (CFD) analysis on Jet impingement cooling. Jet impingement is highly effective convective heat transfer technology and improving heat transfer enhancement in various applications. The fluid flow and heat transfer characteristics of jet impinging on circular copper plate is investigated by experimentally and CFD analysis were done. This study on jet impingement cooling is conducted to optimize the parameters like 6 mm and 8 mm nozzle diameters, Distance between jet to target spacing have taken 10 cm (h/d) and the velocity of the jet (3 LPM,5 LPM,8 LPM). Experiment has conducted with water as coolants .Experimental data is recorded as per requirement and results are validated by using CFD simulation, it gives the rapid cooling rate. This study shows the result about Reynolds number increases with decreasing temperature and Nusselt number increases as the flow rate for different nozzle diameters increases. Form this analysis, obtained optimum cooling range with 6 mm and 8 mm diameters when h/d consider 10 cm with various flow rates. The results shows maximum Reynold no. is at 6 mm nozzle diameter and maximum Nusselt no. is as 8 mm nozzle diameter. There is good results agreement in between experimentation and CFD simulation.

KEYWORDS: Jet Impingement; CFD simulation; Heat Transfer; Cooling range; Reynolds Number; Nusselt number.

INTRODUCTION

New development in engineering industry has always brought about challenging tasks. To fulfill the needs of industries requirement with best result in minimum time span is very important. So in this paper introduce new topic for to enhance the heat transfer rate with the help of jet impingement. It is a time consuming process and provide immediate cooling to product.

It is necessary not only to maintain low temperature of components but also avoid hot spot. Now a day Jet impingement heat transfer is extensively used for cooling electronic components, cooling critical machinery structures, annealing metal plates, and numerous industrial processes and also include turbine blade cooling paper and fabric drying , furnace heating, tempering of glass and metal sheets, electronic chip cooling, food processing and many others. Jet impingement cooling is one of the most efficient solutions of cooling hot objects in industrial processes as it produces a very high heat transfer rate through forced convection. Since the heat transfer rate is very high at the area where the jet directly impinges on it provides rapid cooling or heating on the local heat transfer area. Many researches study on the varying nozzle diameters and specimen structures. Most of the works are available on flat plate.

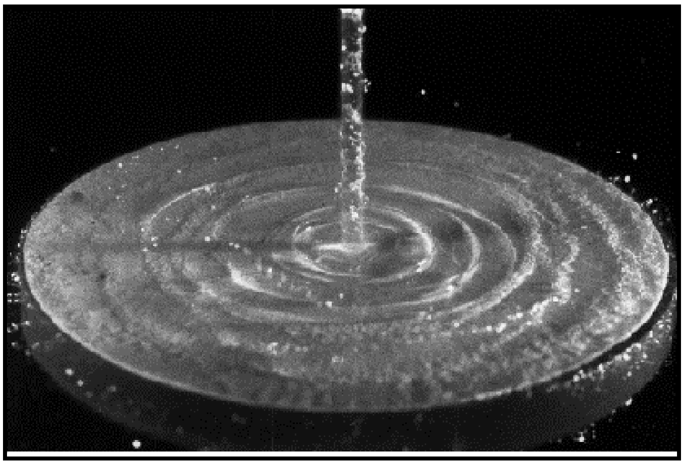

Figure 1: Jet Impingement.

Dushyant singh et. al[1] this study focuses the parameter like nozzle diameter, distance between nozzle exit, h/d and the circular cylinder and ratio of nozzle diameter to the diameter of the heated target cylinder d/D. It was observed that the stagnation Nusselt number increases monotonically as the h/d decreases and the effects of h/d and d/D are significant only in the jet impinging region. Based on the experimental results, a correlation for the stagnation Nusselt number has also been developed.

Kyo sung Choo et. al[2] study on the influence of nozzle diameter on the circular hydraulic jump of liquid jet impingement, it investigate the effect of nozzle diameter (0.381,0.506,1,2,3.9,6.7,8mm) on hydraulic jump radius. So the result show that hydraulic jump radius is independent of the nozzle diameter under fixed impingement power conditions, while the hydraulic jump radius increases with decreasing nozzle diameter under fixed jet Reynolds number condition.

M. Johson et al.[3] Many studies are available on smooth surfaces but investigated the jet impingement on micro scale patterned surfaces exhibiting ribs and cavities tested in both wetted cavity regions called hydrophilic and unwetted cavity regions called super hydrophobic.

Qiang Guo et. al[4] This study consist of 6mm inner diameter and Reynold number varied from 14,000 to 53,000 with nozzle exit to the target plate is varied from 4 to 8.it gives the result the local nusselt number rapidly increases when the air jet began its impingement.
Islam et al.[5] experimented on the transient heat transfer of a target surface under a hot air impinging jet. They placed thermocouples on the target surface to determine the temperature and found that the heat flux at stagnation was maximum. Moreover, the heat flux was maximum at the non-dimensional distance between the nozzle exit and the target plate H/Dn = 2 and thereafter decreased as H/Dn increased.

E. Baydar et al[6] study investigate the effects of Reynold number and nozzle to plate spacing on the flow structure are examined. It consist of spacing range 0.2 to 6 and Reynold numbers ranging from 30,000 to 50,000. A sub atmospheric region occurs on the impingement plate at nozzle-to-plate spacing up to 2 for Reynolds numbers studied and it moves radically outward from the stagnation point with increasing nozzle-to-plate spacing. It is concluded that there exists a linkage among the sub atmospheric region, turbulence intensity and heat transfer coefficients. The numerical results obtained using the standard k–e turbulence model are in agreement with the experimental results except for the nozzle-to-plate spacing less than one.

V. Jeevanlal et. al[7] the present work investigates the parameter like nozzle exit to target plate distance and jet velocity. For the experiment consist of stainless steel plate with 10mm nozzle diameter. It gives the result nusselt number increases with increasing Z/D value upto a certain Z/D value then it starts decreasing.

Kumagai et al.[8] conducted an experimental study on transient heat transfer of a sub cooling water jet impinging on a hot metal plate. They found that an excessive time is necessary for the evaporation of sufficient vapor to form a finite vapor layer because the water jet was sub cooled, thereby resulting in a rapid decrease of the temperature at stagnation.

Rahman et al.[9] conducted a numerical investigation on the transient heat transfer of a free liquid jet impinging on a hemispherical plate. The study was performed for Re of 500–1500, dimensionless plate thickness to nozzle diameter ratio ranging from 0.083 to 1.5, and three solid materials (copper, silicon, and constantan). The results indicated that an increasing Re number and plate thickness reduced the time it takes for the plate to reach the steady-state condition. A higher Nusselt number was obtained with a lower thermal conductivity material.

Experimentation

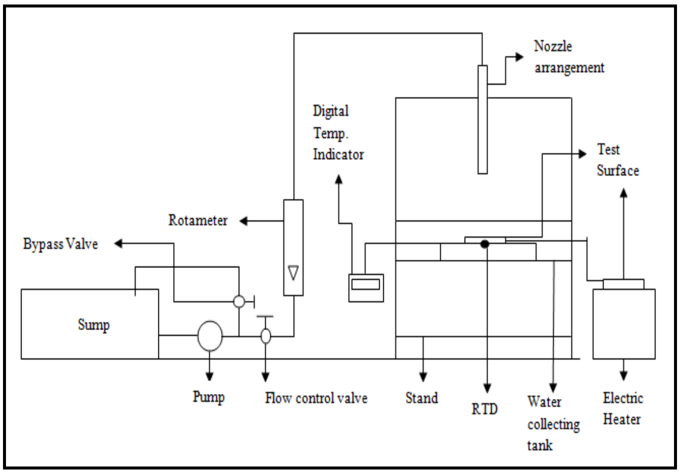

Figure 2: Experimental set up.

A schematic diagram of the experimental apparatus for impinging water jets is shown in Figure 2. The water jet vertically impinges on copper plates. The water flow was supplied by a water tank to ensure a steady flow. A Rotameter flowmeter (1 to 30 LPM) was used to measure liquid flow rates. The jet velocity can be readily found from the mass flow rate and the jet diameter. The circular pipe nozzle was fixed on a 3 axis (x–y–z) stage. Thus, the nozzle could be moved either parallel or perpendicular to the direction of the jet. Two circular, brass nozzles were used in the experiment. The nozzles had diameters of 6 and 8 mm. All of the nozzles in the experiment are straight tubes and to ensure a fully developed flow. The impingement surface was elevated above the remainder of the test section. Thus, as the wall jets fell off the impingement surface into the pool, the jet impingement was not influenced by the downstream conditions. The impingement plates were made of Copper and here used two shapes of plates. The distance between nozzle diameters to target surface had taken 10cm. The water temperature at the nozzle exit was fixed at 32^0C. K-type thermocouple was used for measuring different point temperatures on plates. First Copper plate heated at 247^0C then place in water collecting tank on glass plate. Glass plate provided for insulation purpose after words jet impinges on heated plate and note down the readings.

Table 1: Experimental set up details.

Sr. no.	Particulars	Dimensions
1	Copper Circular Plate	160 mm in diameter
2	Nozzle Diameter	6 mm and 8 mm
3	H/d Ratio	10 cm
4	Flow rate	3 lpm,5 lpm,8 lpm

Figure 3: Copper circular Plate.

Figure 4: Pictorial view of experimental setup.

Reynolds's Number

$$Re = \frac{\text{Inertia Force}}{\text{Viscous Force}} = \frac{\rho V d}{\mu} = \frac{Vd}{\vartheta}$$

Where, ρ = Density of water, kg/m^3; V = Velocity of jet, m/s; d = Diameter of nozzle, m;
μ = Dynamic viscosity, N.s/m^2; ϑ = Kinematic viscosity, m^2/s

Nusselt Number

$$Nu = \frac{\text{Convective Heat Transfer}}{\text{Conductive Heat Transfer}} = \frac{hd}{k}$$

Where, h= convective heat transfer coefficient, W/m^2 -^{0}C; d= diameter of nozzle, m;
k= Thermal Conductivity of water, W/m-K;

$$Nu_{avg} = 1.51\, Re^{0.44} Pr^{0.4} \left(\frac{l}{d}\right)^{-0.11} \quad (10)$$

Where, Nu_{avg} = average Nusselt number; Re = Reynold's number; Pr = Prandtl number;
l/d = nozzle to surface distance to nozzle diameter ratio.

Cfd Simulation

The 3D model for Copper circular plate is created using CATIA software. It is imported for CFD simulation workbench with .igs/step file saved in CATIA. The geometrical specification of Copper circular plate is as per design. Consider specification for circular plate 160 mm diameters and 3 mm thickness.

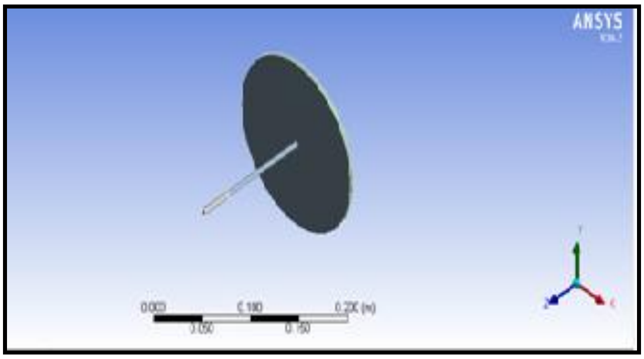

Figure 5: Model of Circular plate.

Grid generation for circular copper plate

More accurate results could be obtained when more suitable grid and step sizes are used in the numerical calculation. In this study, grid generation of nozzle flow and circular plate was prime importance for gives better simulation results which is obtained discrete cell into which the domain is divided. All the fixed parameters were solved at centers of these discrete cells.

So the accurate mesh generally provides better results at the increased computational time. Therefore the size of the mesh in the domain should be gradually increased to such level that the further raise in the number of control volumes does not result in considerable changes in experimental results produced.

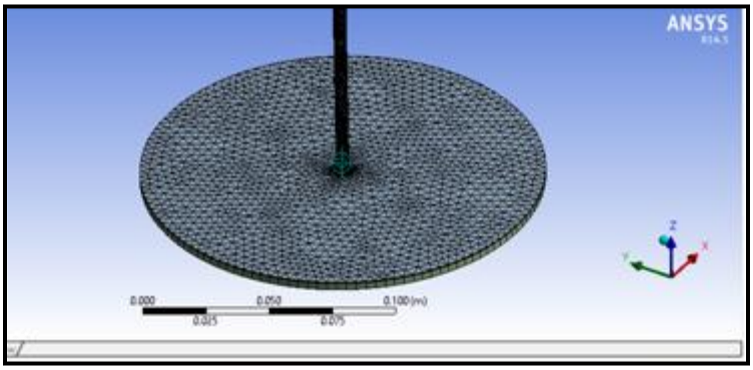

Figure 6: Mesh generation of nozzle flow and circular copper plate.

Boundary Conditions

Boundary conditions are used according to the need of the model. Boundary conditions used at inlets and outlet for nozzle flow velocity and temperature of water and at outlet at static pressure is applied. Domain surface is used as a wall with 'No Slip Condition'.

Steady state Analysis

In this work presents the numerical results obtained from CFD modeling of a simplified model of a nozzle diameter and copper plate. Results obtained using appropriate boundary conditions for model as shown in figure 7. This figure shows that using jet impingement cooling method, temperature of heated surface is rapidly cool down.

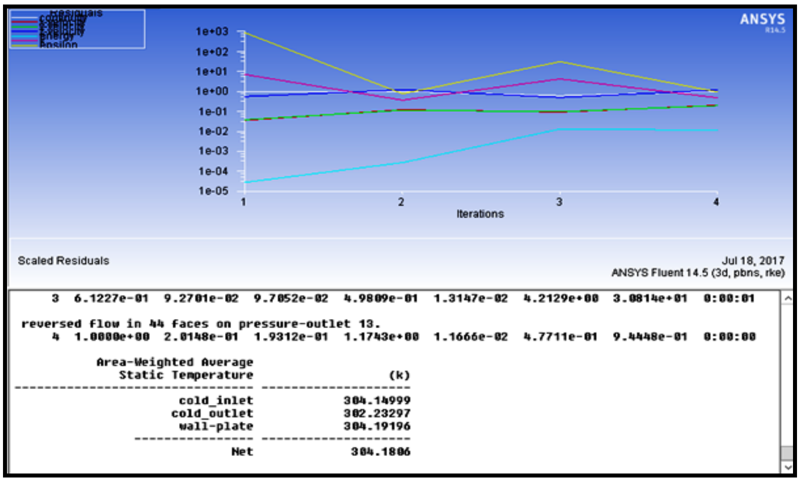

Figure 7: Temperature Result for Copper Circular Plate by CFD simulation.

Effect of jet impingement on heated plates

When water jet impinged on copper plates with different nozzle diameters, flow rates, the heated plates rapidly settle down. Figure 8 shows that temperature difference on whole plate surface at different point temperature in different colors.

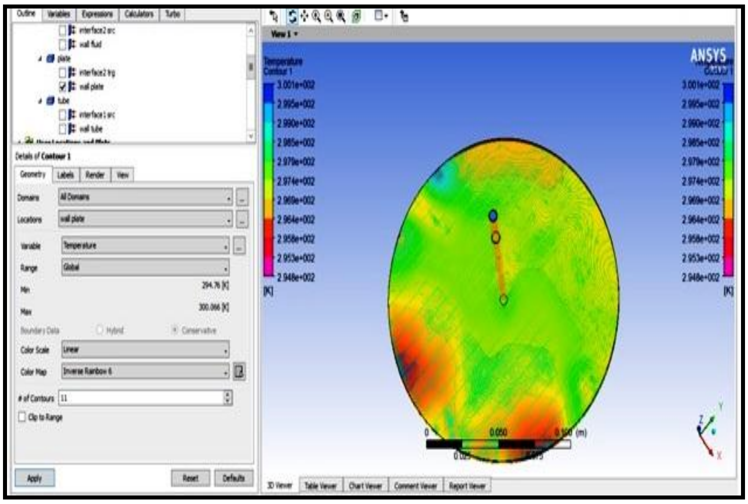

Figure 8: Effect of Jet impingement on heated circular copper plate.

RESULTS AND DISCUSSIONS

This study was investigated for rapid cooling to heated component. So work performed on some essential parameters which play an important role in jet impingement cooling like nozzle diameters(6 mm,8 mm), Distance between nozzle exit to target plate, jet velocity(3 lpm,5 lpm,8 lpm) have taken. In this experiment circular copper plate consider and there result given below with the help of graph.

For Copper Circular plate

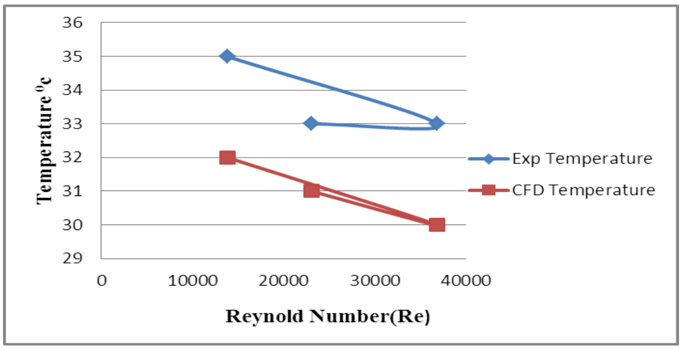

Figure 9: Reynold Number v/s Temperature for 6 mm diameter of nozzle.

Figure 9 shows the comparison study of experimental and CFD analysis results, it shows that for 6 mm diameter of nozzle at 3 lpm by experimentation Reynold number is 13813.59 and temperature is 35^{0}C, similarlly for 5 lpm and 8 lpm Reynold number and temperature is 23022.91, 36831.03 and 33^{0}C, 33^{0}C respectivily. By simulation at the same time and same flow rate and same Reynold number it indicate temperature 32^{0}C, 31^{0}C and 30^{0}C respectivily. And for 8 mm diameter of nozzle from figure 10 at 3 lpm, 5 lpm, 8 lpm by experimentation Reynold number is 10358.76, 17255.92, 27617.8 and temperature is 35^{0}C, 34^{0}C, 33^{0}C. also at same at the same time and same flow rate and same Reynold number the temperature range is 31^{0}C, 31^{0}C, 29^{0}C. So the concluded that Reynold number increases with temperature decreases of circular copper plate.

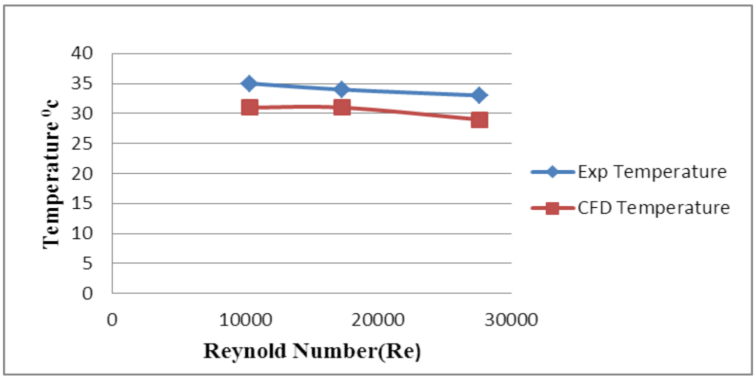

Figure 10: Reynold Number v/s Temperature for 8mm diameter of nozzle.

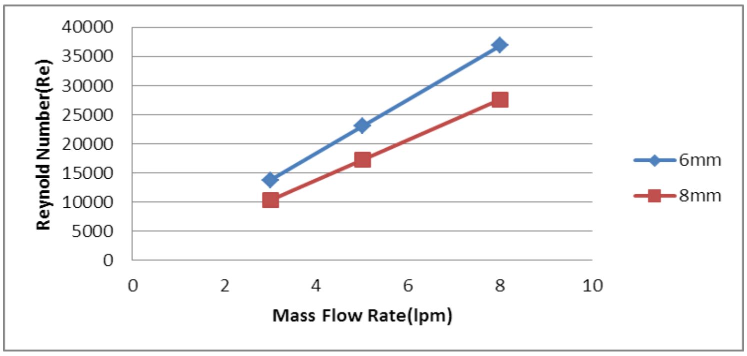

Figure 11: Mass Flow Rate v/s Reynold Number.

When water jet impinged on heated Copper plate under considerable flow rates of 3,5 and 8 lpm, from figure 11 for 6 mm diameter of nozzle shows maximum Reynold number is 36831.03 observed at 8 lpm flow rate and also shows that for 8 mm diameter of nozzle for same flow rate (8 lpm) maximum Reynold number is 27617.8 observed. So it gives final judgement from above figure 11 6mm diameter of nozzle is more effective than 8mm diamter of nozzle.

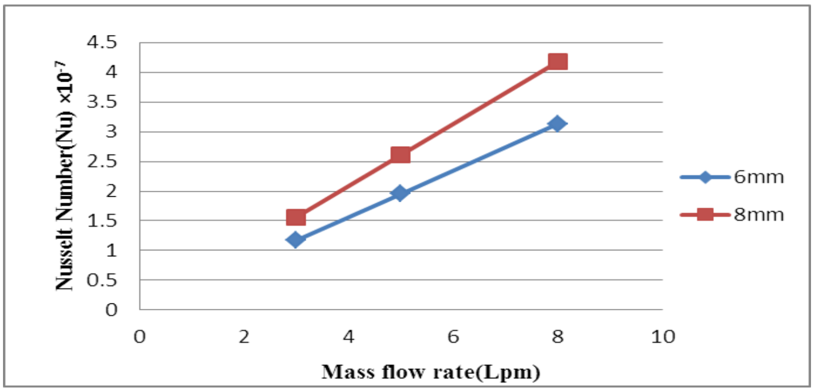

Figure 12: Mass flow rate v/s Nusselt Number.

Figure 12 indicate that Nusselt number v/s mass flow rate, It gives the range of Nusselt number is 1.1742×10^{-7}, 1.9525×10^{-7}, 3.1312×10^{-7} for 3 lpm , 5 lpm and 8 lpm of flow rate when nozzle diameter is 6 mm. Also for 8 mm of nozzle diameter range of Nusselt number is 1.5656×10^{-7} , 2.6095×10^{-7} , 4.1750×10^{-7} for 3 lpm , 5 lpm and 8 lpm of flow rate respectivity.

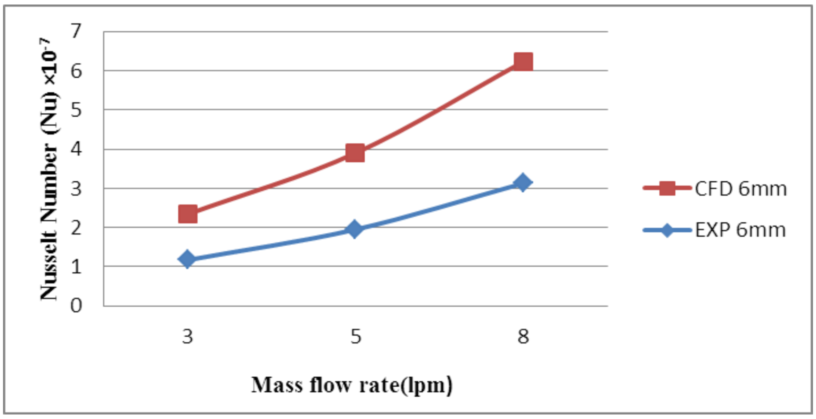

Figure 13: Comparison between Experimental and CFD simulation of Nusselt number v/s Mass flow rate for 6 mm diameter of Nozzle.

Figure 13 and figure 14 shows that the comparison study about experimentation and CFD simulation of Nusselt number v/s Mass flow rate (3 lpm ,5 lpm, 8 lpm). By experimentation the value of Nusselt number is 1.1742×10^{-7}, 1.9525×10^{-7}, 3.1312×10^{-7} for 3 lpm , 5 lpm and 8 lpm of flow rate respectivily for 6 mm diameter of Nozzle. By CFD simulation the value of Nusselt number is 1.1688×10^{-7}, 1.9480×10^{-7}, 3.1001×10^{-7} for 3 lpm , 5 lpm and 8 lpm of flow rate respectivily for 6 mm diameter of Nozzle. Similar observation for 8 mm diameter of nozzle is the values of Nusselt number 1.5656×10^{-7} , 2.6095×10^{-7} , 4.1750×10^{-7} for 3 lpm , 5 lpm and 8 lpm of flow rate by experimentally and by CFD simulation it gives Nusselt number values are 1.5584×10^{-7} , 2.5974×10^{-7} , 4.1188×10^{-7} for same flow rate. It is observed that both combinations gives good results. It exactly indicatate the near actual values.

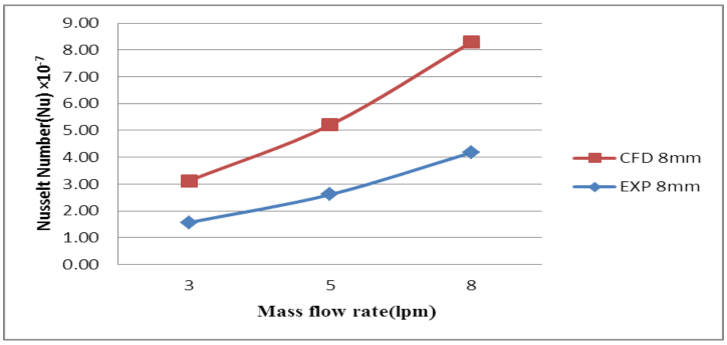

Figure 14: Comparison between Experimental and CFD simulation of Nusselt number v/s Mass flow rate for 8 mm diameter of Nozzle.

CONCLUSIONS

Jet impingement technique provides high levels of convective heat and mass transfer. The Experimental and CFD analysis was made to gain a fundamental understanding and comparing the heat transfer rate for copper plate with different nozzle diameter, when a jet of water is impinged on it. We have found out many conclusions about heat transfer enhancement by changing the parameters like nozzle diameters, h/d ratio and flow rate of water. In the present experimentation we have taken the reference of Stevens and Webb et. al[10]equation for calculating average Nusselt number. Reynolds numbers are from 10,000t to 50,000.

1. Temperature of heated surfaces decrease rapidly with increasing Reynold number of copper plates for 6mm and 8mm diameter.
2. According to mass flow rate, It is found that performance of heat transfer is increases as a flow rate increases.
3. For 6 mm nozzle diameter we get maximum Reynold no. as compared to 8 mm nozzle diameter.
4. For comparison of Nusselt no. we get maximum at 8 mm nozzle diameter instead of 6 mm nozzle diameter.
5. Overall heat transfer performance for 6 mm nozzle diameter shows better results as compared to 8 mm nozzle diameter.
6. CFD analysis also shows that better rapid cooling on copper circular plate by using jet impingement technique as compared to conventional methods.

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