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Investigation of the effects of orifice shape and angle on the impingement cooling of electronics components

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ABSTRACT

The progressive miniaturization of the modern electronics components has resulted into an acute increase of heat dissipation requirement for an efficient and safe operation of the components. This requires development of more and more powerful cooling systems. One of the most promising cooling techniques is impingement cooling of the substrate on which the electronics components are mounted using an air jet. The objective of the present study is to investigate the effects of orifice shape such as circular, square and triangular of same diameter (3mm) and ratio of the distance between the orifice and the substrate on the impingement cooling of the substrate. The values of Reynolds numbers considered are in the range 10000 to 16000. Furthermore, the effects of the angle of impingement (90°, 70°, 60°, and 45°) are also studied.

Keywords— Impingement cooling, orifice shapes electronic components etc.

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I. INTRODUCTION

The world is now progressing towards the different modern and sophisticated technologies in the field of mechanical, electrical/electronics, aeronautical engineering and so on. In fact such advanced technologies will lead to large heat emissions which require faster, smaller, and reliable electronicComponents demand for high powered electronics has increased. These lead to high heat flux that must be removed to avoid the failure. The traditional cooling techniques such as heat sink, heat sink with fan, heat pipes reached their limit. Jet impingement cooling is one of the very efficient solutions of cooling hot objects in industrial processes as it produces a very high heat transfer rate through forced convection. Jet Impinging is widely used for cooling, heating and drying in several industrial applications due to their high heat removal rates with low pressure drop. Cooling of such devices has become a challenge for decades. Numerous researches have been carried out in this field to enhance the rate of cooling of heat generating devices. One of the common day to day examples is the cooling of microprocessor chips used in almost all modern electronic devices such as laptops/computers and industrial processes involving high heat transfer rates apply impinging jets. Few industrial processes which employ impinging jets are drying of food products, textiles, films and papers, processing of some metals and glass, cooling of gas turbine blades and outer wall of the combustion chamber, cooling of electronic equipments etc. Jet impingement is one of the very efficient solutions of cooling hot objects in industrial processes as it produces a very high heat transfer rate through forced-convection. Over the past 30 years, experimental and numerical investigations of flow and heat transfer characteristics under single or multiple impinging jets remain a very dynamic research area. The effects of orifice geometry, jet-to-surface spacing, jet-to-jet spacing, cross flow, operating conditions, on flow and heat transfer have been studied by both experimentally and numerically. Impinging jets may be used for both cooling and heating purposes, but entrainment of ambient temperature fluid by the impinging hot jet will reduce its heating effectiveness, except for short nozzle-to plate distances. The main advantage of this technique lies in the high localization of the cooling, as the use of high speed jets allows removing a large amount of heat on the impinging surface, around the stagnation region.

The effect of orientation of jet arrays on the heat transfer rate has been the subject of investigation by many researchers.

Mangesh Chaudhari et al.[1] Studied the effect of shape of the orifice of a synthetic jet assembly on impingement cooling of a heated surface is experimentally investigated in this study. The shapes considered are square, circular, and rectangular, of different aspect ratios (in the range of 1–20) and hydraulic diameters (3.8–8 mm). The heat transfer enhancement with a square orifice is found to be larger than that with rectangular and circular shapes at larger axial distances z/d > 5, for the same set of boundary conditions

Colin Glynn et al. [2] Studied the convective heat transfer to impinging jets is known to yield high local and area averaged heat transfer coefficients In this study the measurement and comparison of heat transfer to submerged and confined air and water jets. The present paper on surface heat transfer measurements for a range of test parameters. These parameters include jet diameter (d from 0.5mm to 1.5mm), Reynolds number (Re from 1000 to 20000) and jet to target spacing (H from 0.5d to 6d). The results are presented in the form of local and full-field heat transfer coefficients for the range of conditions indicated.

Adnan A. Abdul Rasool et al. [3] conducted the Numerical and experimental investigation of the flow structure and heat transfer of impinging jet on target plate has been performed. The study covers the jet velocity, wall jet velocity, pressure coefficient and Nusselt number for five different orifices (d = 5, 10, 20, 30 and 40 mm) and different Z values

Arun Jacob et al. [4] Studies have been conducted to see the effect of the geometrical parameters such as jet diameter (D), jet to target spacing (Z) and ratio of jet spacing to jet diameter (Z/D) on the heat transfer characteristics. The values of Reynolds numbers considered are in the range 7000 to 42000. The results obtained from the numerical studies are validated by conducting experiments from the studies it is found that the optimum value of Z/D ratio is 5. For a given Reynolds number, the Nusselt number increases by about 28% if the diameter of the nozzle is increased from 1mm to 2mm. Correlations are proposed for Nusselt number in terms of Reynolds number and these are valid for air as the cooling medium

Chougule N.K et al [5] investigated the fluid flow and heat transfer characteristics of multi air jet array impinging on a flat plate both experimentally and numerically. It is found that Shear-Stress Transport (SST) k-w turbulence model can give the better predictions of fluid flow and heat transfer properties for solving such types of problems. Using SST k-w model, the effects of jet Reynolds number (Re), target spacing-to-jet diameter ratio (Z/d) on average Nusselt number (Nu) of the target plate are examined. These numerical results are compared with the available benchmark experimental data. It is found that Nu increases from 40 to 50.1 by increasing Reynolds number from 7000 to 11000 at Z/d =6. By increasing Z/d ratio from 6 to 10, Nu decreases from 50.1 to 36.41 at Re11000. It is also observed that in multi-jet impingement, spacing between the air jets play important role.

NARESH R and Ravinarayana Bhat N [6] carried out experimental work to investigate the variation in heat transfer with the different shape of the nozzle on a inclined plate impinged by a cold air jet. The cold jets having different Reynolds number is used to impinge on the plates and variation in Nusselt number is analyzed over the plate in the various Z/D ratio and at the various plate angles. He studied the variation of Nusselt number for various distances or various Z/D ratios Experimental analysis had done for studying the variation in heat transfer by using 10 mm circular and square nozzle of side 8.87mm at *Z/D* = 1, 2, 4 , 6 , 8, 10 and 12 and for the plate angles and different Reynolds numbers. From his experiment the maximum Nusselt number obtained in the stagnation region (r/D=0). The maximum Nusselt number in the plate is observed when the ratio between the plate centre and the diameter of the plate (Z/D) is 6. When the plate angle is zero degree the Nusselt number distribution is symmetric. As the plate angle increases the Nusselt number at the topside decreases and downside increases.

J. Ujam, T. Onah [7] carried out studies to determine the Convective Heat Transfer Coefficient, h, under multiple jets of impinging cold air on a target heated flat plate. Tests were run with air- distribution plates with hole diameters, *d*, of 1.5mm, 2.0mm, 2.5mm and 3.0mm. The target plate is a carbon-steel flat plate of 6mm thickness, instrumented with a total of three K-type thermocouples. The plate is electrically heated using a variable supply current input. Tests were run at various cooling air flow rate *G*, between 1.0kg/m3sec to 3.0kg/m3sec. Distribution plate-to-target plate distance Z (mm), was varied between 100mm to 200mm. Heat input to the target plate Q Watt, was varied to give a heat flux rate between 10 to 100 watts. Results obtained were reduced and analyzed by evaluating for the dependence of *h* on the impingement jet diameter, Jet Reynolds Number, and the coolant mass flow rate *G*. Correlations were done, using the dimensionless parameters of Nusselt Number, Reynolds Number and Prandtl Number. Based on the results obtained, it is proposed that within the Reynolds Number range of 1500 to 2000.

Purna C. Mishra et al [8] described the experimental results on heat transfer characteristics of array of jet impingement cooling of a steel plate. The experiments were conducted on a stationary electrically heated steel plate. A commercially available shower was used to generate array of jets. The Time dependent temperature profiles were recorded at the desired locations of the bottom surface of the plate embedded with K-type thermocouples. The controlling parameters considered in the experiments were water pressure, mass impingement density, mass flow rate, shower exit to surface distance respectively. The experimental results showed a dramatic improvement of heat transfer rate from the surface and the results established good optimal cooling strategies.

San et al [9] carried out an experimental study of air impingement on a flat plate that flow through two exits in opposite directions. Four orifices of 3, 4, 6 and 9 mm diameters were used with jet Reynolds number in the range of 30000 – 67000 at orifice-to-plate distance Z/d=02. The results showed that for the same Reynolds number, the smaller orifice diameter give lower Nusselt number but the influence decreased for d>6 mm. The measured local surface temperature shows that transition from impingement region to a wall jet region take place at (r/d) values close to 1.0.

Ali A. Al-Mubarak et al [10] Carried out the study of heat transfer characteristics in a channel with heated target plate inclined at an angle cooled by single array of equally spaced centered impinging jets for three different jet Reynolds numbers (Re=9300, 14400 and 18800). Air ejected from an array of orifices impinges on the heated target surface The target plate forms the leading edge of a gas turbine blade cooled by jet impingement technique. The work includes the effect of jet Re and feed channel aspect ratios (H/d = 5, 7, 9 where H=2.5, 3.5, 4.5 cm and d=0.5 cm) on the heat transfer characteristics for a given orifice jet plate configuration with outflow exiting in both directions (with inclined heated target surface). In general, It has been observed that, H/d=9 gives the maximum heat transfer over the entire length of the target surface as compared to all feed channel aspect ratios. H/d=9 gives 3% more heat transfer from the target surface as compared to H/d=5 (for Re=14400). Also, it has been observed that the magnitude of the averaged local Nusselt number increases with an increase in the jet Re for all the feed channel aspect ratios studied.

The present work investigates the heat transfer rate on a plate impinged with cold air jet by using three different types of jets are used namely the circular and square and triangular jets. The Reynolds numbers of these jets are varied in the range of around 10000 to 16000. The distance between the jet exit and impingements plate (*H/D*) is varied in the range of 8 to 22 mm and furthermore the angle of impingement is varied in the range of (90°, 70°, 60°, and 45°)

II. EXPERIMENTAL PROCEDURE

Figure 1 shows the layout of in-house fabricated experimental setup. Air jets for the experiments are generated using air compressor. Air cooled and oil splash lubricated reciprocating air compressor issued for the current study. The compressor can generate the compressed air at the mass flow rate of 0.1499 kg/s. The air is stored in a storage tank of capacity 0.5 m3 (500 Liters).

Fig 1 Experimental setup

A flow regulator valve is connected to the compressor end for varying the air mass flow rate, and Pitot tube is used to measure the velocity of impingement. The U tube manometer is connected for measurement of pressure head. Using a pipe reducer, the orifice shape like circular, square and triangular of diameter 3mm are attached to the air jet.

Impinging plate is a square geometry made of copper plate. It has the dimensions of 80×80×3 mm thick. The impinging plate has shinning smoothened flat area. The plate is fixed with a 240 V electrical coil for heating the plate. That is the heating coil or 50 watt plate type heater is sandwiched in between copper plate and support plate of same dimension. The coil is connected to a wattmeter and Dimmerstate for supplying constant AC voltage which in turn heats the coil to the desired temperature. Precaution has been taken to wrap the heating coil in circle along the stainless steel plate for the uniform heating. Teflon insulating material is placed in between the plates for safety purpose. The copper plate was maintained at constant heat flux of 25 watt. K-type thermocouple was attached to the Copper plate by hard soldering technique at center point for measuring the local temperature distribution along the plate surface as shown in fig. It is to be noted that any other possibilities of fixing the thermocouple to the copper plate was not successful. Temperature at center point of copper plate was recorded by temperature indicator.

The work investigates the heat transfer rate on a plate impinged with cold air jet by using three different types of jets are used namely the circular and square and triangular jets. The Reynolds numbers of these jets are varied in the range of around 10000 to 16000. The distance between the jet exit and impingements plate (*H/D*) is varied in the range of $8 \leq H/D \leq 22$. The temperature measurements are carried using K type thermocouple at center of plate. The methodology followed for the conducting the experiment is discussed below: The AC current is supplied to the heating coil by the arrangement of wattmeter and Dimmerstat and thus the plate is heated to a constant temperature value. By maintaing the constant heat flux of 25 watt. Three different orifice shapes are used for issues the different Reynolds number jet flow. The Reynolds number varied by using pressure regulator valve and range of Reynolds number is 10000 to 16000. The pressure head difference across the orifice meter was noted down by connecting the manometer. The obtained temperature for plate surface is in between 40 ℃ to 50℃. Radiation losses are neglected for experiment work. The natural convection from the back side of the plate is small. So it is considered as negligible. The orifice exit to impinging plate distance (*H/D*) is varied from the range of 8 and 22 by using the slider stand mechanism. And the angle is varied in the range of (90°, 70°, 60°, and 45°)

III.NUMERICAL ANALYSIS

A. Geometry and Boundary Conditions

The computational domain considered for the present study is shown in Fig.2. It consists of an enclosure which has dimensions of (160mm×160mm×25mm).The copper plate which has dimensions of (80mm X 80mm X 3mm) is placed at the centre of the bottom surface of the enclosure. The height of copper plate from top enclosure is taken as 25mm here at centre of top enclosure the orifice such as circular, square and triangular of diameter 3mm are impinging air jet at the copper plate which placed at center of bottom surface of enclosure. Inlet orifice flow velocity is taken as 53.50 m/s and Heat flux of 3906.25 w/m^2 applied to the bottom surface of the copper plate as boundary condition. Mass flow boundary condition is applied to the inlet of the orifice and temperature of air entering is 303 K. The flow is assumed to be steady, incompressible and three dimensional over the entire computational domain.

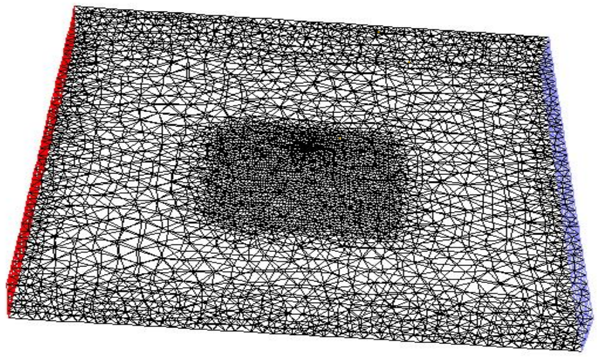

Fig 2 Geometry with mesh elements

B. Numerical Procedure

The computational domain is modeled using ICEM CFD 14 software and the same is meshed with Tet/hybrid elements. The number of elements is about 3 lakhs. No slip condition is applied to the wall surfaces. Fig. 2 shows the computational domain with mesh. The three dimensional Navier-Stokes and energy equations with the standard turbulence model are solved using CFD software (ICEM mesher and fluent solver) which are combined with continuity and momentum equations to simulate thermal and turbulence flow fields. The turbulence model used is standard k-ε model which is found to work the best among the available turbulence models for this flow configuration and is also chosen due to its simplicity, computational economy and wide acceptability. The flow is assumed to be steady, incompressible and three dimensional. The buoyancy and radiation heat transfer effects are neglected and thermo physical properties of the fluid such as density, specific heat and thermal conductivity are assumed to be constant. The schematic diagram of the physical geometry and the computational domain is shown in the following Fig.2.

C. Analysis

The software used for analysis is fluent 14. The turbulence model used is (k- ε) model which is found to be the best among available turbulence models for this type of flow configurations. A geometry and mesh object is imported into fluent solver software environment for solving governing equations. The flow and turbulence fields have to be accurately solved to obtain reasonable heat transfer predictions. Second order scheme is used for all terms that affect heat transfer. Second order discretization scheme is used for the pressure; second order upwind discretization scheme is used for momentum, turbulence kinetic energy, specific dissipation rate, and the energy. Flow, turbulence, and energy equations have been solved. To simplify the solution, the variation of thermal and physical properties of air with temperature is neglected. The standard SIMPLE algorithm is adopted for the pressure velocity coupling. The simulation type is steady state condition and convergence control is set at maximum 300 iterations which can be changed if convergence is not achieved. Analysis have been conducted to see the effect of Reynolds number (Re), jet spacing to jet diameter (H/d) ratio on cooling of copper plate by using three orifice shape.

IV. RESULT & DISCUSSION

Jet Impingement cooling system is constructed to determine the heat transfer coefficient and effect of various parameter on cooling system like effect of orifice shape such as circular square and triangular and the ratio of distance between orifice exit and impinging plate to diameter of orifice (H/D) and various Reynolds number for various angle of impingement For the current study constant diameter of 3 mm for circular, square and triangular orifice shape and velocity is varied for getting different Reynolds numbers flow for studying the heat transfer characteristics of jet impingement. The different shape and angle of impingement gives different heat transfer rate, velocity and Nusselt numbers. Jet impingement heat transfer is dependent on several flow and geometrical parameters. The jet impingement Nusselt number is presented in a functional form as follows:

$$Nu = Nu(Shape, \frac{H}{d}, Re, \theta)$$

Where, Re is the flow parameter, jet spacing to the diameter ratio (H/d) is the geometric parameter, shape used are circular, square and triangular and θ is the angle of impingement.

A. Effect of H/d on Heat transfer

From graph it clearly indicates that as distance between orifice exit and target plate increases from 8 to 22 the heat transfer rate decreases from 228.43 to 134w/m^{2}k. In case of low Z/D ratio the same amount of fluid spreads over lesser surface area causing a higher heat transfer rate. If the Z/D ratio is very low it will prevent the free flow of jet. The following are the graph for three different orifice shape and their effect on heat transfer.

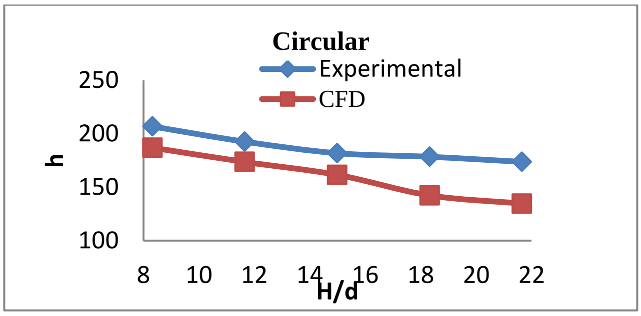

Fig 3 Effect of H/d on HT For circular orifice

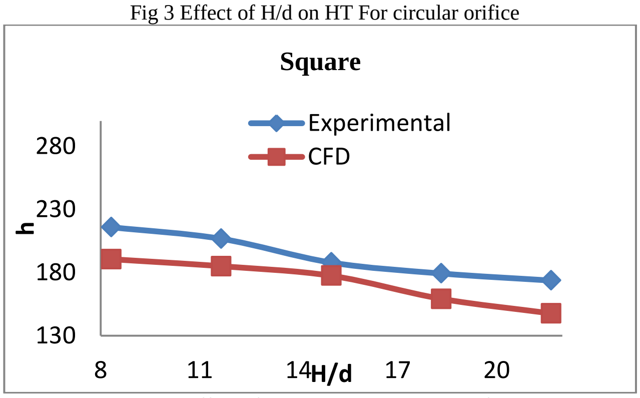

Fig 4 Effect of H/d on HT For square orifice

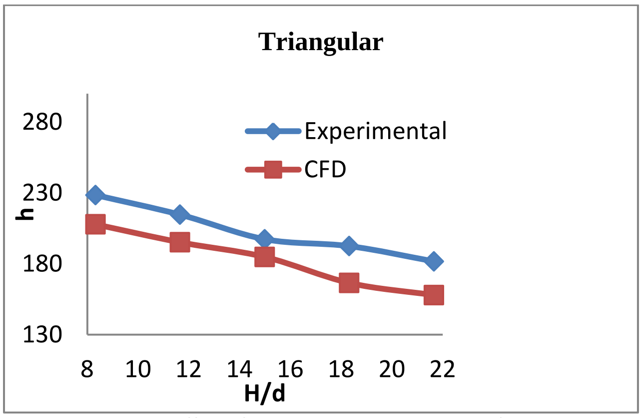

Fig 5 Effect of H/d on HT For triangular orifice

It is noted that for triangular orifice at H/d =8.33 gives higher heat transfer rate as compare to other orifice shape from Numerical and Experimental analysis.

B. Effect of Reynolds Number on HTC

Here Reynolds number is varied from 12000 to 16000 for three orifice shape it is observed that as Reynolds number is increases there is increase in heat transfer and The following are the graph for three different orifice shape and their effect on heat transfer.

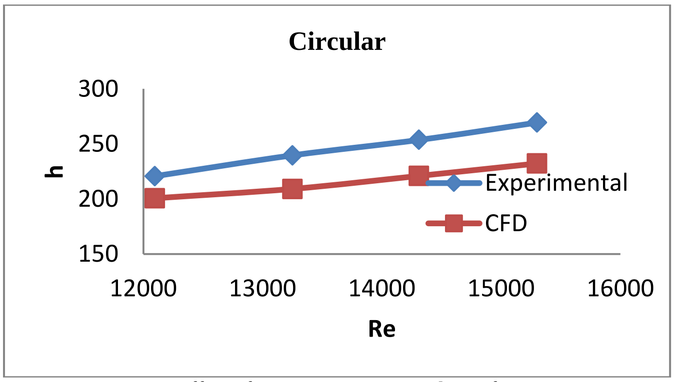

Fig 6 Effect of Re on HTC For circular orifice

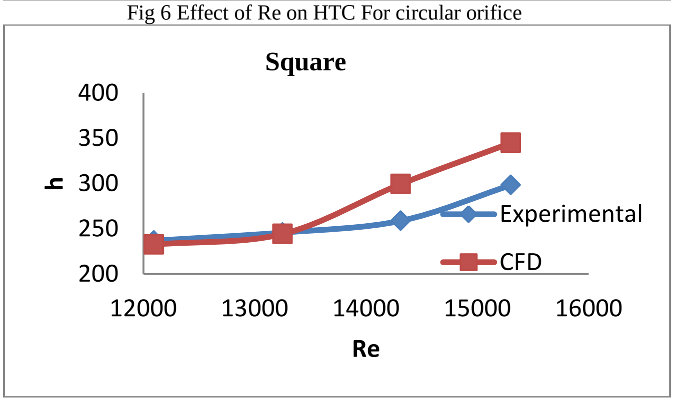

Fig 7 Effect of Re on HTC For square orifice

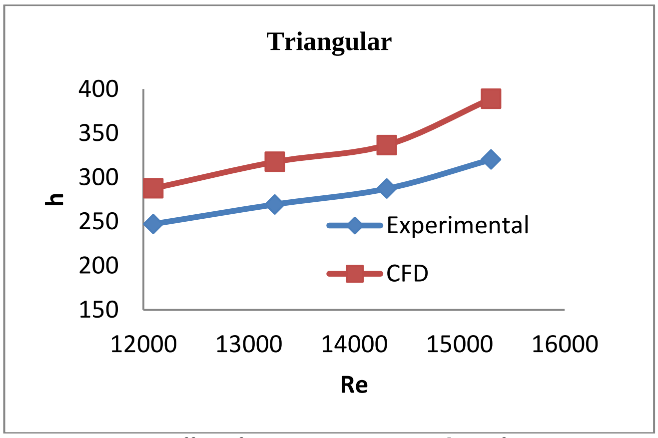

Fig 8 Effect of Re on HTC For triangular orifice

It is noted that for triangular orifice at constant H/d =8.33 and Re = 15302 gives higher heat transfer rate as compare to other orifice shape and given Reynolds number.

C. Effect of Reynolds number on Nusselt number

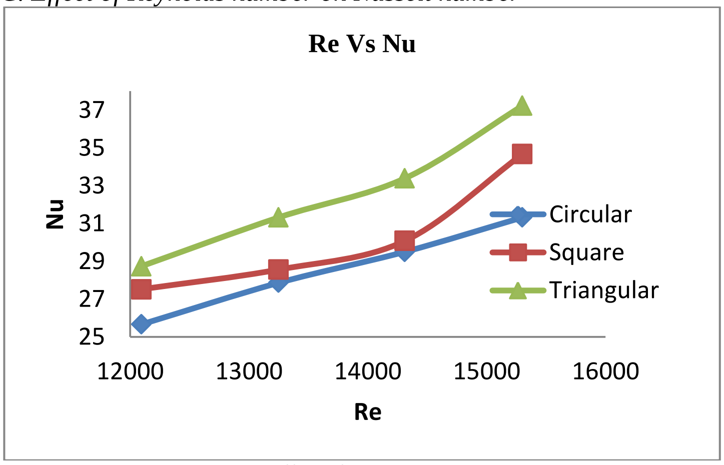

Fig.9 Effect of Re on Nu

It is observed that Nusselt number increases with increase in Reynolds number for all orifice shape

D. Effect Angle on HTC

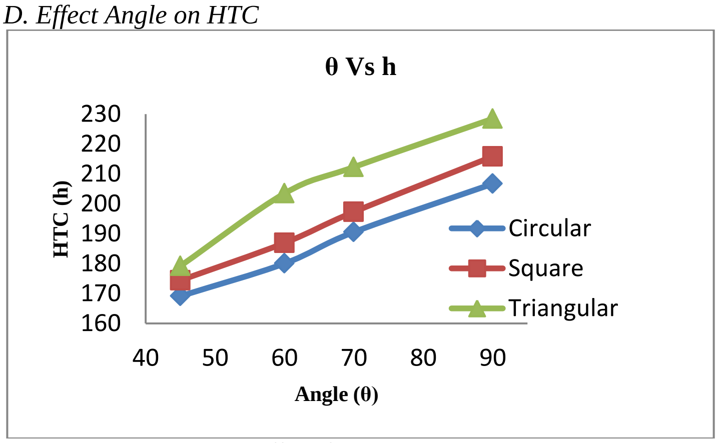

Fig. 10 Effect of Angle on HTC

Here as we increases the angle of impingement for every orifice shape there is increase in heat transfer rate and when orifice shape is at perpendicular to target plate it gives highest heat transfer rate and it is observed by triangular orifice shape.

D. Counters and path liness

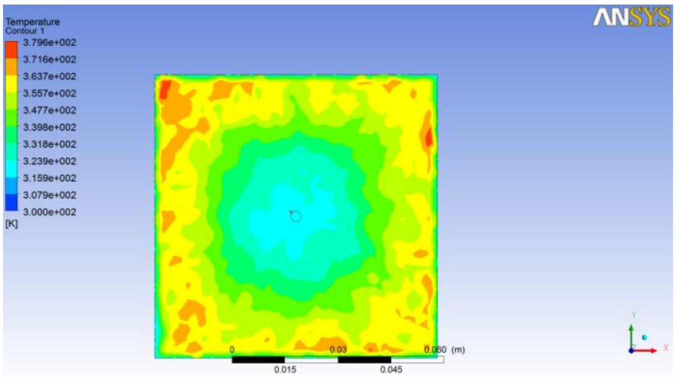

Fig 11 Temperature Counter

This fig 11 shows the the temperature distribution on copper plate by circular orifice shape and is is observed that CFD result has good agreement on experimental result.

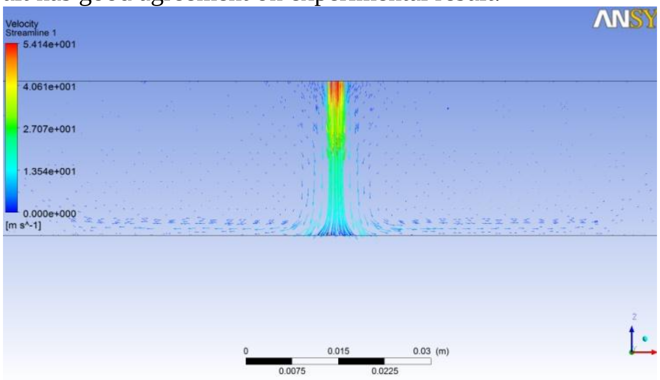

Fig 12 streamlines of air jet

The above graph shows the velocity streamlines of circular orifice shape.

V.CONCLUSION

Numerical and experimental investigations were carried out to study the effect of geometrical and flow parameters on the heat transfer characteristics. The conclusions derived out of the present study are

(i) As distance between orifice exit to target plate (H/d) increases for a given all three orifice there is decrease in heat transfer coefficient

(ii) It is found that triangular orifice gives higher heat transfer rate at H/d=8.33 as compare to other orifice shape.

(iii) As Reynolds number increases from 10000 to 16000 there is increase in heat transfer rate for all shapes.

(iv)It is found that as angle of impingement increases from 45^0 to 90^0 heat transfer rate increases and highest heat transfer rate is found at 90^0

(iv)From this studies is noted that Nusselt number increases with increase in Reynolds number so Nu=Nu (Re, H/d, shape and angle)

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