NUMERICAL INVESTIGATIONS OF THE EFFECT OF IMPINGEMENT PLATE PARAMETERS ON JET IMPINGEMENT HEAT TRANSFER FROM A FLAT PLATE

Mr. R.Veeranjaneyulu[1], *Mr. Maganti Sairam[2], *Dr. Pullarao Muvvala[3]

[1,]M.Tech Student,
[2]M.Tech Student,
[3]Associate Professor,
[1,2,3]Department of Mechanical Engineering

[1,2,3]Lakireddy Balireddy College of Engineering, Mylavaram, Krishna Dist,

Andhra Pradesh-521230, India

[1]Phone: 8143379610, e-mail: veeranjaneyuluanji90@gmail.com
[3]Associate Professor, Phone: 9440651708, e-mail: itsmemuvvala@gmail.com

Abstract

This numerical study investigates heat transfer performance of a three-dimensional, steady and incompressible circler jet of an impinging air normally on a heated flat plate. The bottom face of impinging plate is subjected to a constant heat flux and top surface is cooled by an impingement jet of air. The two equations to handle turbulent Shear Stress Transport (SST) and k-w model are used in this jet impingement problem. Impinged by hot air jets coming out of nozzles of different profiles and different materials of target plates that are (Acrylic, Stainless Steel, Wrought Iron,Nickel,Aluminium) are used. The nozzles employed in the investigation are single orifice, single nozzle. For single nozzle varying the l/d ratio that are (2,3,4,5,6,7,8) at Re 10000 and 0.5mm thickness target plate. For these studies Ansys Fluent Software is used. On the impingement plate temperature distribution, local and average Nusselts number values are recorded. The jet Reynolds numbers adopted in the study are 5000, 10000,15000,20000,25000 is at l/d 5 and 0.5 mm thickness aluminium target plate. In order to gain confidence in the numerical results, the results are validated with the previously published experimental results.

Keywords: Impingement of jets, convective heat transfer co-efficient (h), average and stagnation Nusselt numbers, temperature range (%), thermal conductivity (k), target plate, and Reynolds number.

NOMENCLATURE:

Parameter Symbols	Description	Units
D	Diameter	mm
t	Thickness of plate	mm
L	Length of plate	mm
(h)	Heat transfer co-efficient	W/m^2-K
Nu_{ave}	Average Nusselt number	
Nu_{stg}	Stagnation Nusselt number	
Re	Reynolds number	
L/D	Normalized separation distance	mm
T_{max}	Maximum temperature	K
T_{min}	Minimum temperature	K
T_{avg}	Average temperature	K

Greek letters

μ	Dynamic viscosity of airs	kg/m-s
ρ	Density	kg/m^3
t	Time	sec
υ	Kinematic viscosity	m^2/sec

Subscripts

Avg	average
Max	maximum
Min	minimum
S	impingement plate

INTRODUCTION

Jet impingement can be either by air powered, or some other forms of different liquids and coolants. In these highly developed jet strikes the impingement plate .The jet impingement technique is used for different applications that are used at cooling as well as heating applications. The jet impingement cooling used in cooling of turbine blades ,cooling of voltaic cells, cooling of electronic chip boards, cooling of machinery parts, combustion chamber cooling of engine cylinder, cooling of grinding wheels, drying process in leather and paper industry, annealing process in glass industry, cooling of electronic parts. Jet impingement technique is a modern method for removing high heat transfer at low time and heating process is also done by jet impingement.

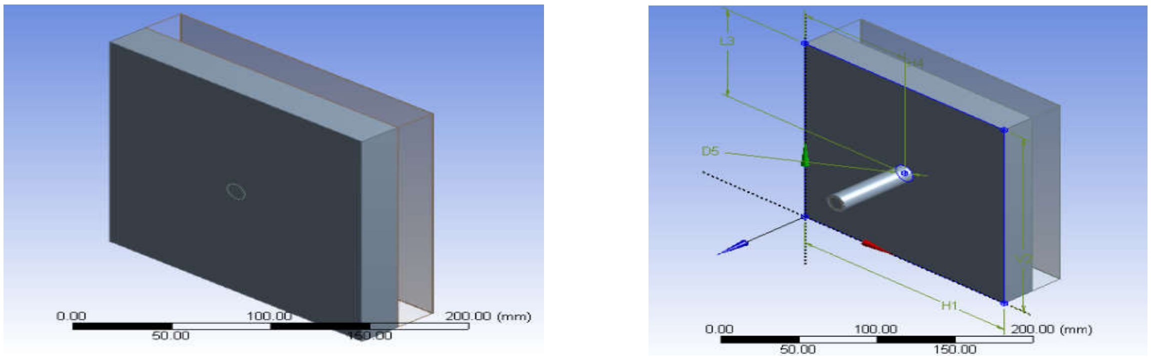
In these present study focus on improving the removing the high heat transfers at varying l/d ratios and Reynolds numbers and also increases thickness of target plates at l/d ratio 2 and (Re)=10000.

Over the few decades many experiments is done on the jet impingement heat transfer. Jambunathan and Glynn et al [1-2] studies the spacing between orifice exit to target plate distance and Reynolds numbers affects the jet orifice .And they explain the effects of average heat transfer increase with reducing diameter of jets. These results increase of jet velocities when smaller size orifice and nozzles are used. Lee and Lee [3-4] are investigated the characteristics of local heat transfer of jet regions .when increasing spacing between jet exit to target plate, due to these reason decreasing the temperature and also local heat transfer. And also studies the effects of nozzles. Ramadhyani et al [5] they investigated the constant heat flux is at bottom surface of plate and SST (shear stress transformation) and k-w model as taken for turbulent model and jet Reynolds numbers, plate thickness and orifice diameter. If found that variations of heat transfer between the orifice diameter and thickness ratio of target plate. Katti and Prabhu [6] these are done by an experiments for effects of jet exit to plate distance and Reynolds numbers, based on the local heat transfer co- efficient(h).They reports the when increase of jet to plate distance as a flat plate. When increasing of temperature in all directions and decrease of Nusselt numbers. Hrylak et al [7] reports the experimental results of heat transfer of circle turbulent jets impinges on flat plate .The target plate distance of different nozzles they observed that increase the nozzle to plate spacing they remains independent on potential core. Huber and Viskanth [8] they both are reported the effects of jet to jet distance on heat transfer performance form the impingement jets and for large plate spacing decreasing of the heat transfer of the target plate.

Most of preceding studies focused on heat transfer performance characteristics and geometrical configuration of single jet and single nozzle. Form the best authors studies the investigate the present study for numerical study of jet impingement on the flat plate with increasing the thickness of target plate at (0.5 mm,1.0 mm,5.0 mm ,10.0 mm, 20 mm).And varying jet Reynolds numbers 5000,10000,15000,20000,25000 and varying the l/d ratio at (2,3,4,5,6,7,8) at re 10,000 and 0.5 mm aluminium thickness target plate.

GEOMETRY:

The figure (1) shows the two different models that are one is single orifice and other one is single nozzle. The both orifice plate and nozzle plate is made with same materials that is acrylic. If I varying the both target plate materials and thickness that materials are (acrylic, stainless steel, wrought iron, nickel, and aluminium. These are based on under the consideration of thermal conductivity(k) and thickness of target plates is at (0.5 mm,1.0 mm,5.0 mm,10 mm,20 mm).The dimensions of single orifice with target plate is at 180 mm x 180 mm x t mm (‘t” means thickness of target plate).And flow domain dimensions are 180 x 180 x l/d (where ‘ l/d =2 at orifice exit to target plate distance).And dimensions of single nozzle with target plate is at 180 mm x 180 mm 0.5 mm and dimensions of nozzle is at 12.4 mm inner diameter and 15.4 mm outer diameter (D+3).And flow domain dimensions are varying based on the l/d ratio at (2,3,4,5,6,7,8)and length of nozzle is 5 times of diameter. The flow fields are taken from at atmospheric pressure is at $1x\ 10^5$ Pa and temperature is at 300K. These all models are created at ansys fluent software 18.0. And I am considering the some assuming the flow is in compressible and steady state and there are no slip conditions at wall. In target side bottom surface is exposed to constant heat flux and top surface is exposed to cooling of jet impingement.



(a)Single orifice (b) single nozzle

Fig: 1 Geometrical Models investigated

BOUNADARY CONDITIONS

The following boundary conditions are taken in that models that is:

Velocity inlet: when taken single orifice the uniform velocity (v =12.89 m/sec) and constant temperature (T) = 300K .But single nozzle the velocity is varying based on the Reynolds numbers (Re at 5000, 10000, 15000, 20000, 25000).from finding the velocity based on that Reynolds number (Re = ρvd/μ).

At wall: There are no slip conditions at wall side and adiabatic conditions.

Heat flux: In that model uniform and constant heat flux (q) =2000 W/m^2.

Insulated: In that insulation is given by four sides of target plate for there are no heat losses for that.

Interface: In these flow domain to solid interface at heat transfer boundary conditions is applied.

NUMERICAL VALUES OF GOVERNING EQUATIONS:

The following governing equations are taken from these models that are momentum, energy, continuity equations at steady state three dimensional flow equations in the ansys fluent soft ware 18.0. For turbulence modals the two equations are taken that are shear stress transformation (SST) and k-ὼ modals. In this second order up wind scheme is used for momentum and energy equations for turbulence. In that residuals values is taken from this modals 1 x10^{-04} for continuity equation and 1 x 10^{-08} for energy equation.

RESULTS AND DISCUSSION

In these study first of all varying the different materials with thickness of target plates at (0.5 mm, 1.0 mm,5.0 mm,10 mm,20 mm,).At l/d ratio 2 and Re 10000. If i also varying the thickness of target plate materials based on the thermal conductivity(k).I observed that by changing materials with same thickens the average temperature is gradually decrease. Whenever the temperature is decrease the average and stagnation Nusselt numbers values are increase based on the local heat transfer co-efficient (h) is calculated by using equation (1).

$$q = h\,A\,(T_{max} - T_{min}) \qquad - (1)$$

$$Nu = hd/k. \qquad - (2)$$

If i varying the materials with different thickness the average temperature is decrease due to increase the thickness of target plate with same amount of constant heat flux is given throughout at all thickness. So thickness of target plate in increased the time taken is gradually increases for a given heat to target plate. Due to these reason the temperature is decreases when the increase of target plate thickens. Whenever the temperature is decrease increase of Average and Stagnation Nusselt numbers values are increase. Due to these reason the temperature range is also decrease.

If i varying the l/d ratio's at Re 10,000and 0.5 mm thickness aluminium target plate at inlet velocity (v) =12.89 m/sec. Due to increasing of l/d ratios the jet spreaded distance is gradually increase in between jet exit to target plate distance is also increase.This reason the temperature distribution on target plate is also increase at that time. And decrease the average and stagnation Nusselt numbers values are decreases. And there is slight variation in the temperature range.

If i varying the Reynolds numbers at 5000,10,000,15,000,20,000,25,000 at l/d ratio 5 and 0.5 mm thickness plate. When increase Reynolds numbers the jet inlet velocity's is increase. The striking of jet speed is also increase and high amount of heat can be removed from target plate. Due to these reason the temperature distribution on the target plate is decrease. When temperatures values are reduce the average Nusselt number and stagnation Nusselt number values are increase. And temperature range values are reduced. The temperature values are calculated by using equation (3).

$$TR = \frac{T_{max} - T_{min}}{T_{avg}} \times 100 \qquad - (3)$$

Validation for present numerical results compare with previous numerical results for single nozzle:

Based on the literature survey, the present study uses the same geometrical parameters to measure the stagnation Nusselt number at Reynolds number (Re) 10000.This comparisons emphasis that the present results reaches to the literature results. By calculating the percentage of error is obtained by 2.0%

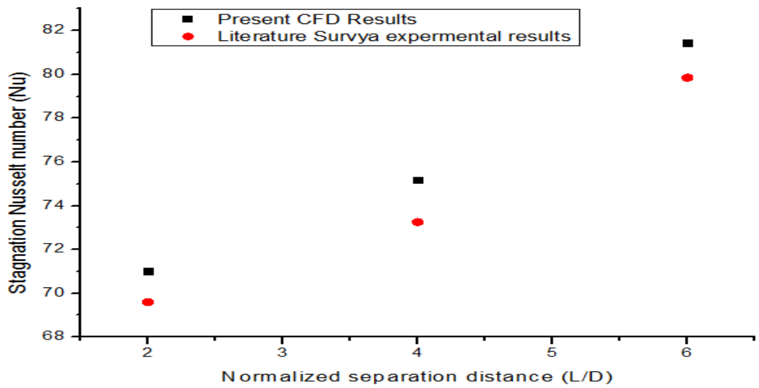
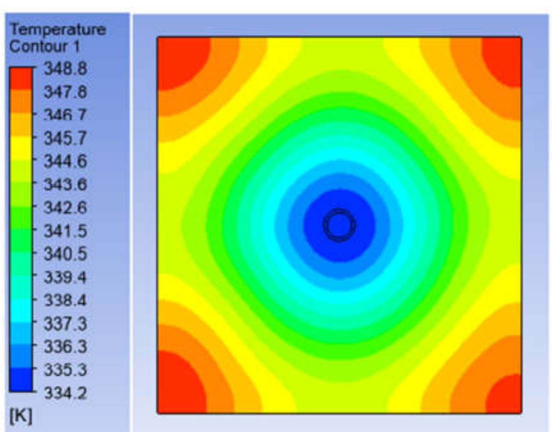


Fig: 2 Effect of normalized separation distance (l/d) on stagnation Nusselt number (Nu)

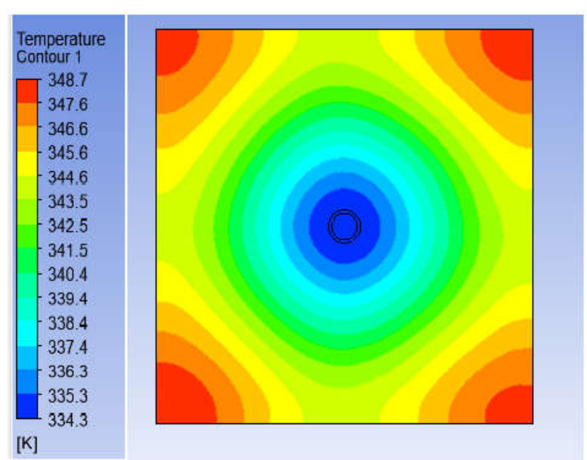
Effect of l/d ratio on temperature distribution (At Reynolds number (Re) =10000 & 0.5 mm thickness aluminium target plate):

The effect of l/d ratio on impingement plate thickness 0.5 mm (at Reynolds number (Re) 10000) the temperature distribution on top face of the plate. When the l/d ratio increase one by one the jet impinges distance increase from nozzle exit to target plate distance is increase and also the increase of temperature distribution on aluminium target plate. When temperature distribution is increase the Nusselts numbers values are reduced.Due to decreasing of heat transfer co-efficient (h).

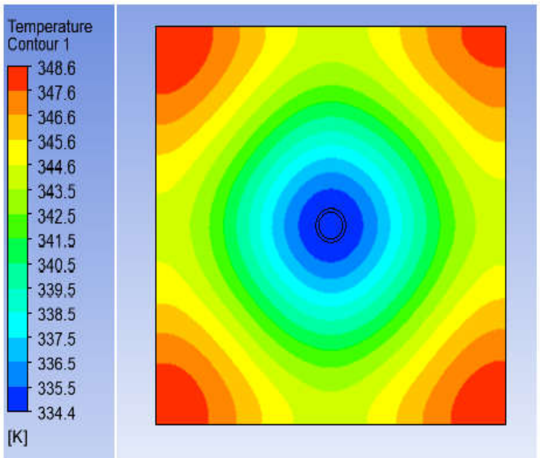
The normalized separation distance (l/d) of the plate increase the jet travelling distance in between nozzle exit to target plate distance is also gradually increase. When the jet travelling distance is increase the stagnation region of jet is also increase. Due to these reason more amount of heat transfer area is covered for removing of heat at target plate. The amount of heat transfer decrease the value of heat transfer co-efficient (h) value is also decrease .these reason the average and stagnation Nusselt numbers values are reducing.



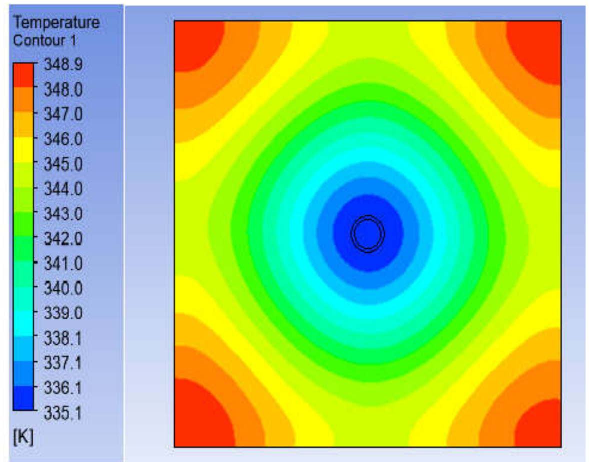
L/d = 2



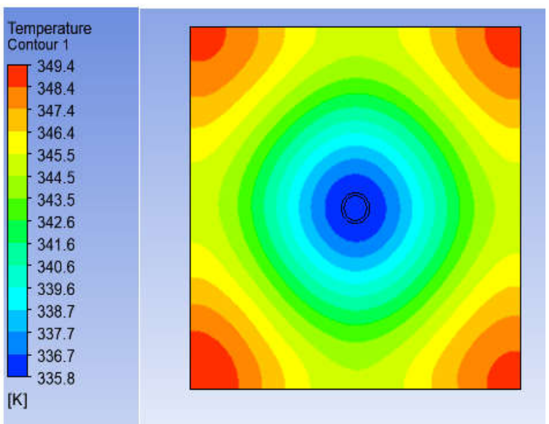
L/d = 3



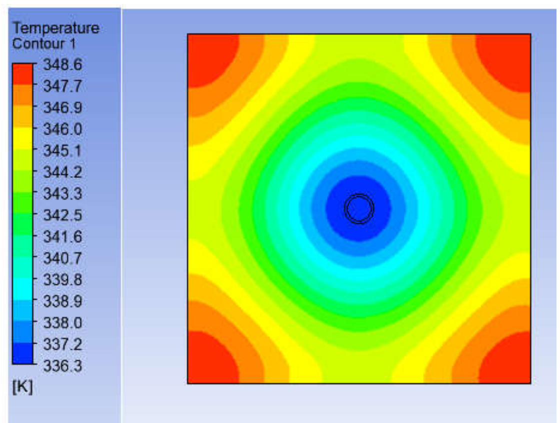
L/d = 4



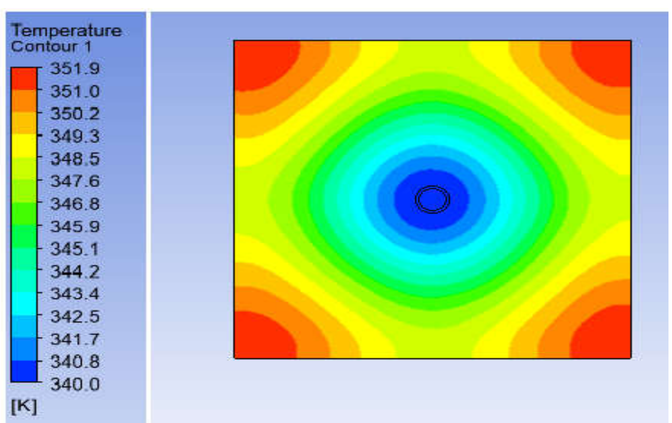
L/d =5



L/d = 6



L/d = 7



L/d = 8

Fig: 3 Effect of l/d on temperature distribution for Aluminium plate

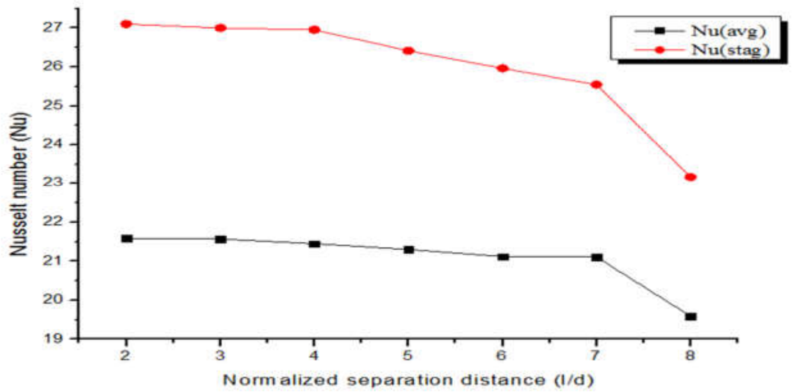


Fig: 4 Effect of normalized separation distance (l/d) on Nusselt number (Nu)

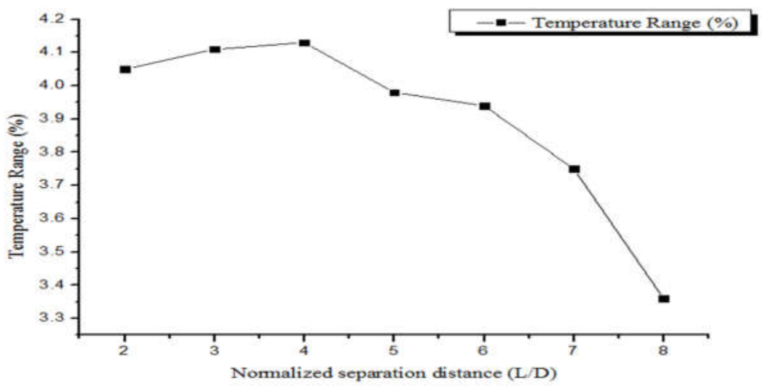
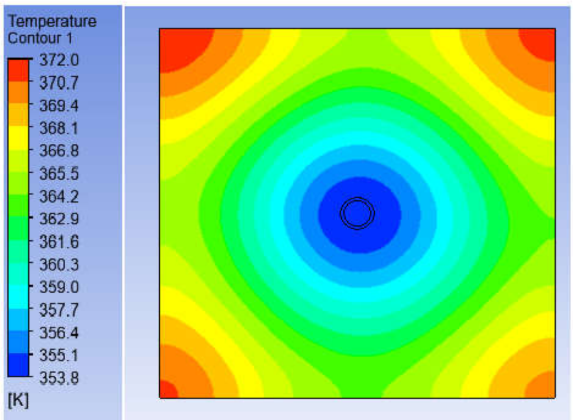


Fig: 5 Effect of normalized separation distance (l/d) on temperature range (%)

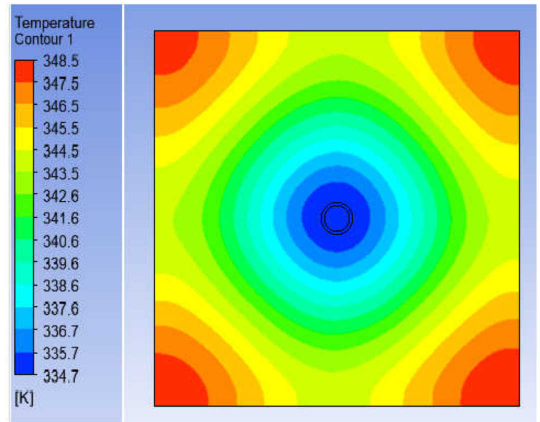
Varying the l/d ratio (i.e. 2, 3, 4, 5, 6, 7, 8) at constant Reynolds number (Re 10000) and inlet velocity (v =12.89 m/sec) at 0.5 mm aluminium thickness target plate. Due to increasing of l/d ratio spread distance b/w the jet and target plate increase and also temperature distribution on the target plate is also increase. If increase the temperature distribution value the value of average Nusselt number and stagnation Nusselt numbers decrease and there is slight variation in the temperature ranges.

Effect of Reynolds numbers on temperature distribution (at l/d = 5 and 0.5 mm thickness aluminium target plate):

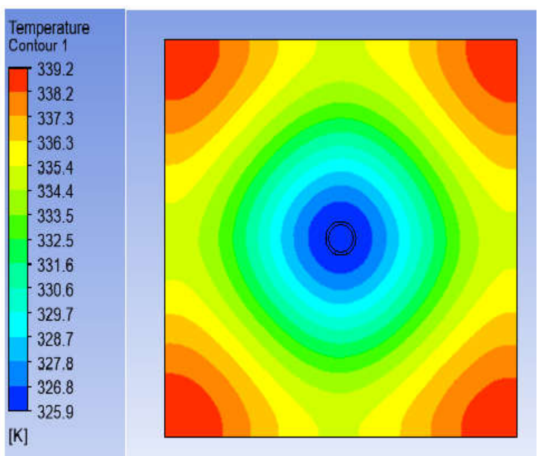
When i considering different Reynolds numbers at l/d = 5 and 0.5mm aluminium target plate and the temperature distribution on the target plate is based on the Reynolds numbers at different velocity's. When Reynolds number increases the velocity of jet inlet is also increase. Due to increasing of inlet velocities the temperature distribution on target plate is decrees. When temperature distribution on target plate is decrease the increasing of average and stagnation Nusselt numbers values are increase.



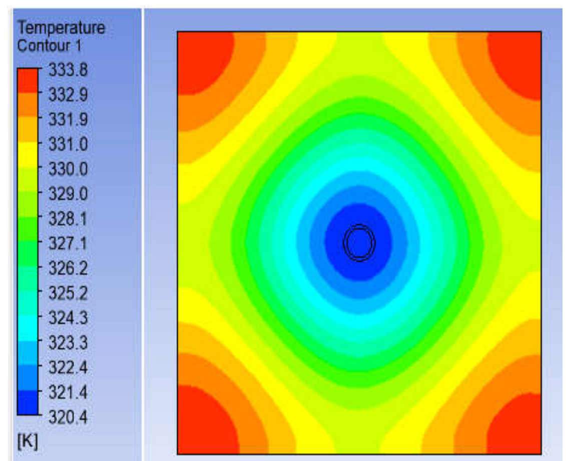
Re = 5,000



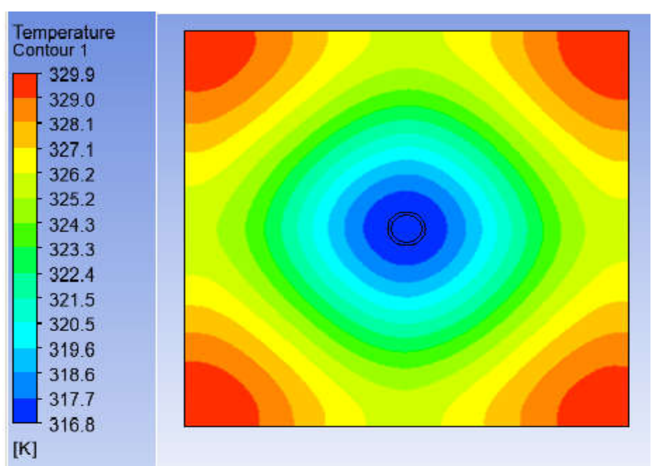
Re = 10,000



Re = 15,000



Re = 20,000



Re = 20,000

Fig: 6 Varying Reynolds numbers (Re) at 0.5 mm thickness aluminium target plate.

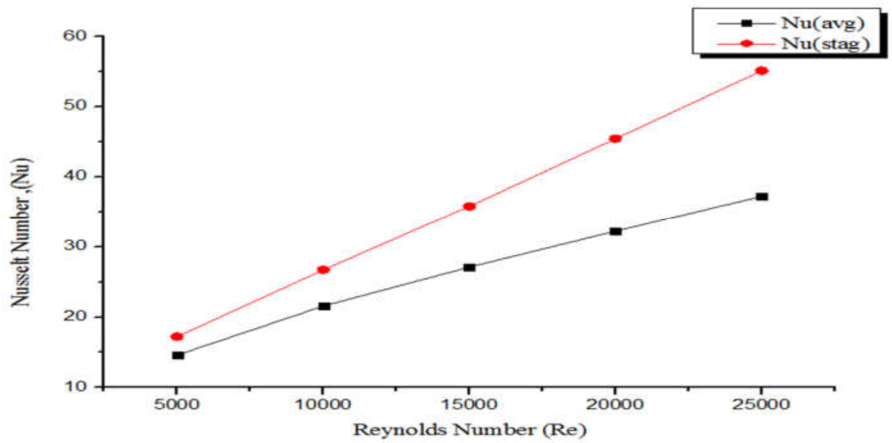


Fig: 7 Effect of Reynolds number (Re) on Nusselt Number (Nu)

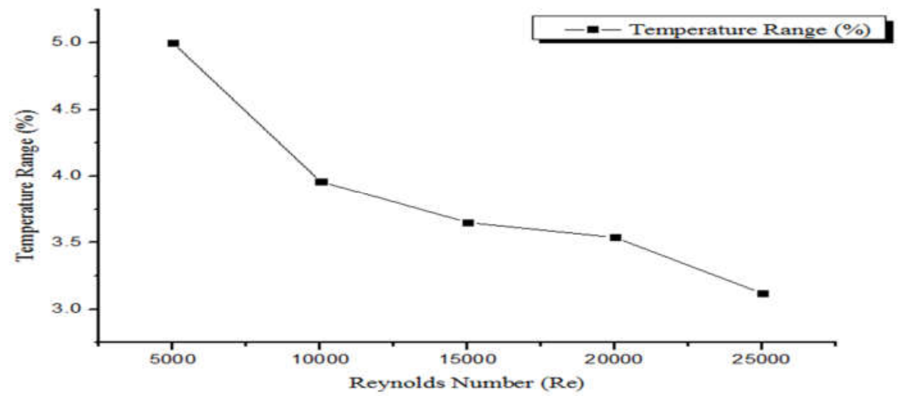


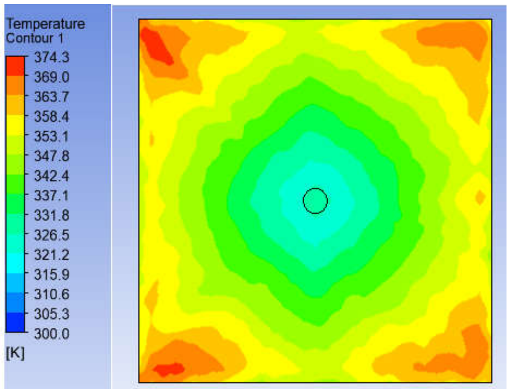
Fig: 8 Effect of Reynolds number (Re) on Temperature range (TR)

Consider different Reynolds numbers at l/d ratio 5 and 0.5 mm thickness target plate .if increasing in Reynolds numbers than jet inlet velocity's increase. Due to decreasing of temperature distribution on target plate .and there is increasing of average Nusselt number and stagnation Nusselt number .finally temperature range is decrease.

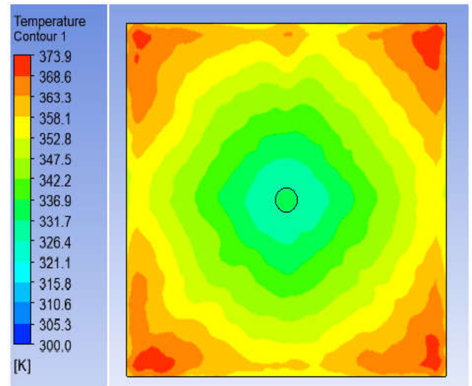
Effect of thickness on tempreature distribution (At l/d=2 , Reynolds number (Re) = 10000):

The effect of temperature distrubution on target plate based on the thermal conductivity increase from 0.21to 202.4 W/m-K at l/d 2 and reynolds number 10000.when taking one material with different thickness of target plate the temperature distribution on the target plate is readuce gradully by increasing the thickness of target plate. Due to the reason the temperature values re decrease .when decrese the temperature values increasing of nussels numbers.

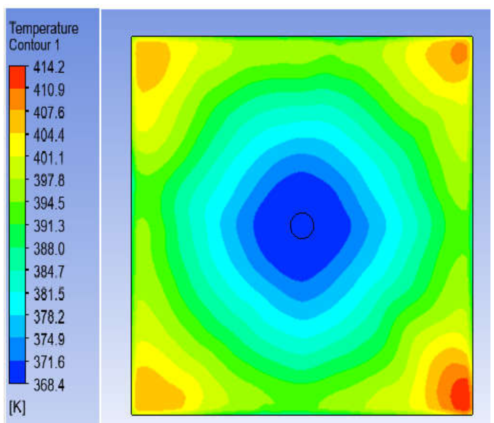
When considering different materials at different thickness the temperature distrubution on the target plate is incease. Based on the thermal conductivity the conduction on the target plate is more.due to these reason the average and stagnation nusselts numbers vallues are reduced.and also temperature range is decrease when increasing of thermal conductivity.



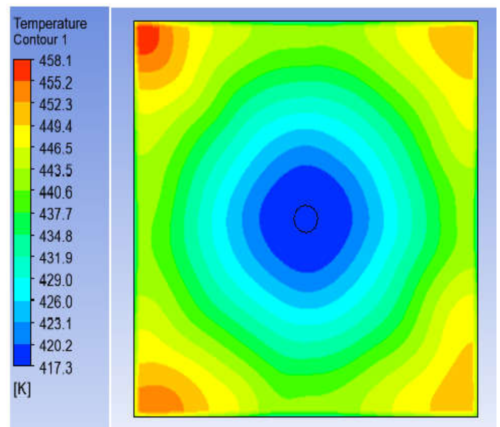
0.5 mm thickness



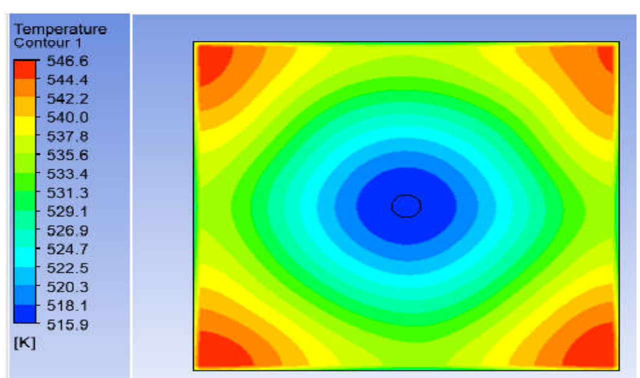
1 mm thickness



5 mm thickness



10 mm thickness



20 mm thickness

Fig: 9 Temperature distributions over the different target plate thickness

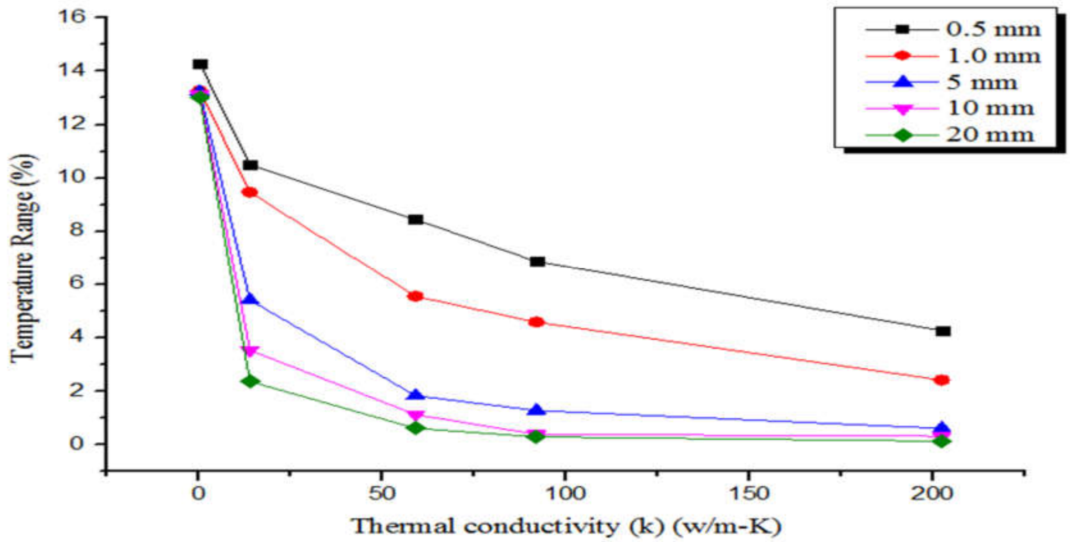


Fig: 10 Effect of Thermal conductivity (k) on Temperature range (%)

In this graph when thermal conductivity is gradually increase. The values of temperature range of all the different thickness of materials is decrease .The reason for decreasing the temperature range values are when the thickness of target plate is increase gradually decreasing of temperature of all the materials. In that case the temperature range values are decrease.

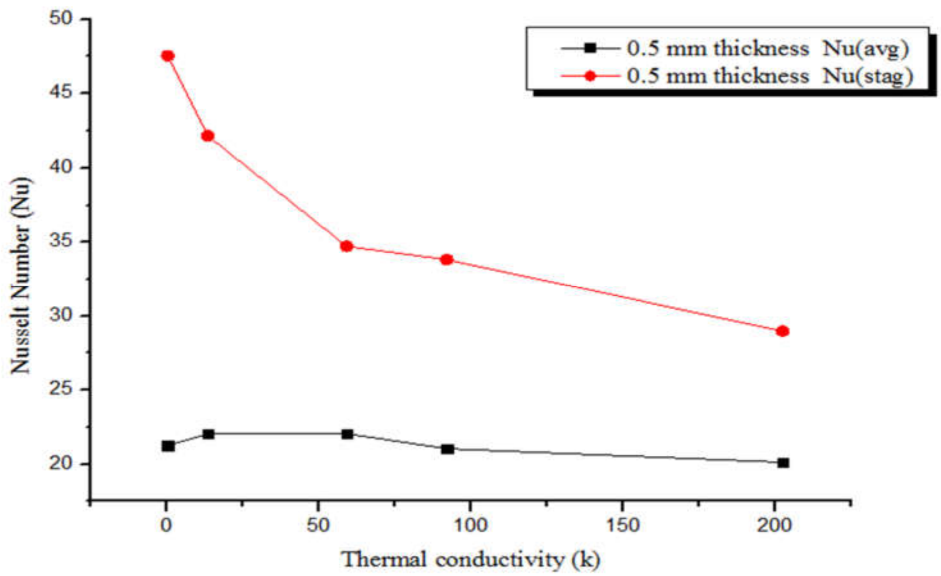


Fig: 11 Effect of thermal conductivity (k) on Nusselt Number (Nu) for 0.5 mm thickness

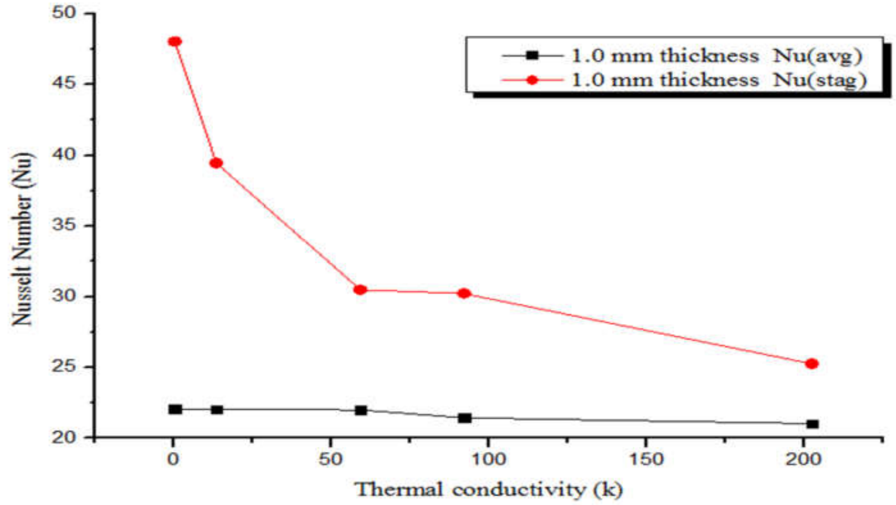


Fig: 12 Effect of thermal conductivity (k) on Nusselt Number (Nu) for 1.0 mm thickness

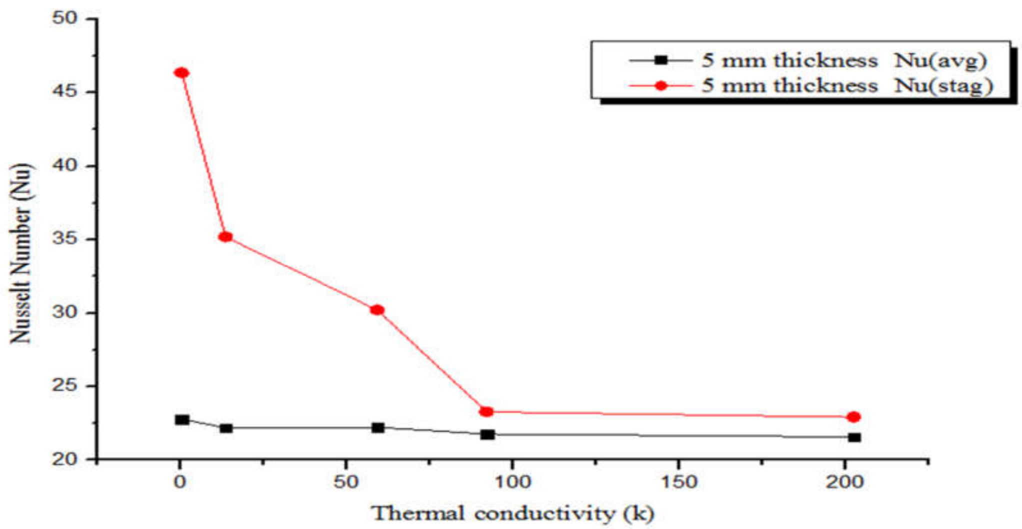


Fig: 13 Effect of thermal conductivity on Nusselt Number (Nu) for 5 mm thickness

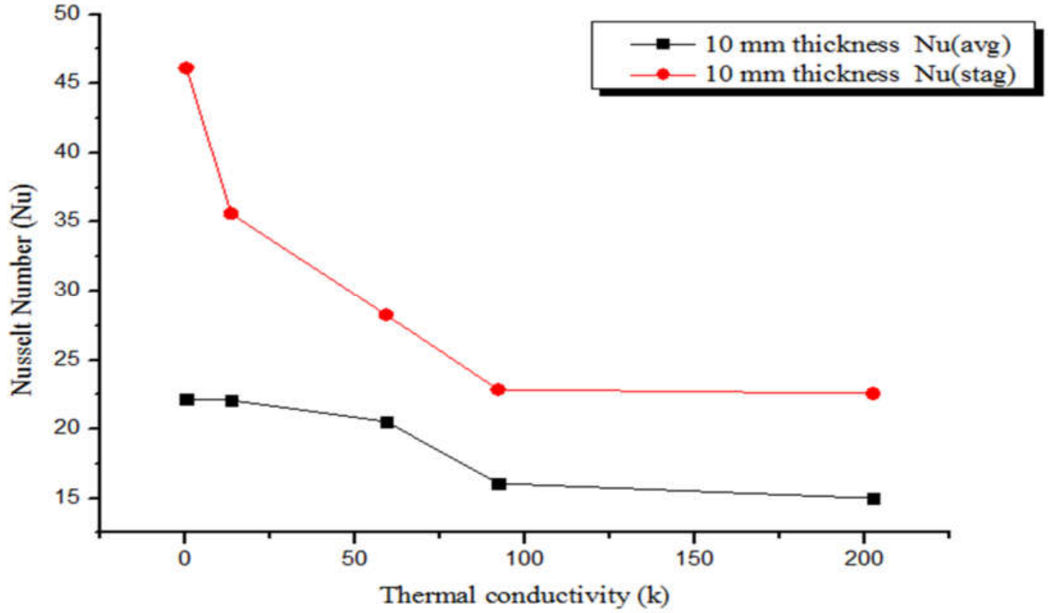


Fig: 14 Effect of thermal conductivity (k) on Nusselt Number (Nu) for 10 mm thickness

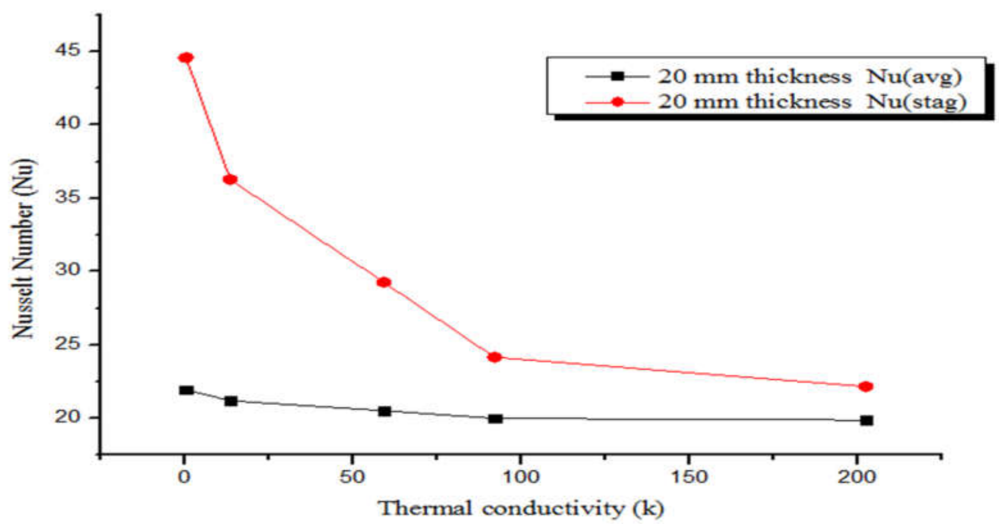


Fig: 15 Effect of thermal conductivity (k) on Nusselt Number (Nu) for 20 mm thickness

Consider different materials at increase thermal conductivity at l/d ratio 2 and Reynolds number (Re) 10000.

If varying the thermal conductivity of target plate materials and gradually increase target plate thickness. It observed that increase of convective heat transfer (h) value there is decreases the value of average Nusselt number and stagnation Nusselt number and also decreases the temperature range also

Conclusions

A numerical examination is carried out based on the heat transfer performance on jet impingement problems using flat plate .by studies the effects of increasing thermal conductivity and thickness of target plates. and also studies the effects of increasing of l/d ratios and increasing Reynolds numbers at 0.5 mm thickness aluminium target plate.

- If thickness of plate increases temperature distribution on plate is decrease. And also temperature range is also decrease.
- If thermal conductivity of materials is increases temperature distribution on the plate is decrease .Hence temperature range decrease.
- Due to increasing of l/d ratio the jet velocity spreaded on the Whole target plate. These increase on overall heat transfer of the target plate.

When increasing Reynolds numbers at 0.5 mm thickness of aluminium target plate. The jet inlet velocities is increases based on the Reynolds numbers and ability of striking of jet is also increase.when heat transfer co-efficient (h) value is gradually decrease. That time increase of Nusselt numbers values. These based on the temperature distribution and heat transfer performance.

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