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Research

Analysis of Heat Transfer and Flow Due to Natural Convection Around Heated Semi-Circular cylinder Placed At Incidences Inside A Square Cavity

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ABSTRACT

This synopsis talks about study of 2-D steady state simulations of laminar natural convection in a square cavity, containing a heated Semi - Circular Cylinder placed at various incidences, filled with air, have been carried out. The top and bottom wall of square cavity is assigned with Neumann Boundary conditions, zero heat flux whereas left and right wall of the square cavity is assigned with Dirichlet Boundary conditions, constant wall temperature and the flow geometry is assigned with higher temperature then the walls with no heat generation. The governing partial differential equations describing the fluid flow and heat transfer have been solved using Ansys Workbench 15.0, a finite volume based solver, over a 10^4 range of the dimensionless parameter, namely, Rayleigh number. The detailed flow and temperature fields in the proximity of the heated Semi - Circular Cylinder are visualized in terms of the streamline and isotherm profiles, respectively. It is found that Surface Nusselt number Nu and Surface Heat Transfer Co-efficient show similar trends, increasing, for all incidences, for 10^4 Rayleigh number.

I. INTRODUCTION

Natural convection in an enclosure, where flow is caused by temperature-induced density variations, has been studied extensively over the past years because it is relevant to many industrial and environment applications. It is found from the literature that the work done in this area was pertained to Newtonian fluids like air and water. Many researchers have also worked with similar enclosures with higher range of Rayleigh numbers, different solution methods. Over the decades, meticulous research efforts have been given for broad understanding of the fluid flow and heat transfer past bluff bodies of various cross-sectional geometries. Most of the effort is dedicated in analyzing the complex flow physics and thermo-fluid transport phenomenon for circular, square, rectangular, and elliptic cross-sections in particular. To be specific, most of the literature deals with the circular geometry whereas a very less attention has been paid to square, rectangular, and elliptical shapes. Furthermore several studies have been accomplished in understanding the heat transfer characteristics at different flow conditions. In such studies, the momentum and heat transfer under cross flow situation have been found a subject of considerable theoretical and practical importance. The practical application for flow and heat transfer past a Semi - Circular Cylinder include designing chimney stack, cooling tower, thermal processing of food stuff, processing of fibrous suspensions, electronic circuit cooling, paper making, under water vessels etc. the present work shows the effect of incident angle and position of Semi - Circular Cylinder inside a square enclosure on the flow and heat transfer at Rayleigh numbers 10^4 is studied.

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II. PHYSICAL MODEL

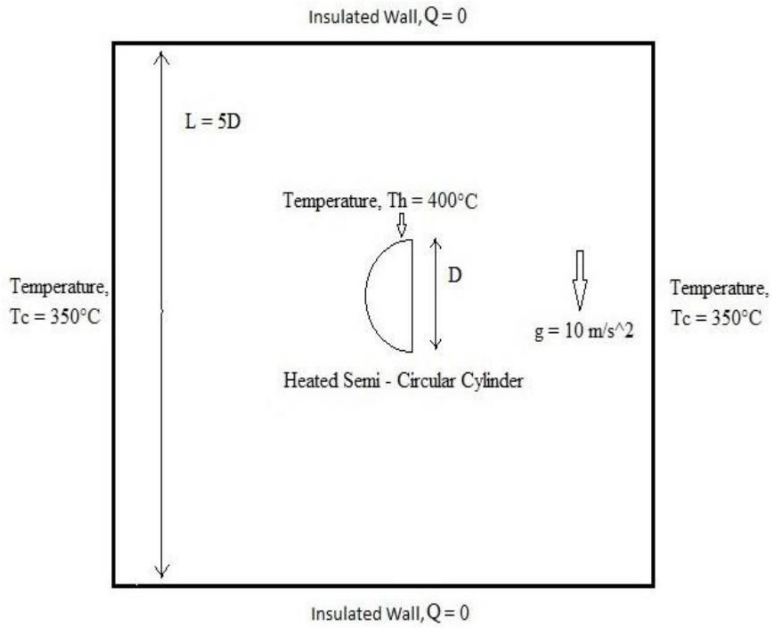
Consider a Semi – Circular Cylinder whose surface is maintained at a constant temperature T_h, confined in a duct of square cross-section (side, L) as shown schematically in Figure Consider a Semi - Circular Cylinder whose surface is maintained constant temperature T, confined The top and bottom walls of the confining duct are maintained at constant heat flux and left and right walls are maintained at constant temperature T_c ($<T_h$), as shown schematically in Fig. 1. In this study we assumed that the Semi - Circular Cylinder is placed exactly at the centre of the square enclosure. As shown in Figure.

III. EQUATIONS AND BOUNDARY CONDITIONS:

Within the framework of these assumptions, the coupled velocity and temperature fields are governed by the continuity, momentum and thermal energy equations as follows.

Continuity equation-

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0$$



X - momentum equation

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right)$$

Y- momentum equation

$$u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial p}{\partial x} + \nu\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) + g\,\beta\,(T - T_0)$$

Energy equation

$$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = \alpha\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right)$$

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Grashof Number $Ra = Gr\,\mathrm{Pr} = \frac{g\beta(T_s - T_\infty)\delta^3}{\nu^2}\mathrm{Pr}$

Grashof number is a dimensionless group. It represents the ratio of the buoyancy force to the viscous force acting on the fluid:

$$Gr = \frac{g\beta(T_s - T_\infty)\delta^3}{\nu^2}$$

Rayleigh Number

The complexities of the fluid flow make it very difficult to obtain simple analytical relations for natural convection. Thus, most of the relationships in natural convection are based on experimental correlations. The Rayleigh number is defined as the product of the Grashof and Prandtl numbers

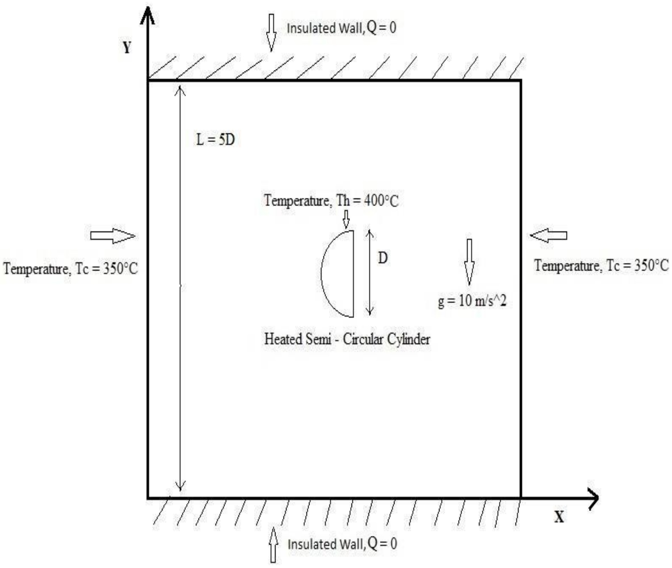
Boundary conditions:

The top and bottom wall of square cavity is assigned with Neumann Boundary conditions, zero heat flux whereas left and right wall of the square cavity is assigned with Dirichlet Boundary conditions, constant wall temperature and the flow geometry is assigned with higher temperature then the walls with no heat generation. No slip condition is assumed at all the walls

For Enclosure:	Left wall	$T=T_c$,
	Right wall	$T=T_c$,
	Top wall	Q=0,
	Bottom wall	Q=0,

For Semi - Circular Cylinder:

	Geometry	$T=T_h$,



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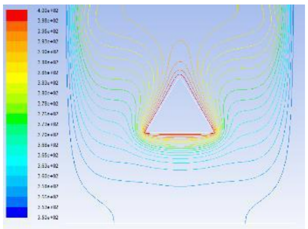
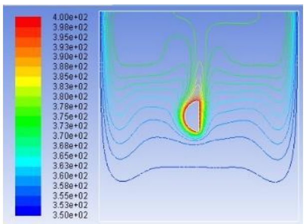


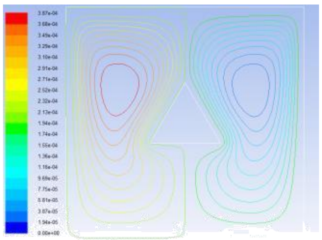


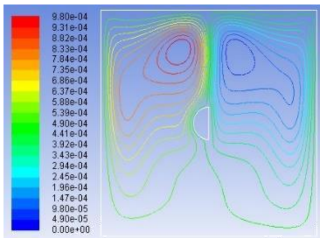
(a). Reference Geometry at 0° (b). Validated Geometry at 0°

Validation of Contours of Isotherms for θ= 0°

IV. VALIDATIONS OF RESULTS

In recent study, Sahu et al. [12] studied "Analysis of heat transfer and flow due to natural convection in air around heated triangular cylinders of different sizes inside a square enclosure". For the purpose of validation, their results have been reproduced here. A comparison in terms of stream lines and isotherms with already present result for Raleigh number Ra 10^4**.**





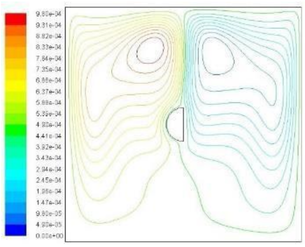
(a).ReferenceGeometry at 0° (b) Validated Geometry at 0°

Validation of Contours of Stream Function for θ= 0°

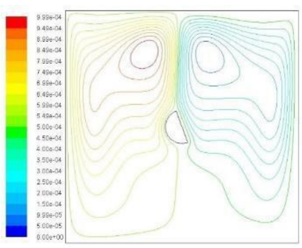
V. RESULT AND DISCUSSION:

Contours of steam function

Due to symmetric nature of the domain and boundary conditions about the Semi - Circular Cylinder, the flow distributions are also symmetrical for 0˚ and 180˚. But there is slightly deviation in other incidences. The value of stream function will vary slightly from (**ψ_{max} = 0.0009801347**). The air move upwards near the inclined walls of the cylinder as these are at higher temperature and move downwards near the vertical walls of the enclosure as these are at low temperatures. So, there are two loops formed at left and right side with air moving anticlockwise direction at left side and in clockwise direction at right side. With fixed temperatures of Semi - Circular Cylinder and vertical walls of enclosure for Ra =104, Effect of incidences on stream function are shown below.



(a). 0°



(b). 20°

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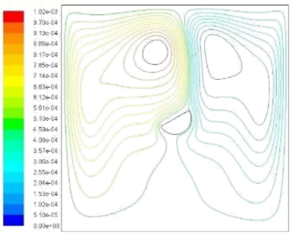
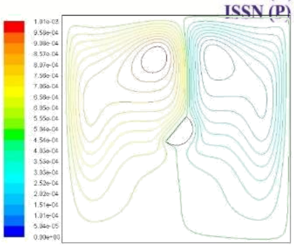
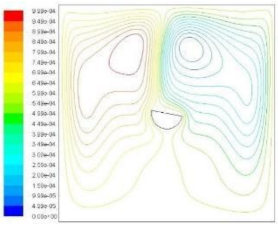


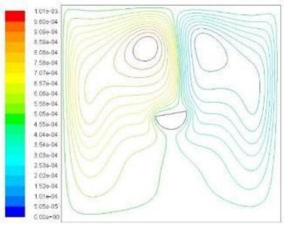
(c). 40°



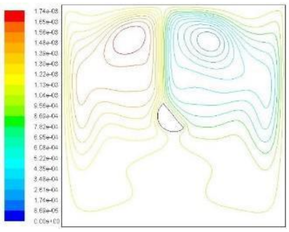
(d). 60°



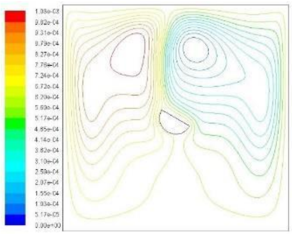
(e). 80°



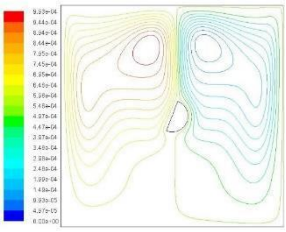
(f). 100°



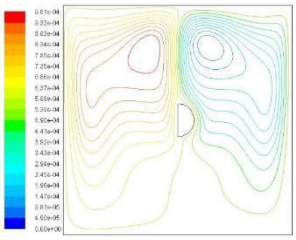
(g). 120°



(h). 140°



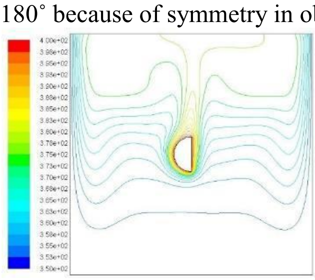
(i). 160°



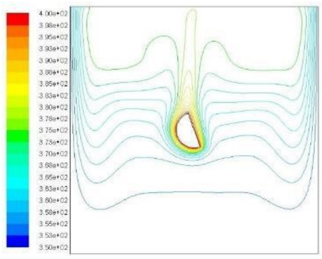
(j). 180°

Contours of static Temperature

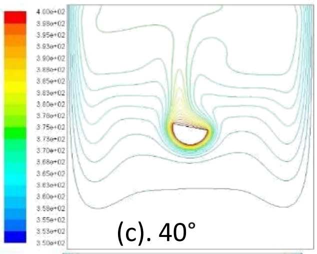
At the upper portions of the vertical walls, the temperature gradient is more as observed from the isotherms whereas at the lower portions of these walls, the temperature gradient is less. This is because of that, the fluid after carrying the heat from the heated object, first interacts with the cold enclosure walls at the upper portion. Due to higher temperature difference at these locations, the heat transfer rate is more there. As the heat is transferred, the temperature of the fluid decreases and the temperature difference between the fluid and vertical enclosure walls decreases towards the bottom portion of these walls. This results less heat transfer at these portions. Isotherm profile for all incidences are shown below. It is symmetrical for 0˚ and 180˚ because of symmetry in object and boundary conditions.



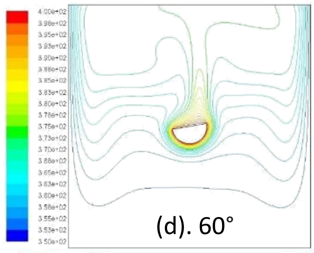
(a). 0°



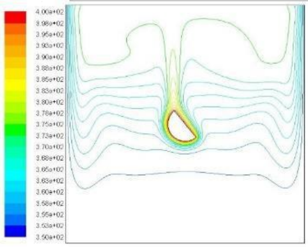
(b). 20



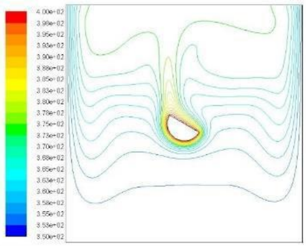
(c). 40°



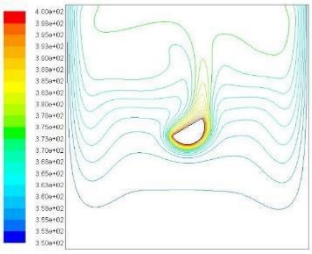
(d). 60°



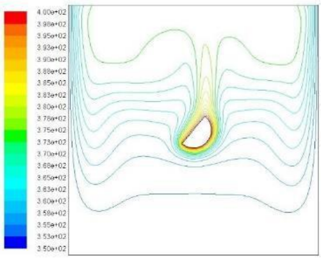
(e). 80°



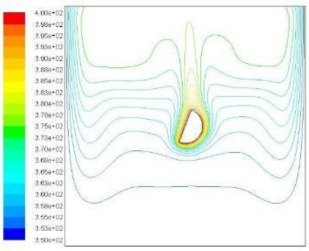
(f). 100°



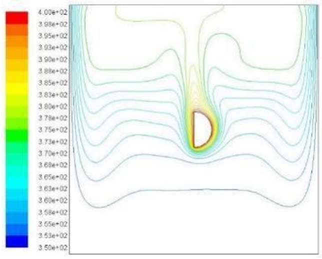
(g). 120°



(h). 140°



(i). 160°



(j). 180°

Variation on Surface Heat Transfer Coefficient and Nusselt number

Matter of fact that the fluid after carrying the heat from the cylinder walls first interacts with the cold enclosure walls at the upper portion. Due to higher temperature difference at these locations, the heat transfer rate is more there. As the heat is transferred, the temperature of the fluid decreases and the temperature difference between the fluid and vertical enclosure walls decreases towards the bottom portion of these walls. This results in less heat transfer at these portions. The variation of Nusselt number along the active enclosure walls also corroborates this. Fluid coming from the enclosure wall first interacts near the base and then goes upwards. So the heat transfer rate is comparatively higher at the upper portions of the vertical enclosure walls than the base of the cylinder.

Mathematically, we know, (Nu=hl/k), where, h=heat transfer coefficient, l=characteristics length & k=thermal conductivity, we can bring out the conclusion that the Surface Nusselt number is directly proportional to the Surface Heat transfer coefficient, so, if heat transfer coefficient increased which it does as shown in the graph for the upper portion, then Nusselt no. do increases for the upper portion of the enclosure walls. The graphs of Nusselt no. & heat transfer coefficient shows that heat transfer rate is high at the upper portion of the walls than the bottom portion of the walls.

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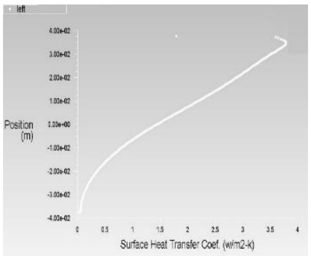
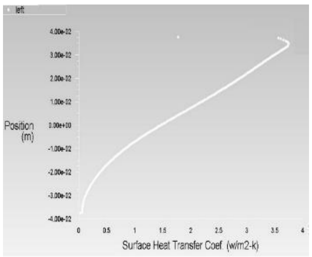
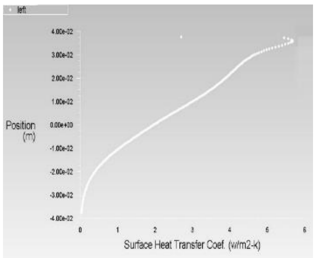
X-Y Plot: Surface Heat Transfer Coefficient v/s Position



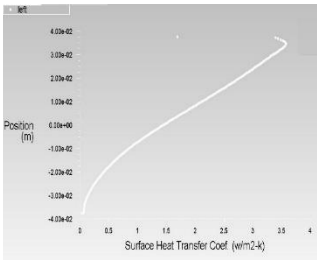
(a). 0°



(b). 20°

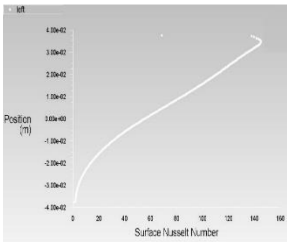


(c). 40°

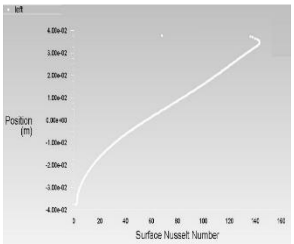


(d). 60°

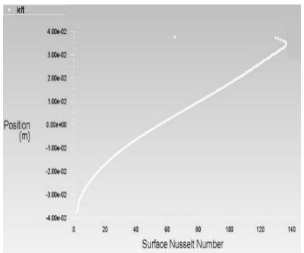
X-Y Plot: Nusselt Number v/s Position



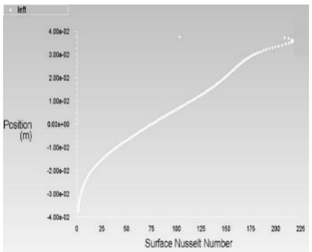
(a). 0°



(b). 20°



(c). 40°



(d). 60°

VI. CONCLUSION

In this study, heat transfer characteristics of 2D steady laminar natural convection of a heated Semi - Circular Cylinder placed at incidences in a square enclosure with walls subjected to different boundary conditions have been numerically studied. In this problem statement, density is assumed to be a function of temperature and is imposed in solver by using the Boussinesq approximation. The effects of Rayleigh number R_a range 10^4, on heat and momentum transport have been systematically investigated. The detailed flow and temperature fields in the proximity of heated cylinder are visualized in terms of streamline and isotherm and velocity vectors profiles, respectively. The temperature gradient is almost uniform between the enclosure and cylinder for lower R_a and the heat transfer rate is comparatively higher at the upper portions of the vertical enclosure walls and from the base of

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the cylinder. The results show that the surface Nusselt number and surface heat transfer co-efficient of heated Semi - Circular Cylinder shows similar trends when placed at various incidences.

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