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# Effect of Radiation on Natural Convection Heat Transfer from Heated Horizontal Cylinder in Vented Enclosure

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**Abstract.** The natural convection heat transfer from a heated circular cylinder placed in a square vented enclosure was investigated considering the effect of the thermal radiation from cylinder using finite volume method with simple algorithm that used pressure-velocity coupling to solve Navier-Stockes and energy equations using Computational Fluid Dynamics CFD (Fluent software). The flow domain is filled with air. The enclosure width is 12.5 cm, two symmetrical openings at its lower and upper walls with size O = 2.5 cm and the cylinder diameter is 5 cm. Different rang of cylinder's surface emissivity with Rayleigh number range between $10^3$ to $10^6$ was applied in this study as operating condition. The effect of the Ra, cylinder radiation for vented square enclosure on the convection, radiation and total Nusselt numbers Nu and flow and thermal patterns were investigated. The numerical results for pure natural convection were compared with available experimental results, good agreement was obtained. The results revealed that the natural convection heat transfer from the cylinder in the enclosure is increased as compared with that of the unbounded cylinder without radiation effect. The results also revealed that there is a linear relationship between the heat transfer enhancement and the emissivity, there is a significant effect of the cylinder surface radiation which gives high augmentation compared with that of the free cylinder and natural convection heat transfer without radiation effect. A maximum total Nusselt number is obtained at high emissivity compared with that of natural convection heat transfer, the maximum Nu enhancement ranged between 70 to 350 % for low Ra and 25 to 125% for high Ra.

***Keywords:*** *natural convection, radiation, emissivity, heat transfer, cylinder, enclosure.*

## 1.Introduction

The increase of the free convection heat transfer from a horizontal cylinder received much attention to improve the performance of many applications such as cylindrical components for computer components, heat exchangers and solar collectors. There are numerous methods to improve the heat transfer that have been used recently.

Placement of the cylinder in the vented enclosure is one of the effective technique that can be used to improve the heat transfer (Ali, 2008). In this technique, the fluid moves through the channel and reaches the bottom of the cylinder. The thickness of the generated boundary layer around the cylinder is thinner than that of the free cylinder, which increase the natural convection heat transfer (Kahwaji et al., 2012).

There are many studies which investigated the enhancement of the natural convection from a heated cylinder using different methods and different fluid mediums. The placement of the cylinder in an open enclosure is one of the effective methods. (Sparrow & Pfiel, 1984) presented an experimental investigation to estimate the augmentation of the natural convection from a heated horizontal cylinder placed between two confiding walls. The study used 15 different heights of the channel H and wall spacings S to cylinder diameter D with different range of Rayleigh number (Ra). The results showed that the heat transfer increased by up to 40 percent for the confined cylinder compared with the unconfined cylinder. The results also revealed that there is a significant augmentation in heat transfer when the wall spacing S is decreased and the wall height is increased, maximum enhancement was achieved when S/D = 1.5 and H/D = 20.

(Kahwaji et al., 2013) provided an experimental study to investigate the heat transfer by natural convection from a cylinder has square cross section placed in a symmetrical vented square enclosure. The Nusselt number (Nu) was determined based on the temperature of the cylinder's surface and the temperature of air inside the enclosure during transient state for the free and bounded cylinder. Different range of Rayleigh number (Ra) was applied with different ratio of enclosure width to cylinder diameter and opening size to cylinder diameter. The results showed that the Nu is increased when the Ra is increased for all cases. The Nu is proportionally increased with the size of the opening for low enclosure widths. The results also revealed that the Nu is inversely proportional with opening size for large enclosure widths. The maximum percentage of enhancement was reached at 20% for enclosed square cylinder compared with free cylinder.

The radiation heat transfer has many applications in thermal engineering such as heat exchangers, solar energy, radiators, which combined with convection heat transfer to indicate the rate of heat transfer. However, the heat transfer coefficients for the natural convection heat transfer was very low values compared with that of forced convection. The radiation heat transfer was neglected and not considered in the forced convection heat transfer case, but it was considered in the natural convection heat transfer case.

In the natural convection heat transfer, the emissivity of the solid surface is close to zero and the heat transfer from the solid surface with a valuable emissivity is the combination of the convection and radiation components (Gengel & Ghajar, 2015). There are many studies about the effect of the surface radiation of the cylinder on the enhancement of heat transfer such as (Wei & Tao, 1996), (Saleh et al., 2015) and (Bello-Ochende, 2019). (Wang et al., 2011) investigated the combined effect of the natural convection-conduction and surface radiation in an open cavity with constant heat flux in a laminar region. The results showed that the radiation and conduction can increase the average total of the Nu. The average Nu was increased with the increasing of the emissivity for more than 0.2. The results also revealed that the conduction heat transfer for the wall can improve the total cooling effect and the enhancement of the heat transfer under surface radiation effect was between 54.1% to 64.0%.

(Ngo et al., 2014) provided a numerical study to assess the laminar natural convection with the effect of surface radiation in a hollow receiver using plate extended surface. Three-dimensional assessment simulation was applied to determine the effect of convection and radiation on the heat losses. The assessment considered the prediction of the temperature, emissivity, orientation and parameters of the geometry on the total heat loss. The results showed that the convective heat loss from the cavity receiver was affected by the inclination, the presence of fins and the number of fins. While the radiation heat loss was considerably affected by surface properties of the receiver. (Pandey & Kumar, 2017) investigated the radiation and convection influence of Cu-water nanofluid flow over an extending cylinder in a porous layer using slip and viscous dissipation boundary conditions. The dimensionless velocity and temperature distribution were displayed with skin friction and heat transfer coefficients. The results showed that the Nusselt number is decreased when the radiation parameter, thermal slip parameter and Eckert number increased. The Nu also increased when the slip velocity and natural convection increased.

(Nadjib et al., 2018) provided a numerical 2-dimensional study to determine the free convection and radiation of surface in a domain includes air connected with hot extended surface. The boundary conditions of the square enclosure were constant temperature and adiabatic boundary conditions. The position of the heating element was varied from a horizontal position (HPFU, HPFD) to a vertical position (VPFL). The effects of the Rayleigh number, fin length, position of the fin position and emissivity of the wall were considered in investigated. The results showed that the improvement in the heat transfer within the cavity and the optimum thermal performance was obtained for a vertical position. An empirical correlation was developed for Nusselt numbers with a maximum deviation less than 4%.

(El Moutaouakil et al., 2020) applied computational fluid dynamics (CFD) to assess the interaction between natural convection and radiation for Inner Wavy Body in a square body. Different Ra and emissivity were used with variable undulations number as operating conditions. The results revealed that the average radius and the amplitude influenced the total heat transfer and there was no effect on the undulations number of the wavy wall.

From the open literature, there are many studies considered the enhancement of natural convection from a heated horizontal cylinder using different methods to transfer the heat. However, the radiation effect from the cylinder's surface on the natural convection still needs more investigation using different range of enclosure size and dimension. This paper investigates the effect of the natural convection mixed with radiation on the heat transfer from a horizontal cylinder in a symmetrical vented square enclosure using finite volume numerical method that based on simple algorithm with employment of Fluent software. Wide range of Rayleigh number, outer cylinder emissivity and constant enclosure width and opening size were applied. The study predicts the thermal behavior for Nusselt number, fluid temperature inside the enclosure, streamlines and isotherms.

## 2. Mathematical formulation and numerical method model

Figure 1 presents the configuration of the investigated geometry. The circular cylinder diameter (D) is 50 mm and 500 mm length using a square enclosure with length (W) of 125 mm. The circular cylinder is placed in the middle of the enclosure. The opening size O is 25 mm. The temperature of the circular cylinder (Ts) and the enclosure surface temperature are assumed to be constant in this study. In numerical method, some assumptions have been applied to investigate the natural convection heat transfer from heated horizontal circular cylinder: 2-dimension, steady state, and constant properties for the laminar flow.

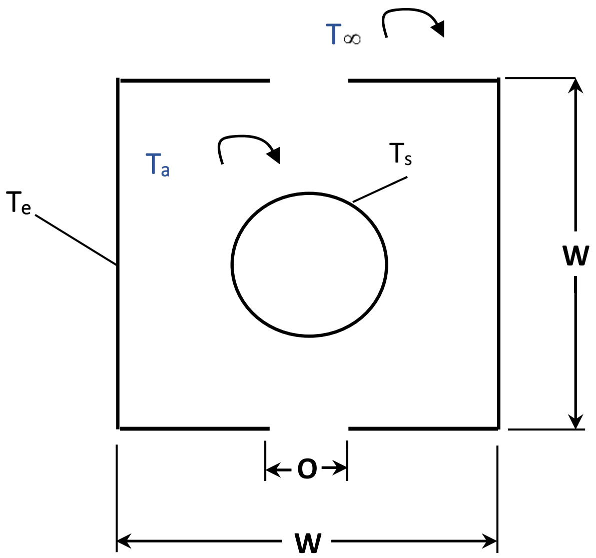


**Figure 1.** Combination of cylinder and enclosure.

*2.1 Governing equations*

The flow and thermal behavior of the fluid domain between the cylinder and enclosure walls can be described using the Navier-Stokes equations and energy equation. The flow in the computational domain is assumed as steady, laminar, two dimensional with constant property (incompressible flow). The Navier-Stokes equations (Nada et al., 2007) in the general coordinate system are:

$$\frac{\partial u_i}{\partial x_j} = 0 \qquad (1)$$

$$\frac{\partial}{\partial x_j}\left(u_i u_j\right) = -\frac{\partial P}{\partial x_i} + Pr\frac{\partial^2 u_i}{\partial x_j \partial x_j} + RaPr\theta \qquad (2)$$

Where xi, $x_j$ indicates dimensionless Cartesian coordinates, ui, $x_j$ indicates the corresponding dimensionless velocity components, p is the dimensionless pressure, θ is the dimensionless temperature, and Pr is the Prandtl number.

The energy equation can be presented as follows,

$$u_j\frac{\partial \theta}{\partial x_j} = \frac{\partial^2 \theta}{\partial x_j \partial x_j} \qquad (3)$$

Buoyancy force is the dominant force in the natural convection when the density varies due to temperature change. The strength of the buoyancy can be measured by the Rayleigh number as follows,

$$Ra = \frac{g\beta\Delta T D^3 \rho}{\mu\alpha} \quad (4)$$

Where ρ is the fluid density, ΔT is the temperature difference between cylinder surface temperature and mean fluid temperature inside the enclosure, D is the diameter of the cylinder, μ is the fluid dynamic viscosity, α is the fluid thermal diffusivity and $\beta$ represent the thermal expansion coefficient and can be estimated as follows,

$$\beta = -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial T}\right)_p \quad (6)$$

$$\alpha = \frac{k}{\rho C_p} \quad (7)$$

Where k is the thermal conductivity of the air and $C_p$ represents the specific heat at constant pressure. The average Nusselt number of the cylinder surface is calculated from the integration of the following equation (Wang et al., 2011):

$$Nu_{c,av} = \frac{h_{avg}D}{k} = -\frac{1}{2\pi}\int_0^{2\pi}\left(\frac{\partial\theta}{\partial n}\right)_{r=ro} r d\emptyset \quad (8)$$

Where

$h_{avg}$ : is the average cylinder heat transfer coefficient, W/m$^2$.°K.

n : is the unit normal coordinate to the cylinder surface.

θ : is the dimensionless temperature.

ϕ : is the angle from the centerline of the cylinder.

For the surface radiation effect, the net heat fluxes of the radiation over the surfaces can be alienated into subdivisions based on the employed mesh. The equation formulations of the radiosity-irradiance can also be applied. The radiosity estimation of the radiative sub surfaces can be written as follow (Wang et al., 2011),

$$J_i = \varepsilon_i\sigma T_i^4 + (1-\varepsilon_i)\sum_1^{NF} J_i F_{ij} \; (i = 1,2, \ldots, \text{NF}) \quad (9)$$

Where $\varepsilon_i$ is the sub surface emissivity, Fij is the shape factor from the i$^{th}$ subsurface to the j$^{th}$ subsurface of the enclosure, and NF is the total number of sub surfaces along the enclosure surface.

The net radiation heat flux ($q_r$) for the i$^{th}$ subsurface of the enclosure's walls and can be determined by

$$q_{ri} = \sum_{j=1}^{NF}(J_i - J_j)F_{ij} \qquad (i = 1,2, \ldots, \text{NF}) \quad (10)$$

The average radiative Nusselt number can be presented as follows,

$$Nu_{r,av} = -\frac{1}{2\pi}\int_0^{2\pi}(Q_r)_{r=ro} r d\emptyset \quad (11)$$

The total Nusselt number is:

$$Nu_t = Nu_{c,av} + Nu_{r,av} \quad (12)$$

*2.2 Boundary Conditions*

The boundary conditions to predict the flow and thermal behaviors for the natural convection were applied. Geometry configuration presented in Figure (1) was used. The boundary conditions can be summarized as in the following table:

| **Boundary name** | **Boundary conditions** |
|---|---|
| Cylinder surface | T = const., u = v = 0 |
| Enclosure surface | T = const., u = v = 0 |
| Lower opening | $T = T_{amb.}$, u = 0, v = const. |
| Upper opening | $dT/dy = 0$, m = const. |

Where u is the x-component of velocity, v is the y-component of velocity and m is the mass flowrate from upper opening.

*2.3 Numerical Method*

The governing equations are solved using FLUENT 16.2. The method is assumed the Boussinesq approximation during the solution of the momentum equation The properties of the working fluid were based on the average temperature of the receiver surface and the ambient air. The surface-to-surface S2S radiation model is used in the FLUENT software to account the effect of the radiation exchange in an internal surface between cylinder surface and enclosure walls (ANSYS, 2018). The cylinder surface is assumed as gray and diffuse, while the enclosure surfaces are assumed as black. The combined natural convection and surface radiation from the heated horizontal cylinder in a cold square enclosure is investigated using a numerical model. For pressure velocity coupling, SIMPLE algorithm has been used, with second order upwind scheme for the discretization of momentum and energy equations. A convergence criterion of $10^{-6}$ was imposed on the residuals of the continuity equation, momentum equation and energy components as displayed in figure 2..

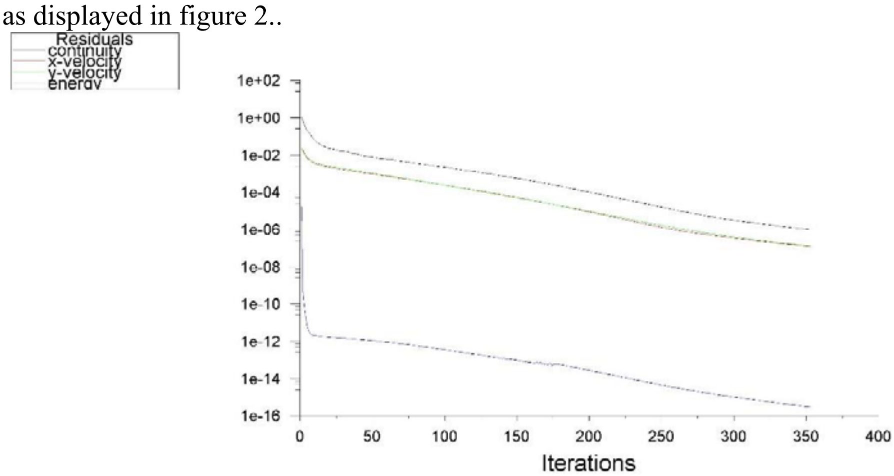


**Figure 2:** Convergence of the x and y velocities and temperature to the solution in the numerical method.

### *2.4 Grid independence study*

Grid was generated in the 2D flow domain as displayed in Figure 3. Three different grid sizes were used to investigate the optimum grid number and size: 6417, 8618, and 15582. The different grid sizes are used to simulate the pure natural convection heat transfer from cylinder in a vented enclosure with W/D= 2.5 and O = 2.5 cm to keep the consistency of the numerical simulation using same operating condition at Ra = $5\times10^5$. The Nusselt number for the three cases was obtained and compared with the experimental results from previous study. The numerical results for the Nu for the three different grid numbers are 14.62, 14.57 and 14.48, respectively. The difference between the three values of Nu are not significant. However, the minimum percentage error was achieved at grid number of 15582 and grid size of 2 mm compared with the experimental value of the Nu, therefore, this grid size and number was selected for numerical simulation.

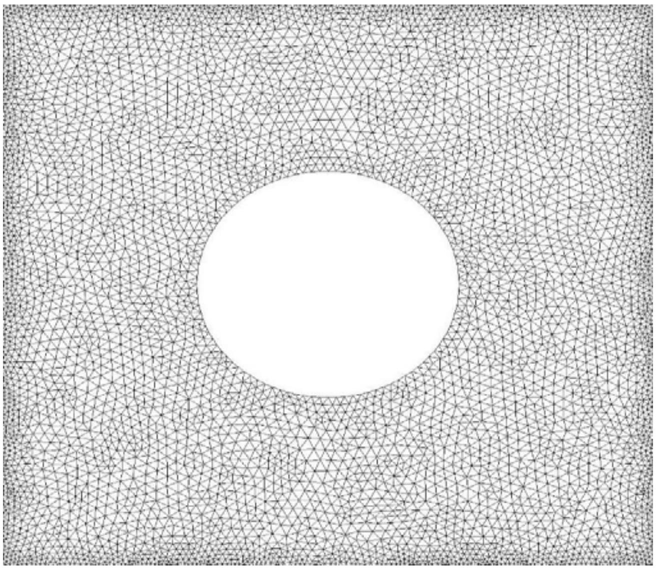

**Figure 3.** Grid distribution in the computational domain between the circular cylinder and the enclosure

### *2.5 Validation of numerical results*

The experimental results from pervious study were used to validate the numerical results of this study because the same cylinder-enclosure with openings configuration and boundary conditions are used for both works. Figure 4. presents a comparison between the present results with the experimental results, presented by (Ali, 2008), for the heated horizontal cylinder with W = 12.5cm, D =5cm and O = 2.5 cm. Excellent agreement is obtained, the maximum percentage error between both results is about 1 %.

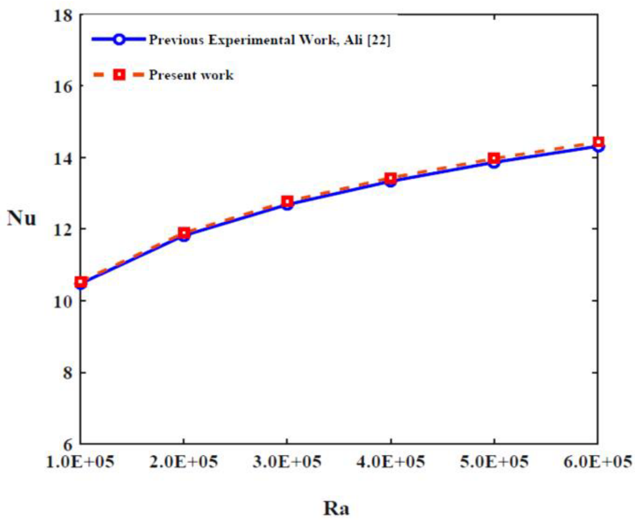


**Figure 4:** Comparisons between the present work and previous experimental work for W = 12.5 cm, O = 2.5 cm

## 3. Results and Discussions

This section will present and discuss the numerical results. The results of the present work for the natural convection from heated cylinder placed in a cold square enclosure with lower and upper openings are presenting in this section. Air was a medium in the enclosure and surrounded the cylinder.

Figure 5. presents the Nusselt number (Nu) for the convection, radiation, and total effect for the different emissivity of the surface of cylinder ($0 < \varepsilon \leq 1$) when W/D =2.5 and O = 2.5 cm. Figure 4a is the total Nu from the cylinder for the natural convection mode is presented at $\varepsilon = 0$ that it is increased with the increase of Ra in the presence of the cold square enclosure which its value is larger than those of unbounded cylinder due to the effect of confiding walls. The convection Nu is same for all cylinder emissivity values. The radiation heat transfer from the cylinder occurred when the cylinder surface emissivity increased. Figures from 5b to 5f present the Nu for the convection, radiation, and total effect when the emissivity increases from 0.2 to 1. The radiation heat transfer from horizontal cylinder to the enclosure surfaces influences the Nu as a result of the cylinder emissivity increasing from 0.2 to 1. The radiation Nu is approximately constant with the increase of Ra because the natural convection flow has no effect on the radiation Nu value for low emissivity values (0.2-0.4). The Nu from radiation is increased with the increase of Ra for high cylinder emissivity values due to the effect of high radiation heat transfer on the flow. The enhancement of the total heat transfer is obtained between 70% to 300% for the range of Ra from $10^3$ to $5\times10^4$ and emissivity range from 0.2 to 1. The enhancement of the total Nusselt number is also obtained between 25 % to 125 % for Ra values between $5\times10^4$ to $10^6$ and emissivity range from 0.2 to 1.

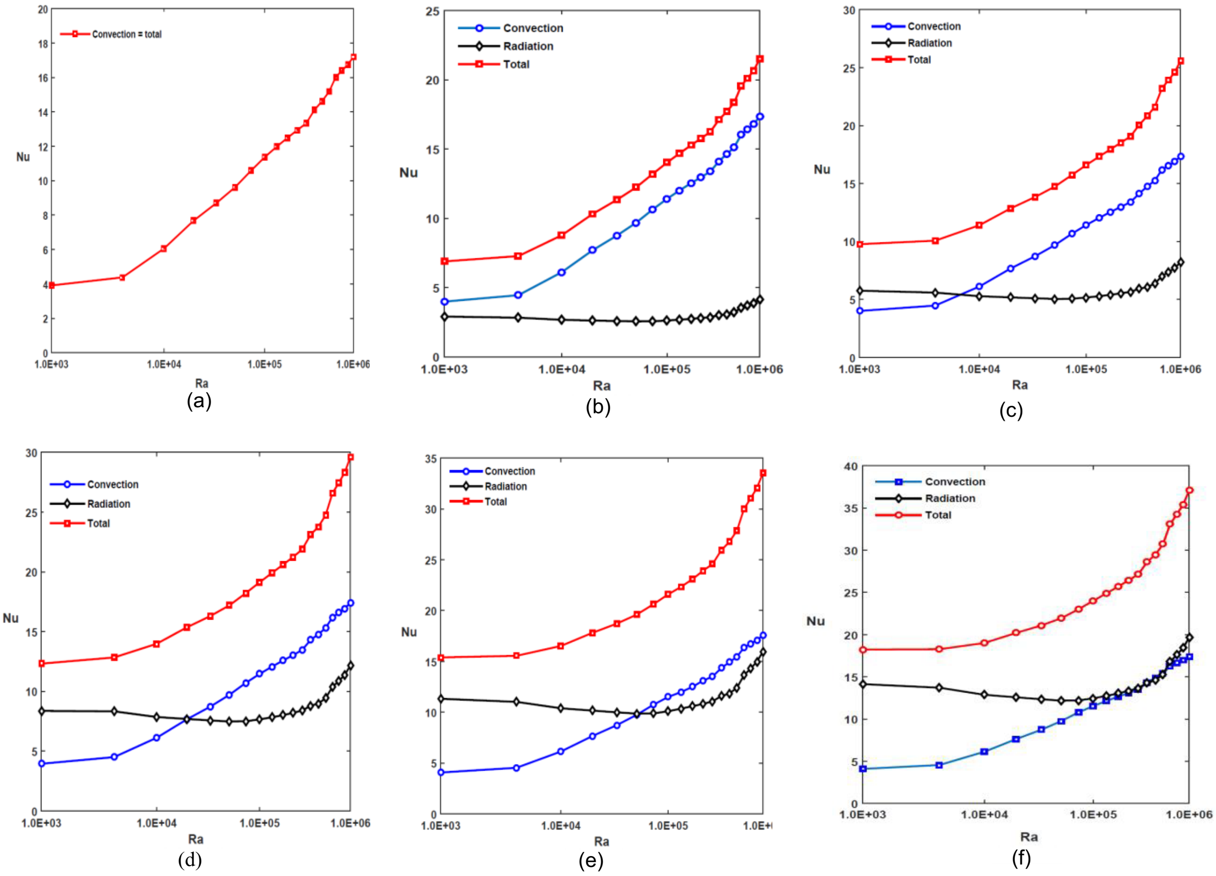


**Figure 5.** Convection, radiation and total Nusselt number for different Rayleigh numbers due to cylinder surface emissivity variation (a) ε =0, (b) ε =0.2, (c) ε =0.4, (d) ε =0.6, (e) ε =0.8, (f) ε =1.

Figure 6. presents the enhancement of the heat transfer as a result of the radiation heat transfer effect for the range of Ra from $10^3$ to $10^6$. Figures from 5a to 5e show that the emissivity variation of the cylinder's surface do not influence the Nu for the natural convection heat transfer for each Ra with the variation of the cylinder emissivity. For Ra = $10^3$ and $10^4$, the convection Nu is low because the conduction heat transfer is the dominant mode and the convection contribution is low. For Ra > $10^4$, the convection heat transfer become more and it is the dominant mode due to the large temperature difference between cylinder surface and fluid temperature inside the enclosure that lead to the density variation causing high buoyancy force and Ra. There is a linear relationship between the total Nu and the emissivity because the radiation Nu is increased with the high emissivity cylinder surface that transfer to the enclosure surfaces. The enhancement for the Nu is very large when the Ra is in the low range, then it decreases when the Ra increase.

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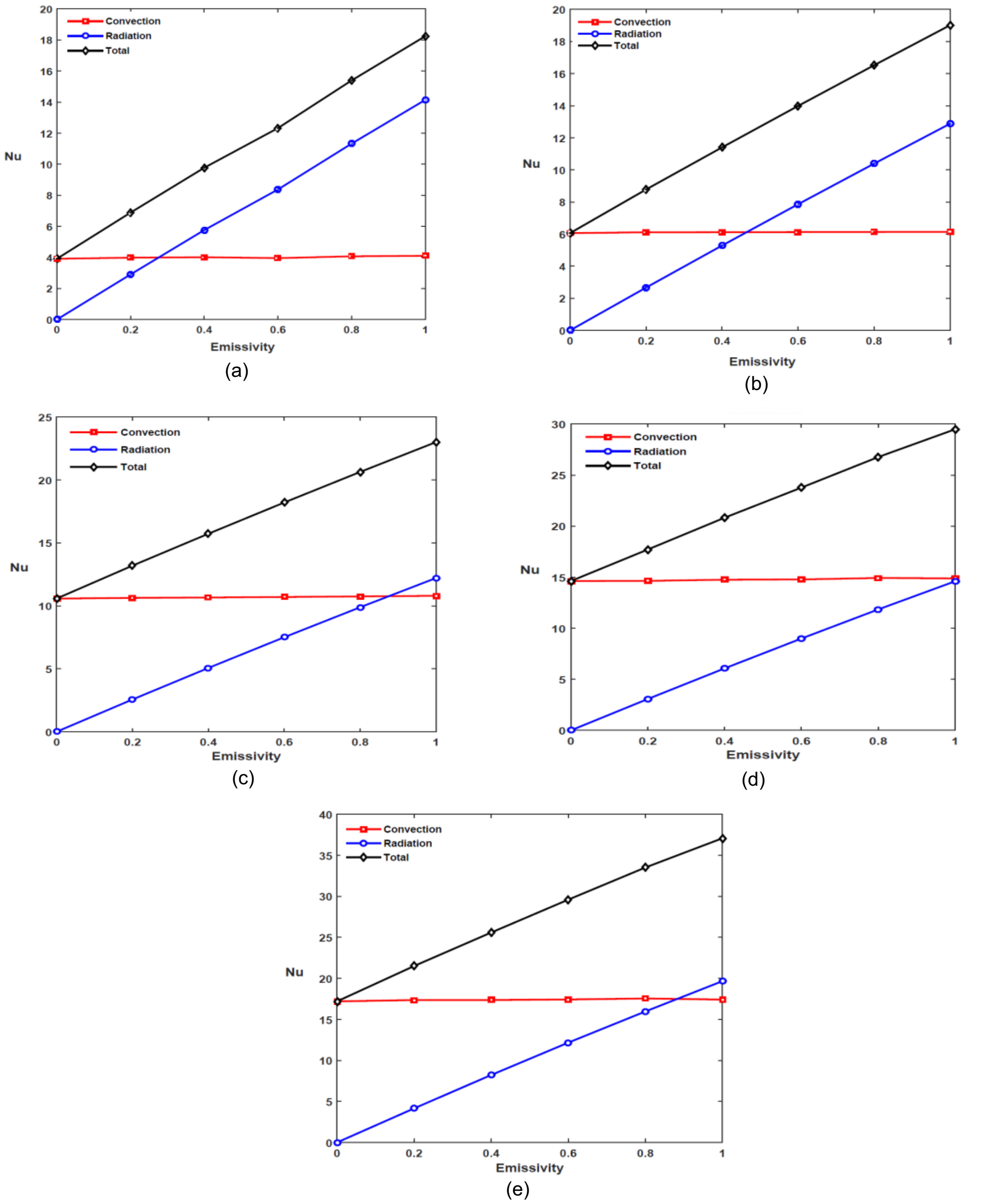


**Figure 6.** Enhancement of the Nusselt number for different surface emissivity's for Rayleigh numbers (a) Ra = $10^3$, (b) Ra = $10^4$, (c) Ra = $10^5$, (d) Ra = $5 \times 10^5$, (e) Ra = $10^6$.

Figure 7. presents the mean temperature of the fluid in the domain between the heated circular cylinder and vented enclosure for different Ra and emissivity. The mean fluid temperature (Tm) is increased when the emissivity (ε) increases for all Ra, but the increasing become sharp for high range of Ra. The fluid temperature is increased with high Ra because the flow movement become more that causes from the density variation due to high temperature difference. The increase of the emissivity lead to enhance in the heat transfer by radiation, therefore the fluid temperature is increased.

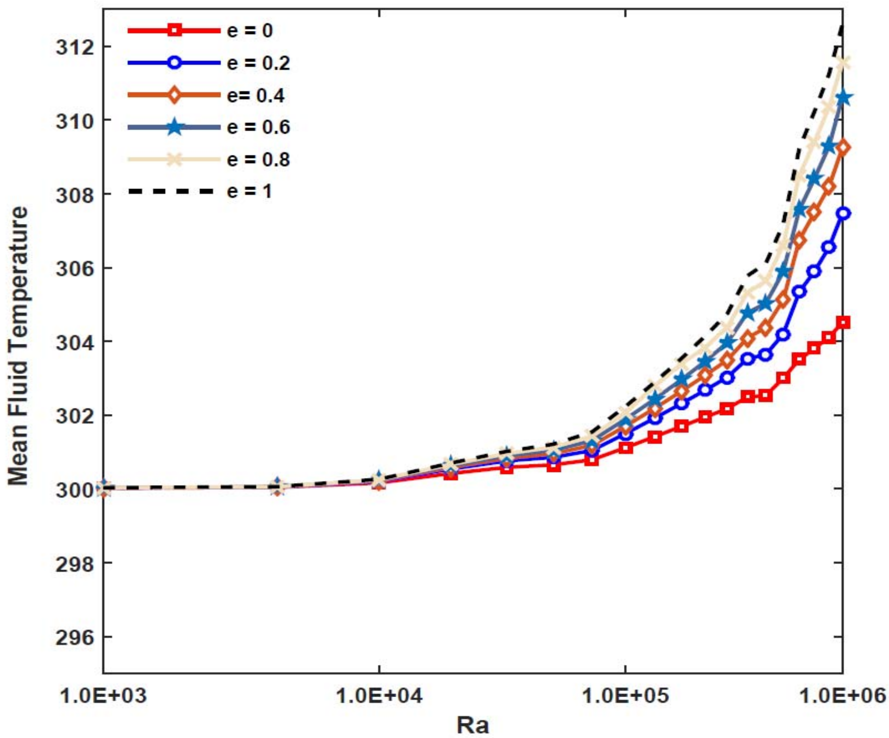


**Figure 7:** The mean temperatures of the fluid for different Ra and different emissivity.

Figure 8. shows the stream function and temperature distributions of natural convection heat transfer from the heated circular cylinder in a symmetrical enclosure with different Rayleigh number (Ra). The figure presents the flow and thermal behavior when the Ra increased from $10^3$ to $10^6$, there is a significant change in the behavior with increasing of Ra. For Ra = $10^3$, the streamlines distributed in the whole fluid domain, the flow is symmetrical around y-axis, the stream function values are weak and the thickness of the hydrodynamic boundary layer with the cylinder is large. The temperature distribution shape appeared as circular rings around the cylinder which ensures that the conduction heat transfer is the dominant mode and thermal boundary layer is very thick. For Ra = $10^4$, the flow around y- axis remains symmetrical but the stream function values are increased and the hydrodynamic boundary layer thickness is decreased. The isotherms shape is changed to become closer to the cylinder surface, a thermal plume is appeared above the cylinder and the thermal boundary layer thickness is decreased that ensures the convection heat transfer mode become more, but the conduction mode still effective. For high Ra, the hydrodynamic and thermal

boundary layer thicknesses around the cylinder are decreased and become thinner and the strength of stream function is also enhanced when the Ra increased which ensures that the convection heat transfer is the governed mode. The streamlines become closer to the cylinder surface and two eddies are appeared along both sides of the enclosure with inner circular vortices at the upper corners of the enclosure due to the high flow movement. The temperature contours for high Ra displayed that the thermal plume become narrower as Ra is increased. The effect of conduction heat transfer decrease when the Ra is increased and the convection heat transfer become the dominant mode due to the thinner boundary layers.

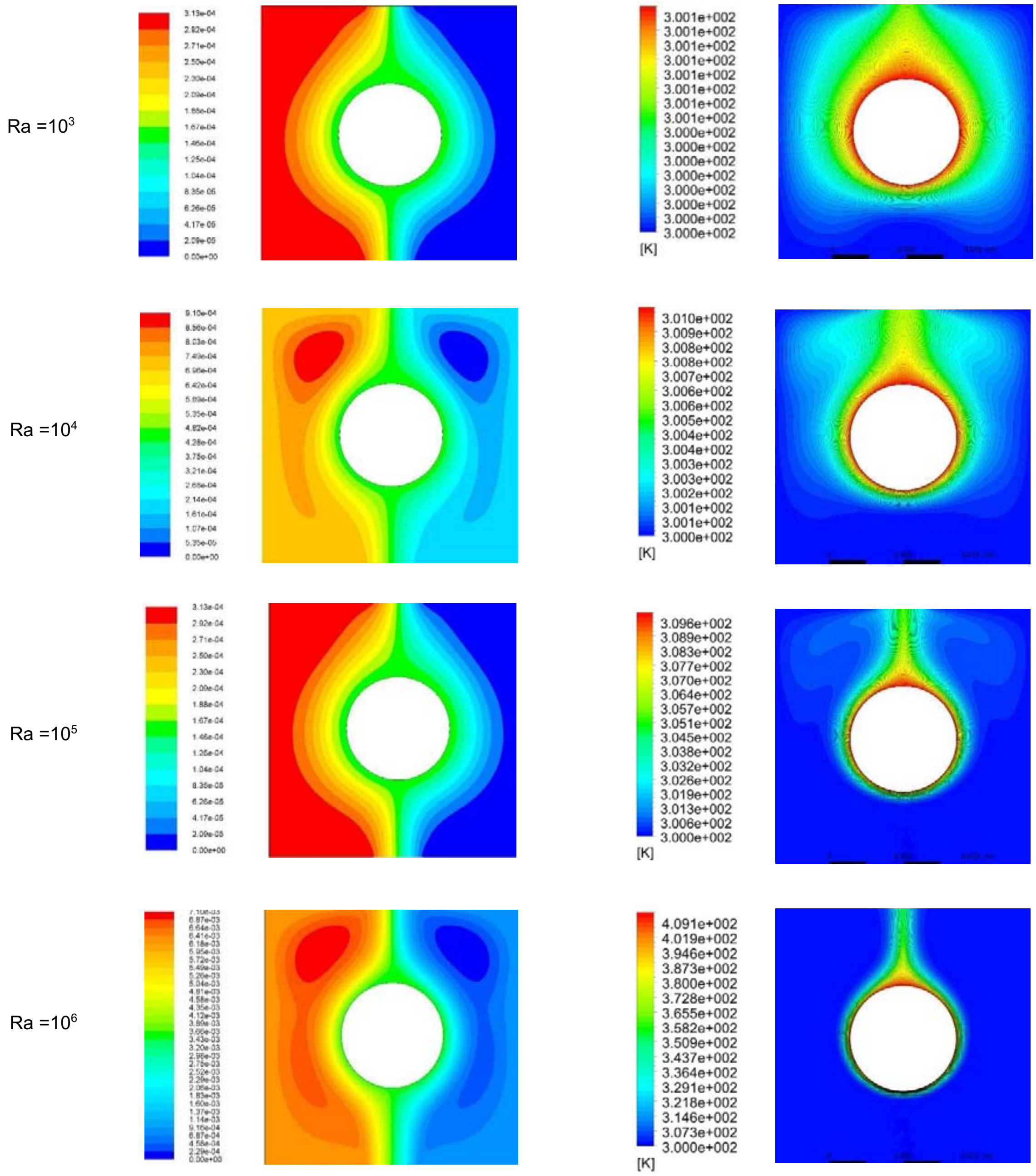


**Figure 8.** Streamlines and isotherms for pure natural convection heat transfer

Figure 9. shows the streamlines of the natural convection heat transfer from the circular cylinder for different range of Ra considering the effect of the surface radiation effect from the cylinder. The stream function values are slightly decreased as cylinder emissivity is increased due to the effect of radiation heat transfer on the flow movement. For Ra = $10^3$, the arrangement of the streamline does not change with the emissivity of the cylinder's surface because the fluid flow is very slow and it distributed to cover most of the fluid domain. When Ra increased to $10^4$, the streamlines with radiation heat transfer starts to be developed and changed compared with that of the pure natural convection. Two eddies are appeared above the cylinder surface and covered the sides of the enclosure, each eddy have a circular vortex at the upper portion of it. The arrangement of the streamlines starts to be changed when the emissivity is increased as a result of the radiation heat transfer effect. The eddies along enclosure sides are changed and move to the upper portion of the enclosure corners as cylinder emissivity is increased. When the Ra increased more to be equal to $10^5$, a significant change and arrangement clearly appear for each cylinder's emissivity which have different arrangement compared with that of the natural convection flow. The shapes of the streamlines along y-axis still unchanged, but some eddies and vortices are appeared in the remaining flow domain near enclosure surfaces and corners. The eddies and vortices in the flow become more and disorder in the same region for Ra = $10^6$ and ε = 0.2. For ε = 0.6 and 1, the eddies and vortices concentrated at enclosure corners below cylinder surface and plumes are displayed at the sides above the cylinder surface. These changes due to the combined effect of convection and radiation heat transfer on the flow that arises the fluid temperature and affected on the flow behavior inside the fluid domain.

Figure 10. presents the temperature distribution of the natural convection heat transfer from the circular heated cylinder for different range of Ra considering the effect of the radiation. For the low Ra from $10^3$ to $10^4$, the isotherm behavior are same as pure natural convection at the upper part of the enclosure, the temperature distribution are slightly changed as that at the upper part of the enclosure for natural convection heat transfer under different radiation effect, the temperature is increased and its layers are moved toward the enclosure surfaces. However, the isotherm behavior and temperature distribution at the lower opening vent are completely have different behavior when the emissivity change that a thermal plume is appeared from the lower vent due to an increase in the temperature layers under circular cylinder. The effect of radiation heat transfer is appeared apparently for Ra = $10^4$ that the temperature of the layers near the enclosure surfaces is raised as cylinder emissivity is increased. When Ra increased more between $10^5$ to $10^6$, the temperature distribution and the thermal plume for all emissivities above the cylinder surface approximately are similar as that of the pure natural convection. The distribution of the isotherm and its arrangement away from the cylinder surface have different behavior compared with that of the natural convection as a result of the effect of radiation heat transfer from the cylinder, which the temperature of the layer are increased and displaced to the enclosure surfaces as the cylinder emissivity is raised.

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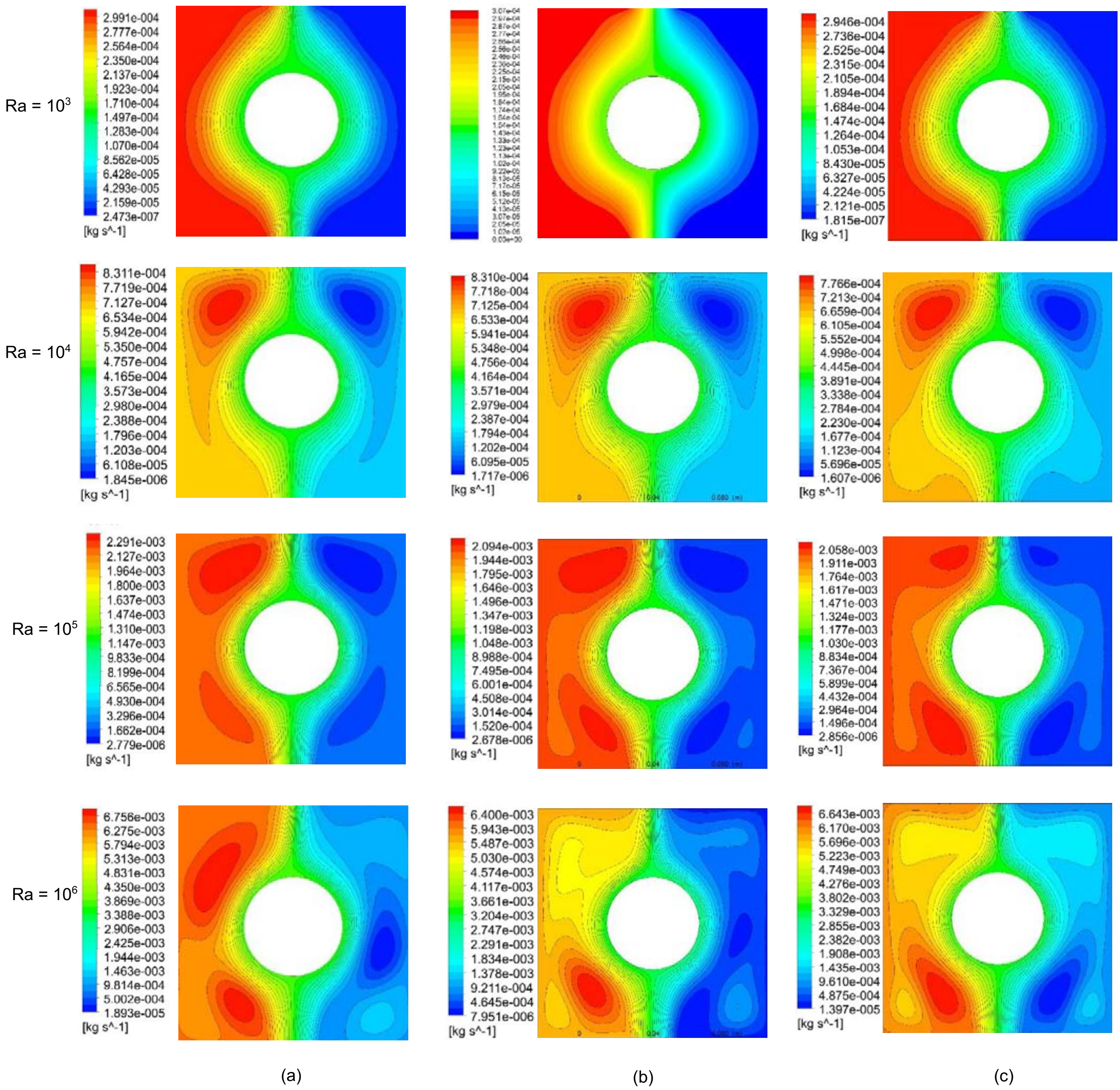


**Figure 9:** Streamline distribution around the cylinder at different Rayleigh numbers and different cylinder surface emissivity: (a) ε =0.2, (b) ε =0.6, (c) ε =1.

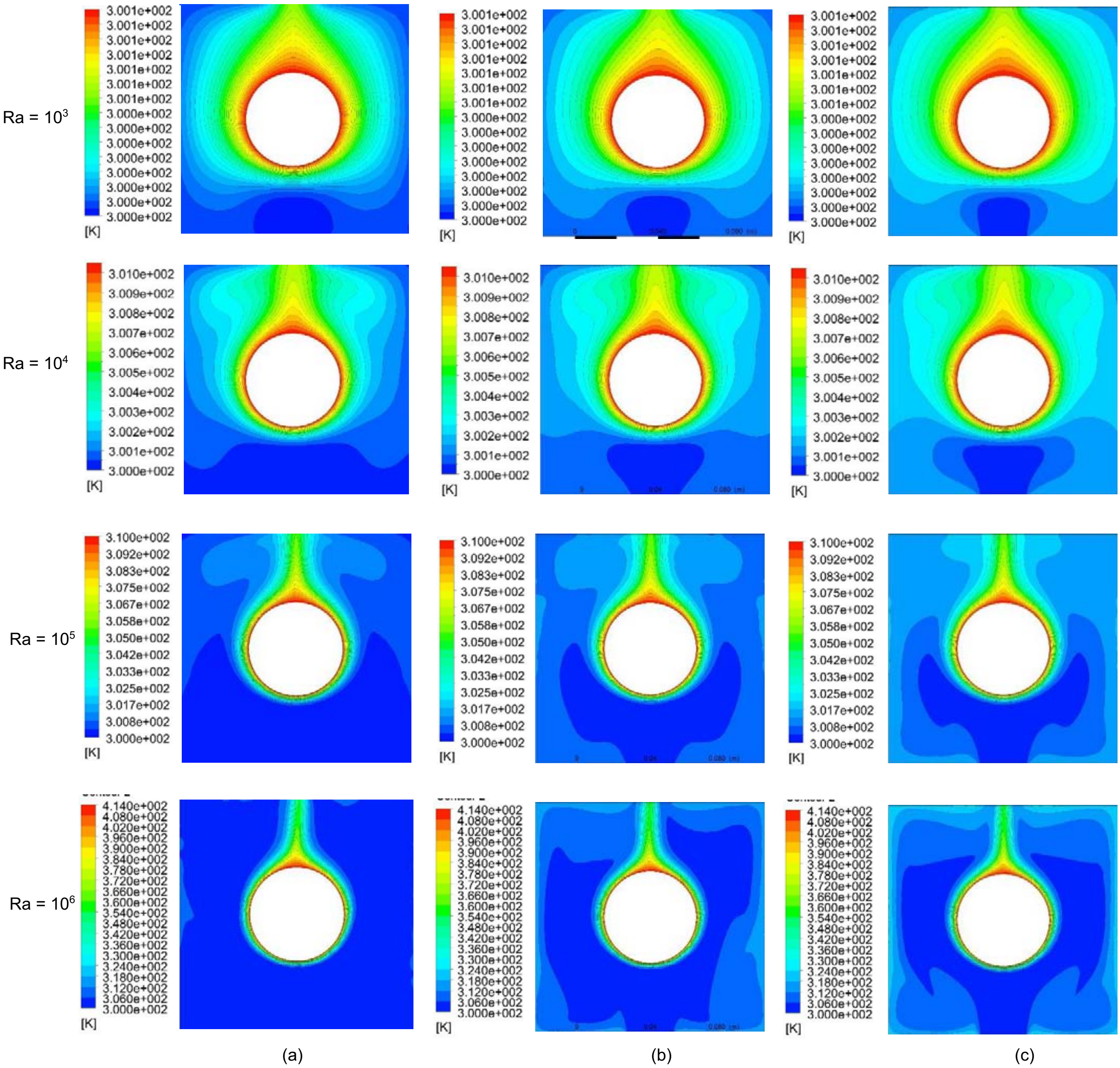


**Figure 10:** Temperature distribution inside the enclosure at different Rayleigh numbers and different cylinder surface emissivity: (a) ε =0.2, (b) ε =0.6, (c) ε =1.

## 4. Conclusions

The effect of surface radiation on the natural convection heat transfer from the heated cylinder in a symmetrical vented square cylinder has been investigated numerically. Experimental results from previous experimental work have been used to compare and asses the numerical results. The conclusion of this work can be summarized as follows,

1. The Nu of the natural convection is increased with Ra.
2. For low Ra, the dominant mode is the conduction heat transfer without and with surface radiation effect.
3. The strength of the natural convection heat transfer is increased with the increase of the Ra, and the convection heat transfer is the dominant mode for large Ra without and with surface radiation effect.
4. There is a linear relationship between the cylinder emissivity values and the radiation heat transfer, consequently; the total heat transfer is increased.
5. The Nu can be enhanced from 70 % to 350 % under the radiation effect at low rage of the Ra.
6. The heat transfer augmentation is decreased for medium and large Ra with the influence of the radiation heat transfer that reduced from 25% to 125% for total Nu as compared with those for natural convection heat transfer.
7. The streamlines and isotherms behavior displayed the conduction mode at low Ra.
8. The flow and temperature distribution can be used to identify the convection heat transfer mode when the Ra increases.
9. The radiation heat transfer has slight effect on the streamlines and isotherms behavior and arrangement above the cylinder surface and large effect beneath the cylinder surface at low Ra.
10. The is a significant effect on the thermal behavior when the radiation effect increased at high range of Ra, which the temperature layers are changed away from the cylinder surface and y-axis.

## References

[1] Ali, Omar. 2008. "Experimental and Numerical Investigation of Natural Convection Heat Transfer from Different Cross Section Cylinders in a Vented Enclosure." Ph.D. Thesis, Mosul University.
[2] Ali, Omar. 2014. "Numerical Investigation of Prandtl Number Effects on The Natural Convection Heat Transfer from Circular Cylinder in an Enclosed Enclosure." Science Journal of University of Zakho 2(2): 358–74.
[3] Ali, Omar, and Ghalib Y. Kahwaji. 2014. "Numerical Investigation of Natural Convection Heat Transfer from Circular Cylinder Inside an Enclosure Using Different Types of Nanofluids." International Journal of Mechanical Engineering and Technology (IJMET) 5(5): 214–36. http://www.iaeme.com/MasterAdmin/Journal_uploads/IJMET/VOLUME_5_ISSUE_5/IJMET_05_05_022.pdf.
[4] Bello-Ochende, T. 2019. "Suppression of Natural Convection and Radiation Heat Losses in Solar Cavity Receivers: A Novel Approach." Journal of Physics: Conference Series 1378(4).
[5] Gengel, Younus A., and Afshin J. Ghajar. 2015. Heat and Mass Transfer Fundamentals and Applications. fifth. McGraw-Hill Series in Mechanical Engineering.

[6] Kahwaji, Ghalib Y., Abbas S. Hussien, and Omar Ali. 2013. "Experimental Investigation of Natural Convection Heat Transfer from Square Cross Section Cylinder in A Vented Enclosure." Journal of University of DUHOK Pure and Engineering Science 16(1).

[7] Kahwaji, Ghalib Y., Abbas S. Hussien, and Omar M. Ali. 2012. "Numerical Investigation of Natural Convection Heat Transfer from Square Cylinder in a Vented Enclosure." Applied Mechanics and Materials 110–116: 4451–64.

[8] El Moutaouakil, L., M. Boukendil, Z. Zrikem, and A. Abdelbaki. 2020. "Natural Convection and Surface Radiation Heat Transfer in a Square Cavity with an Inner Wavy Body." International Journal of Thermophysics 41. https://link.springer.com/article/10.1007/s10765-020-02688-7#citeas.

[9] Nada, S. A., H. El-Batsh, and M. Moawed. 2007. "Heat Transfer and Fluid Flow around Semi-Circular Tube in Cross Flow at Different Orientations." Heat and Mass Transfer/Waerme- und Stoffuebertragung 43(11): 1157–69.

[10] Nadjib, Hamici, Sahi Adel, Sadaoui Djamel, and Abderrahmane. 2018. "Numerical Investigation of Combined Surface Radiation and Free Convection in a Square Enclosure with an Inside Finned Heater." Fluid Dynamics and Manufacturing Process 12(3): 175–95. https://www.researchgate.net/publication/328598013_Numerical_investigation_of_combined_surface_radiation_and_free_convection_in_a_square_enclosure_with_an_inside_finned_heater.

[11] Ngo, Lloyd C., Tunde Bello-Ochende, and Josua P. Meyer. 2014. "Numerical Modelling of Combined Natural Convection and Surface Radiation Heat Transfer in Cavity Receiver with Plate Fins." In Proceedings of the 15th International Heat Transfer Conference, IHTC-15 August 10-15, 2014, Kyoto, Japan.

[12] Pandey, Alok Kumar, and Manoj Kumar. 2017. "Natural Convection and Thermal Radiation Influence on Nanofluid Flow over a Stretching Cylinder in a Porous Medium with Viscous Dissipation." Alexandria Engineering Journal 56(1): 55–62. http://dx.doi.org/10.1016/j.aej.2016.08.035.

[13] Saleh, Habibis, Ammar I. Alsabery, and Ishak Hashim. 2015. "Natural Convection in Polygonal Enclosures with Inner Circular Cylinder." Advances in Mechanical Engineering 7(12): 1–10.

[14] Sparrow, E. M., and D. M. Pfiel. 1984. "Enhancement of Natural Convection Heat Transfer from a Horizontal Cylinder Due to Vertical Shrouding Surfaces." ASME J. of Heat Transfer 106(1): 124–30. https://asmedigitalcollection.asme.org/heattransfer/article-abstract/106/1/124/414385/Enhancement-of-Natural-Convection-Heat-Transfer?redirectedFrom=fulltext.

[15] Wang, Zhiyun, Mo Yang, Ling Li, and Yuwen Zhang. 2011. "Combined Heat Transfer by Natural Convection - Conduction and Surface Radiation in an Open Cavity under Constant Heat Flux Heating." Numerical Heat Transfer; Part A: Applications 60(4): 289–304.

[16] Wei, J. G., and W. Q. Tao. 1996. "A Numerical Study of Natural Convection in a Vertical Annulus with Constant Heat Flux on the Inner Wall." International Journal of Numerical Methods for Heat and Fluid Flow 6(7): 31–46.