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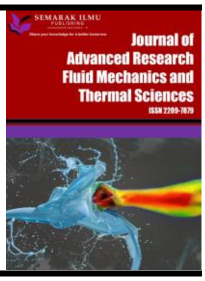

An Analysis of How Different Forms of Heated Bodies Affect Thermal Conductivity Inside a Nanofluid Square Domain

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ABSTRACT

Two thermal cylinders with varied shapes (circular (R = 0.15), square (L = 0.15), ellipse (R_x = 0.2, R_y = 0.15), and circular (R = 0.15) near the cold wall of the square enclosure where the (AR = 0.7) is explored numerically in the present study. The nanofluid is contained within the cavity (Al_2O_3). Left-side vertical wall and inner bodies are maintained at a fixed temperature (Th), while the right-side vertical wall is maintained at a cool temperature (Tc). Thermal insulation is used to insulate the upper and lower horizontal walls. This code is used the (technique of finite elements), which is utilized to resolve dimensionless equations in the COMSOL program. The basic parameters that were utilized in this paper where: the Rayleigh number (Ra), which ranged from 10^3 to 10^6; the percentage of solid volume (φ=0.06); and the aspect ratio (AR =0.7). The outcome demonstrates that: When the heated internal bodies are used in different forms, the effect of fluid movement will be different, and when the two inner bodies are combined, the highest stream function of up to 33 can be obtained. The isotherm line shows the clear and important effect of internal bodies in enhancing and improving heat transfer. For the two-square case, the average Nu was at its lowest point. While the highest Nu was for two – the ellipse case followed by the cylinder – the ellipse and the two circular cylinders.

1. Introduction

Due to the numerous engineering uses, for example, heat exchangers and solar energy collection, natural convection inside enclosures has been and continues to be a significant subject of study [1-4].

The study has witnessed an increase in popularity in recent years of natural convection within cavities [5]. To improve heat transfer, scientists have resorted to different shape of enclosure through infusing the basic fluid with nanoparticles [6].

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Numerous researchers have examined the influence of various parameters in a square nanofluid enclosure. Ho *et al.,* [7] discussed how thermal conductivity affects heat transfer. The cavity is angled at 45° in the direction of heat convection [8-11].

Lubis's [12] study on using rice husk as a renewable energy source in Indonesia to reduce reliance on fossil fuels. Khattak's *et al.,* [13] research study of the European Union and global energy security. By Khan *et al.,* [14] MHD Flow and Heat Transfer of Double Stratified Micropolar Fluid across a Vertical Permeable Shrinking/Stretching Sheet with Chemical Reaction and Heat Source were investigated. Asghar and The's [15] research is on rotating stretching/shrinking sheets and joule heating in three dimensions MHD hybrid nanofluid flow. Rusdi *et al.,* [16] research thermal radiation in a nanofluid penetrable flow constrained by a partial slip condition. Elfaghi *et al.,* [17] CFD's simulation of enhanced forced convection heat transfer in pipes using an Al_2O_3/water nanofluid. Jahan *et al.,* [18] study of mixed convective non-isothermal hybrid nanofluid over a moving thin needle examined the effects of solar radiation and viscous dissipation. The research of Bakar and Roslan [19] examined Mixed Convection in a Lid-Driven Horizontal Cavity in the Presence of Internal Heat Generation or Absorption. According to research by Mahat *et al.,* [20], MHD Mixed Convection of Viscoelastic Nanofluid Flow is caused by Constant Heat Flux. Akaje and Olajuwon [21] study the effects of nonlinear thermal radiation on a stagnation point of an aligned MHD Casson nanofluid flow with Thompson and Troian slip boundary conditions. Ab Rahman *et al.,* [22] conducted experimental research on the Peltier-Based Thermoelectric Cooling Box System. Bajuri *et al.,* [23] study on Computational Fluid Dynamics (CFD) Analysis of various Savonius Rotor Wind Turbine sizes.

Sheikholeslami and Ellahi [24] observed an increase in (Nu) with a rise in Rayleigh and volume fraction when a cubical enclosure was heated. The generation of entropy in heat transfer was investigated with nanofluid in a hollow containing undulation [25]. The angle of the cavity affected the heat convection of (porous medium and nanofluid (copper)). Several researchers have investigated the use of multiple cylinders within the cavity [26]. Another method for entering mixed convection limits has been to move one or more of the enclosures' walls to increase heat transfer with various parameters [27-33]. Other research investigated mixed convection differently, by rotating an internal cylinder [34-39].

A rotating circular cylinder was used to study mixed convection by Abdulsahib and Al-Farhany [40]. They discovered that when using lower Rayleigh numbers, cylinder rotation is added effect pronounced. Numerous researches have examined the cavity-driven lid and cylinder rotation within it have been conducted, both of which have a significant effect on mixed convection [41-44]. The effect of two thermal cylinders with varying shapes (circular, square, ellipse, and the final circular and ellipse) on convection inside a square cavity with nanofluid was studied in the current study. The enhancement of heat transfer inside the cavity was not studied in previous research using hot internal bodies and different shapes inside the cavity that have a hot wall and a cold one.

2. Research Methodology

Illustration of the physical geometry of a mathematical model in Figure 1 of natural convection in a square enclosure with a length (L) and two thermal cylinders of different shapes: circular (R = 0.15), square (L = 0.15), ellipse (R_x = 0.2, R_y = 0.15), and circular (R = 0.15) near the cold wall of the enclosure where the (AR = 0.7). Nanofluid has been pumped into the cavity. Water is utilized as the basis fluid and (Al_2O_3) is added to the base fluid to manufacture nanofluid (the thermophysical characteristics of (water and Al_2O_3) are shown in Table 1).

The perpendicular left-side wall and inner bodies are maintained at a constant temperature (Th), whilst the vertical right-side wall is maintained at a cooling temperature (Tc). Both the horizontal top and lower walls are maintained in their thermal insulation. In this study, the Boussinesq approximation is used to model the thermo-physical features of a nanofluid system. Within the confines of this experiment, the cylinder is situated toward the left-hand of the cavity cold wall. This study investigates the impact of the aforementioned states on isotherms lines, stream function, and local and average Nusselt numbers. The modeling assumptions are also explained in detail for the geometry in the next paragraph

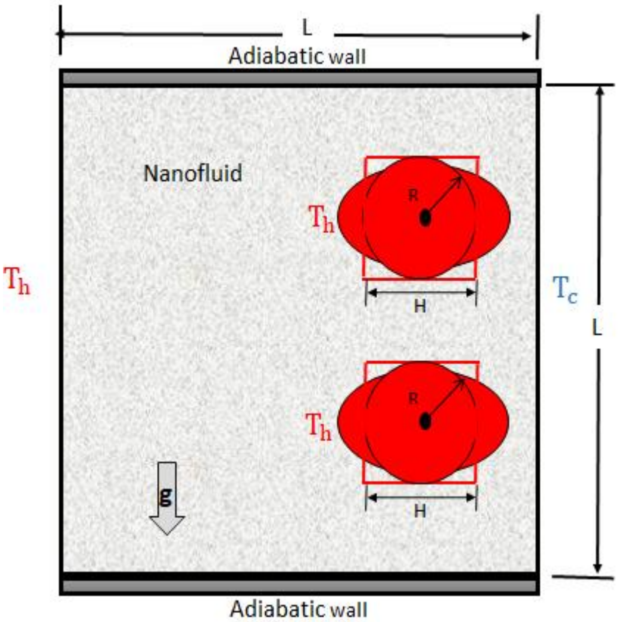

Fig. 1. The problem's physical geometry

Table 1
Water and nanoparticles thermophysical characteristics [45]

Substance	ρ *(kg/m^3)*	*Cp (J/kg.K)*	*K (W/m.K)*	β (1/ T)
Water	997. 1	4179	0.613	2.1* 10^{-4}
Al_2O_3	3970	765	40	8.5 * 10^{-6}

The dimensional governing equations for the present study are denoted by [46,47]

Equation of continuity

$$\frac{\partial U_{nf}}{\partial X}+\frac{\partial V_{nf}}{\partial Y}=0 \tag{1}$$

Equation of momentum

$$U_{nf}\frac{\partial U_{nf}}{\partial X}+V_{nf}\frac{\partial U_{nf}}{\partial Y}=-\frac{\partial P}{\partial X}+\frac{pr}{(1-\Phi)^{2.5}}\frac{\rho_f}{\rho_{nf}}\left(\frac{\partial^2 U_{nf}}{\partial X^2}+\frac{\partial^2 U_{nf}}{\partial Y^2}\right) \tag{2}$$

$$U_{nf}\frac{\partial V_{nf}}{\partial X}+V_{nf}\frac{\partial V_{nf}}{\partial Y}=-\frac{\partial P}{\partial Y}+\frac{pr}{(1-\Phi)^{2.5}}\frac{\rho_f}{\rho_{nf}}\left(\frac{\partial^2 V_{nf}}{\partial X^2}+\frac{\partial^2 V_{nf}}{\partial Y^2}\right)+\frac{(\rho\beta)_{nf}}{\rho_{nf}\,\beta_f}Ra\,\Pr\theta \tag{3}$$

Equation of energy

$$U_{nf}\frac{\partial \theta_{nf}}{\partial X}+V_{nf}\frac{\partial \theta_{nf}}{\partial Y}=\frac{\alpha_{nf}}{\alpha_f}\left(\frac{\partial^2\theta_{nf}}{\partial X^2}+\frac{\partial^2\theta_{nf}}{\partial Y^2}\right) \tag{4}$$

The nanofluid's properties and other physical quantities, such as

i. Density (*ρnf*)
ii. The coefficient of thermal expansion (*βnf*)
iii. Diffusivity of heat (*αnf*)
iv. Capacitance (*Cpnf*), is computed based on the papers examined [46,47]

$$\rho_{nf}=(1-\phi)\rho_f+\phi\rho_{np} \tag{5}$$

$$(\rho\beta)_{nf}=(1-\phi)(\rho\beta)_f+\phi(\rho\beta)_{np} \tag{6}$$

$$(\rho C_P)_{nf}=(1-\phi)(\rho C_P)_f+\phi(\rho C_P)_{np} \tag{7}$$

$$\alpha_{nf}=\frac{K_{nf}}{(\rho C_P)_{nf}} \tag{8}$$

$$\mu_{nf}=\frac{\mu_f}{(1-\phi)^{2.5}} \tag{9}$$

$$K_{nf}=K_f\frac{(K_{np}+2K_f)-2\phi(K_f-K_{np})}{(K_{np}+2K_f)+\phi(K_f-K_{np})} \tag{10}$$

As shown below, the (Nu_L) and ($Nu_{average}$) along the hot-wall on the enclosure's left side are used.

$$Nu_L=-\left(\frac{K_{nf}}{K_f}\right)\frac{\partial T}{\partial X} \tag{11}$$

$$Nu_{ave}=\int_0^1 Nu_X\,dY \tag{12}$$

3. Boundary Conditions for An Enclosure

The enclosure's boundary conditions are as follows, as illustrated in Figure 1. For the cavity's left wall (Th=1) and right wall (Tc=0), the cavity's upper and lower sidewalls

$$\partial\theta_{nf}/\partial Y=0$$
$$\partial\theta_p/\partial Y=0$$

On the internal bodies surface (Th=1).

4. Solution Procedure and Validation

In this paragraph, the accuracy of the present code was tested by comparing the current findings with the results obtained from Basak *et al.,* [48].

Comparative analysis was carried out using numerical results generated by the COMSOL software and the results of Basak *et al.,* [48] in terms of isotherm line and stream function at (Ra=10^6, Da = 10^{-5}, and Pr = 0.71), as shown in Figure 2, and the results were found to be identical. As a result, the results in this research paper were obtained using the current code.

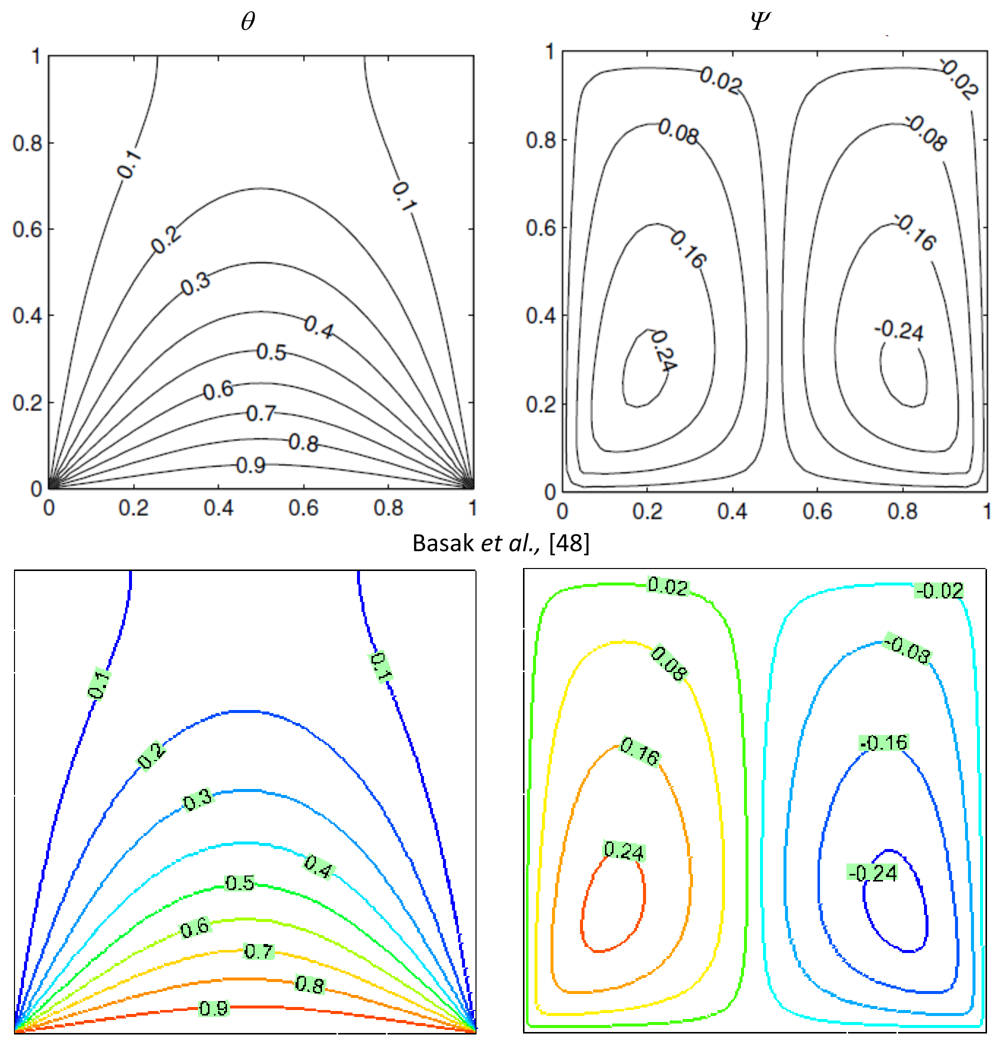

Fig. 2. The present model's isotherms and streamlines are compared to those of Basak *et al.,* [48] at (Ra=10^6, Da = 10^{-5}, and Pr = 0.71)

To create a grid-dependent test, Table 2 describes the impact of mesh production on these parameters and shows that the inaccuracy decreases as the grid size increases. The findings of the mesh test were presented as (Ra =10^5, φ = 0.06, AR=0.7). When compared to the extremely fine (27202), the results revealed that the average Nusselt number has a very tiny fluctuation for the extra fine (21874). As a result, in every case in our investigation, an extra fine was applied. However, as seen in Figure 3, an additional fine grid was given, utilizing triangular components to shorten the calculation time.

Table 2
The average Nusselt number along cavity height using various mesh sizes at (Ra =10^5, φ = 0.06, AR=0.7)

Mesh name	Normal	Fine	Finer	Extra fine	Extremely fine
Mesh elements	1648	2510	7586	21874	27202
$Nu_{average}$	4,4270	4,4208	4,4118	4,4111	4,4113

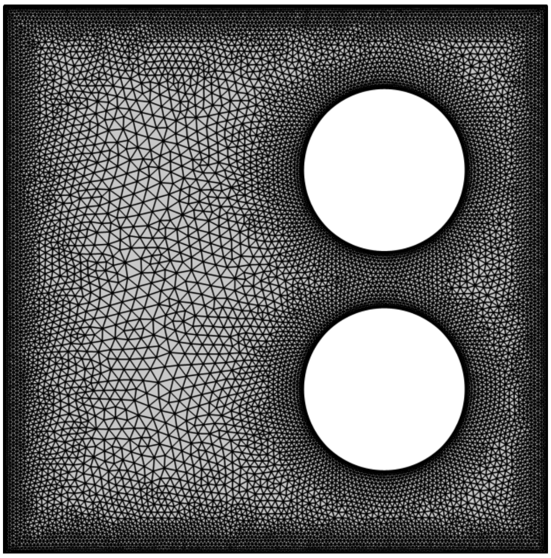

Fig. 3. The triangle mesh Distribution of the enclosure

5. Results and Discussion

In the current work, the following parameters were used: "Rayleigh number" (Ra)" (10^3 to 10^6) is used, and the percentage of solid volume " (φ = 0.06) with different inner shapes (circular (R = 0.15), square (L = 0.15), ellipse (R_x = 0.2, R_y = 0.15), and circular (R = 0.15) and ellipse (R_x = 0.2, R_y = 0.15)) nears the cold wall of the enclosure where the (AR = 0.7).

To find out the effect of the internal bodies (circular, square, ellipse, circular –ellipse) close to the cold wall where (AR = 0.7) inside the cavity, the Rayleigh number was fixed at 10^5, while the study was conducted at the percentage of solid volume (φ = 0.06) as shown in Figure 4.

The movement of the fluid is affected by the temperature difference in cavities with thermally different vertical walls and thermally insulated horizontal walls, as it begins to rise at the hot vertical wall to reach the thermally insulated horizontal wall, after which it begins to descend due to the influence of the cold wall to complete its path inside Cavite.

In this research paper, heated internal bodies were used in different forms, so the effect of fluid movement will be different as a large part of the fluid will be affected by the internal bodies and complete its cycle around these bodies.

Except for the two hot squares, notice the appearance of vortices close to the internal bodies in the left column and the effect of temperature on the function of the stream. It is also noted that when the two inner bodies are circular, the cause of the highest stream function of up to 33 can be obtained, and the reason for the circular shape is what gives fluidity in the movement of the fluid affected by temperature.

The importance of the two inner bodies (two ellipses, ellipse, and circular) is no less than the two inner circulars because they have a noticeable impact on fluid movement and the increase in stream function.

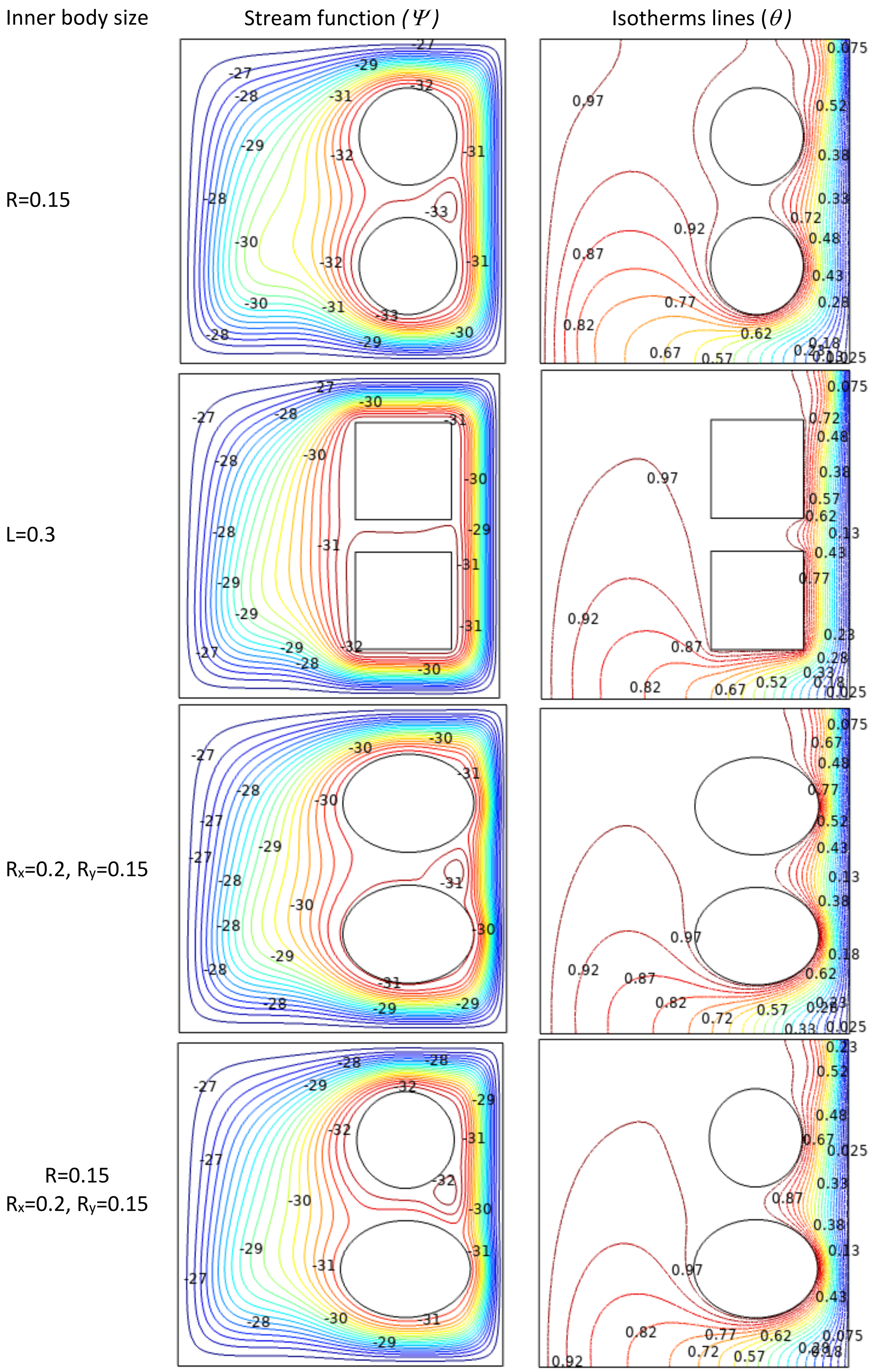

Fig. 4. Effect of a heated internal body on stream performance in the left columns and isotherm line in the right columns for (Ra =10^5, φ = 0.06, AR=0.7)

The presence of internal bodies can constitute an obstacle to the movement of the fluid if it is thermally isolated or its temperature is cold, while it has an important effect and improves heat transfer inside the cavity when it is at a high temperature. Heat transfer is greater in addition to being far from the hot wall and close to the cold wall, so the effect of the cold-temperature wall will be weakened.

It is also noted in general in all figures that the value of the function of a stream near the hot wall is equal in all cases due to the stability of the Rayleigh number and the presence of hot inner bodies plays the largest role in improving the stream function.

The right column shows the effect of temperature distribution lines inside the cavity. The isotherm line shows the clear and important effect of internal bodies in enhancing and improving heat transfer, as the effect of the cold wall recedes only in the area near it, while the left side of the cavity is affected by the hot left wall, reinforced by internal bodies that reduce the effect of the cold wall. The inclination of the temperature lines between the two internal bodies is also observed due to the high heat emitted from the internal bodies, and it has the greatest value in this region.

About Figure 5, which explains the local (Nu) on the hot wall for diverse shapes of inner bodies at (Ra =10^5, φ = 0.06, and AR =0.7). The physical impact is identical in all cases, starting from the lower of the left hot wall with the highest value and gradually decreasing to the lowest value at the higher point of the hot wall. Because of the effect of the upper wall where it is thermally insulated, in addition to the distance of the heated internal bodes from the hot wall, it is less valuable for NuL in this area. Noted that the highest Nusselt number was for the two circular cylinders, while the lowest case was for the two elliptical cylinders. The cylinder–ellipse case was the second in the Nu profile, followed by the two–square case.

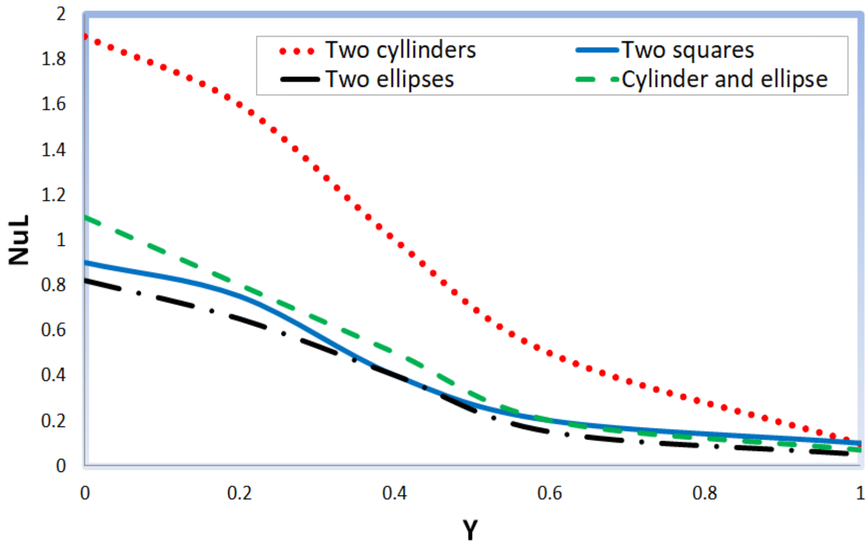

Fig. 5. Local Nusselt number variation with cavity height for various inner forms at (Ra =10^5, φ = 0.06, AR=0.7)

However, the average Nu concerning the Ra under different shapes of inner bodies, as shown graphically in Figure 6, For low Ra, it can be noticed that the average Nu was at its minimum case for the two-square case. While the highest Nu was for two – the ellipse case followed by the cylinder – the ellipse and the two circular cylinders. At high Ra, the highest average Nu is at (cylinder – ellipse and the two circular cylinders), while the effect of two ellipses decreases, and the two squares continue to maintain the lowest average Nu.

This shows an important matter of hot internal bodies that can change their behavior when increasing the temperature represented in the Rayleigh number. In the case studied in this research paper, it is recommended to use two ellipses when the Rayleigh number is less than 10^5. While it is recommended to use (two cylinders and a cylinder–ellipse) when the Rayleigh number is 10^6.

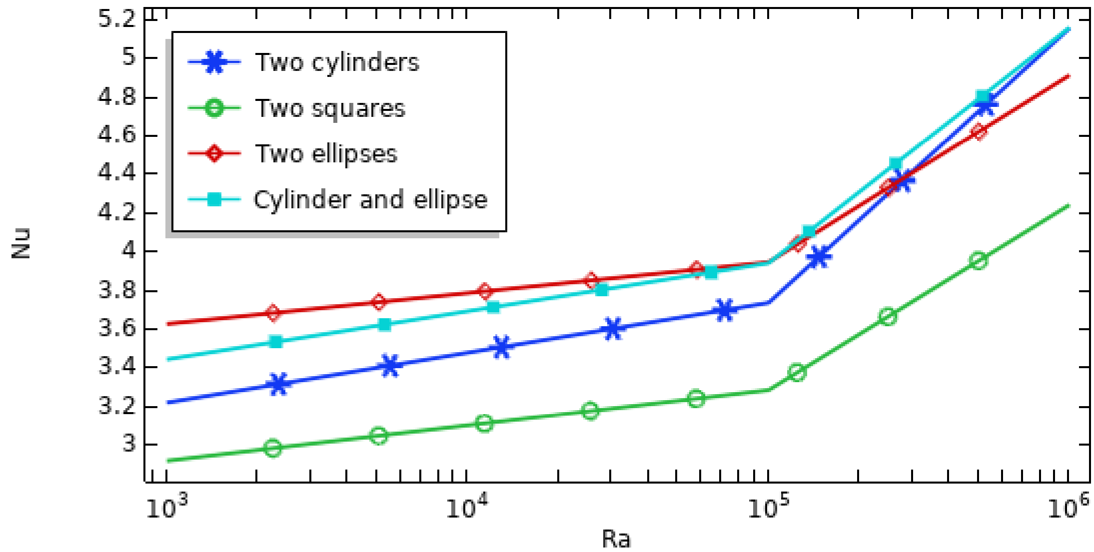

Fig. 6. Averaged Nusselt number variation with a heated inner body for various Rayleigh number values at (φ = 0.06, AR=0.7)

6. Conclusions

A summary of the results obtained can be concise in the following

i. The heated internal bodies are used in different forms, and the effect of fluid movement will be different, as a large part of the fluid will be affected by the internal bodies and complete its cycle around these bodies.
ii. It is noted that when the two inner bodies are circular, the cause of the highest stream function of up to (33) can be obtained.
iii. The importance of the two inner bodies (two ellipses, ellipse, and circular) is no less than the two inner circulars because they have an obvious impact on the fluid movement and the increase in the stream function.
iv. The isotherm line shows the clear and important effect of internal bodies in enhancing and improving heat transfer.
v. The highest (Nu_L) on the hot wall, when using two circular cylinders. while the lowest case was for that of two elliptical cylinders.
vi. The average Nu was at its minimum case for the two-square case. While the highest Nu was for two – the ellipse case followed by the cylinder – the ellipse and the two circular cylinders.

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