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# Numerical analysis of fluid flow and combined natural and force convection heat transfer for nanofluid in concentric /eccentric rotating cylinders

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## Abstract

Improving the properties of fluids has always been the focus of industries and power plants, and nowadays adding nanoparticles to fluids has been introduced as one of the effective ways. Therefore, in recent years, scientists have turned their attention to finding the unique properties and behavior of nanofluids. Therefore, in this research, the effect of Reynolds and Rayleigh parameters on the flow and heat transfer (combined free and forced convection heat transfer) of nanofluid confined in the space between two concentric/eccentric cylinders rotating horizontally along the infinitesimals kept at two different temperatures have been discussed. The results show that the relationship between the parameters of Reynolds and Rayleigh numbers with the amount of heat transfer is indirect and direct, respectively.

**Keywords:** Nanofluids, Concentric and Eccentric Cylinders, Combined Convection Heat Transfer, Rotating Cylinder

## 1. Introduction

Due to the widespread use of rotating cylindrical geometries in industries and power plants, it is of particular importance to investigate the issues related to heat transfer and fluid flow in these geometries. In general, the rotation of cylindrical geometries is one of the factors that affect the rate of heat transfer and the nature of the flow [1].Heat transfer in rotating cylinders is of a combined free and forced convection heat transfer and the speed and direction of rotation of the cylinder has a direct effect on its rate [2]. Researchers found that the use of nanofluids improves the heat transfer rate [3] and the use of aluminum oxide/water nanofluids instead of pure fluids in heat exchangers increases heat transfer [4].

## 2. Governing Equations

In this research, in order to investigate the heat transfer and flow of nanofluid confined in the space between two cylinders with radii R_i and R_o=2R_i in concentric (ec=0) and eccentric (ec=10%) situations using the method Single-phase and two-phase have been used. The schematic of the geometry investigated in this research is presented in Fig.1

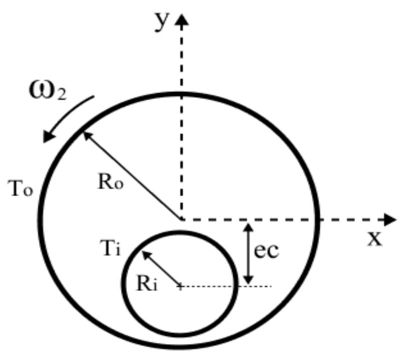



**Fig1. The schematic of the cylinder geometry**

The space between the two cylinders is filled with aluminum oxide/water nanofluid, the properties of nanoparticles and base fluid at a reference temperature of 20°C are presented in Table.1

**Table1. Thermophysical properties of base fluid and nanoparticles**

| properties | Nano particle: $Al_2O_3$ | Basic fluid: Water |
|---|---|---|
| $\rho$ (kg/m$^3$) | 3970 | 997.8 |
| $c_p$ (j/kg. k) | 765 | 4179 |
| $\mu$ ($\frac{j.s}{kg}$) | - | 9.58e-4 |
| $k$ (w/ m . k) | 25 | 0.6 |
| $\beta$*۱۰۴(1/K) | 0.85 | 2.3 |
| $d_p$ (nm) | 100 | - |

It is assumed that all the thermophysical properties of the fluid are constant except the density. The density of nanofluids was calculated from the "Peck and Cho" relationship, the thermal conductivity coefficient was calculated from the "Wasp model", and the viscosity of the nanofluids was calculated from the "Brinkman model".

Continuity equation for fluid:

$$\nabla . \mathrm{V} = 0 \tag{1}$$

Continuity equation for nano particles:

$$\frac{\partial \varphi}{\partial t} v . \nabla \emptyset = \nabla . (D_B \nabla \emptyset + D_T \frac{\nabla T}{T}) \tag{2}$$

where $\emptyset$ is the nanofluid volume fraction, $D_B$ is the Brownian diffusion coefficient and $D_T$ is the thermal diffusion coefficient.

The momentum equation for fluid and nanoparticle are expressed by relations (3) and (4), respectively:

$$\left(\vec{V} . \nabla\right) \vec{V} = -\vec{\nabla} P + \frac{1}{Re} \nabla^2 \vec{V} + \frac{Ra}{PrRe^2} \theta \left[(cos\,\varphi) \vec{e_r} - (sin\,\varphi) \vec{e_\varphi}\right] \tag{3}$$

$$v . \nabla v = -\frac{1}{\rho_{nf}} \nabla p + \nabla . \tau + g \tag{4}$$

After applying the dimensionless variables for the base fluid, the energy equation becomes as follows:

$$(\vec{V} . \vec{\nabla}) \theta = \frac{1}{RePr} \nabla^2 \theta \tag{5}$$

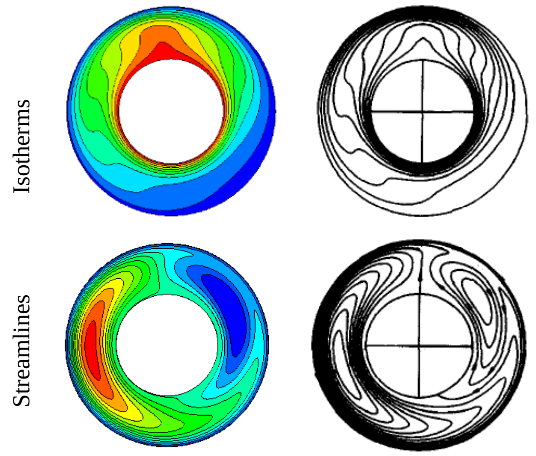
And for nanoparticles it will be as follows:

$$V . \nabla T = \nabla(\alpha_{nf} \nabla T) + \frac{\rho_P c_P}{\rho_{nf} c_{nf}} \left(D_B \nabla \emptyset . \nabla T + D_T \frac{\nabla T . \nabla T}{T}\right) \tag{6}$$

The dimensionless form of the initial conditions for the present problem at $t = 0$ is defined as $V_r = 0$, $V_\varphi = 0$ and $\theta = 0$, and the dimensionless form of the boundary conditions at $r = R_i$ is defined as $V_r = 0$, $V_\varphi = 0$, $\theta = 0$ and in $r = R_0$ it is $V_r = 0$, $V_\varphi = 1$, $\theta = 0$.

## 3. Results and Discussion

To ensure the accuracy of the obtained results, the results obtained from the present study were compared with the results obtained from the Yu [5] research in Fig.2




(a) (b)

**Fig 2. Comparison of streamlines and isotherms in (a) present study and (b) Yu study for fluid with Pr=0.7 ،Ra=104 ،Re=100**

First, with the increase of Reynolds number due to the dominance of inertial forces over buoyancy and finally the reduction of mixed convection heat transfer, the rate of heat transfer decreases, but at values of Reynolds number greater than 200, heat transfer decreases at a lower rate. The two-phase state and non-concentric cylinders predict more heat transfer than the single-phase state and concentric cylinders (Fig.3).

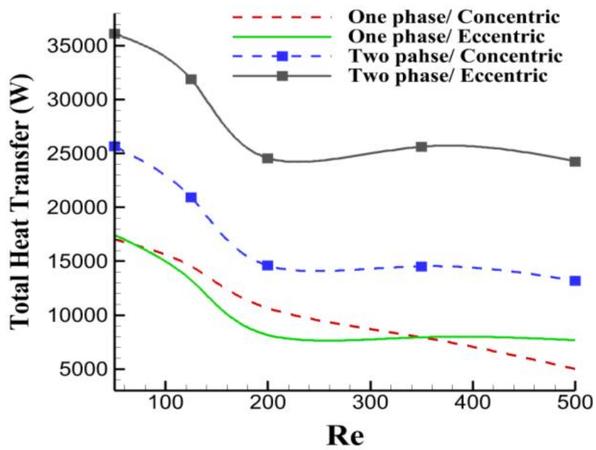



**Fig 3. Comparison of the effect of Reynolds number changes on the total heat transfer rate from the wall in different single-phase and two-phase states for concentric and eccentric cylinders.**

In Fig.4, with the increase of Rayleigh number, the total heat transfer rate increases in all cases. The two-phase state has more heat transfer than the single-phase state. The heat transferred between the concentric and non-concentric cylinders in the two-phase state has a significant difference, but in the single-phase state, there is not much difference.

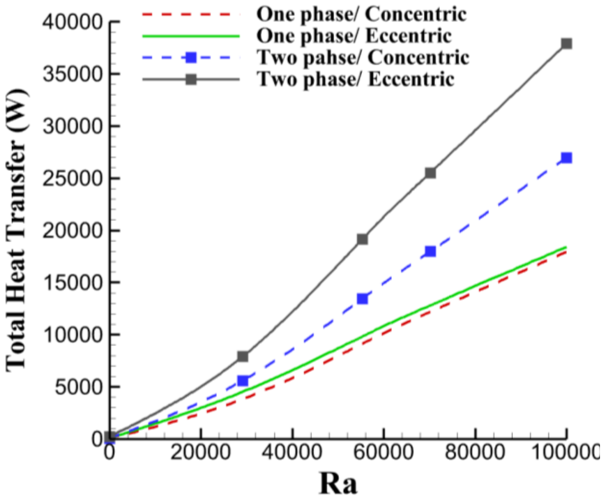



**Fig 4. Comparison of the effect of Rayleigh number changes on the total heat transfer rate from the wall in different single-phase and two-phase states for concentric and eccentric cylinders**

In Fig.5, increasing the volume fraction increases the heat transfer rate in all cases, which is more evident in the two-phase case for concentric and non-concentric cylinders. Also, according to the diagram, it can be seen that the highest heat transfer rate in single-phase and two-phase states is related to non-concentric cylinders.

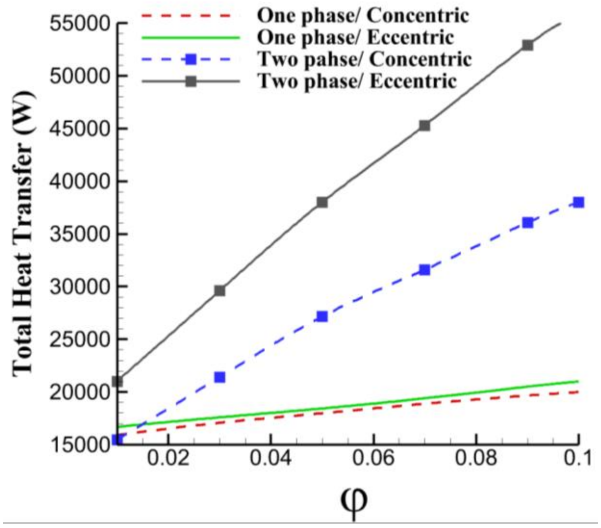



**Fig 5. Comparison of the effect of the volume fraction of nanoparticles changes on the total heat transfer rate from the wall in different single-phase and two-phase states for concentric and eccentric cylinders.**

## 4. Conclusions

- As the Reynolds number increases, the heat transfer rate in the walls decreases, so that at high Reynolds numbers, the heat transfer is mainly forced.
- An increase in the Rayleigh number causes non-uniformity of the flow and isothermal lines and increases the heat transfer in the walls. The highest heat transfer was related to the two-phase state of non-concentric cylinders.
- Increasing the Prandtl number causes the effects of buoyancy forces to disappear and the flow lines and isothermal lines to become uniform.
- By increasing the volume fraction of nanoparticles, the thermal conductivity coefficient of the fluid increases, which increases the heat transfer.
- It is clear that in all cases, the two-phase state in non-concentric cylinders has the highest heat transfer rate.

## 5. References

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