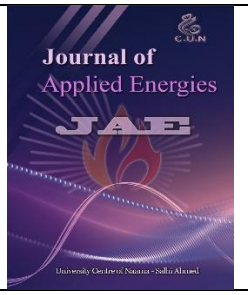
Journal of Applied Energies 01 (2022) 20-29

Journal of Applied Energies



Cooling and heat transfer efficiency of a Newtonian fluid in a vented duct

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Abstract: Mixed convection is studied numerically to investigate the performance of the better heat transfer and also the effective cooling in a vented cylinder cavity, which is covered by two rotating discs. An external airflow enters the enclosure through an opening in the bottom vertical side and exits from another opening in the top of the opposite vertical one. The bottom disc is kept at a constant temperature, while the other sides are adiabatic. CFD code is used to solve the governing equations (continuity, momentum, and energy equations). The calculus is carried out for different values of $Ri = Gr/Re^2$ ($0.1 \leq Ri \leq 20$). Nusselt numbers, velocity and temperature profiles, and heat transfer rate are presented and compared to the literature.

Keywords: Mixed convection; Cooling; Nusselt numbers; Richardson number.

1. INTRODUCTION

Mixed convection in Rotating-disks flow has long been an essential topic in fluid dynamic research for the interests in practical and academic senses. It is often encountered in many engineering applications such as heat exchangers, solar collectors, boilers, cooling of electronic devices, compact rotating-disc heat exchangers, and the cooling core of nuclear reactors, etc.

Many scholars have acknowledged the thermal heat problem over the years and have tried to present solutions to increase cooling performances. A literature review concerning ventilated enclosures shows that some available works have considered the problem of mixed convection. Mixed convection heat transfer for assisting thermally developing flow in a uniformly heated vertical circular cylinder is investigated by Mohammed and Salman [1]. Those results have demonstrated an increase in the Nusselt number values as the heat flux increases. A general analysis has been developed to study fluid flow and heat transfer characteristics for mixed convection along with a rotating vertical cylinder by Singh and Roy [2]. The effects of rotational, buoyancy, and suction/injection parameters have been investigated while the numerical results are presented for the Nusselt number. Double-diffusive convective flow in a vertical tube with upward or downward flow investigated by Mohamed et al. [3], the laminar flow and under steady-state condition are considered where the numerical procedure adopted in this analysis yields consistent performance over a wide range of parameters, Richardson number, $10^{-2} \leq Ri \leq 10$. The numerical results are reported for the effect of the Parameters on the isotherms. Kreith [4] simplified the Navier-Stokes equations for laminar source flow between two corotating parallel disks and obtained solutions by series expansion. Joye [5] investigated numerically the coupled laminar flow and heat transfer between a pair of disks attached to a hub rotating about a vertical axis in a fixed cylindrical enclosure. Heat transfer rates are calculated for a range of Reynolds numbers and inter disk spacing. Saha et al. [6] studied numerically the transverse mixed convection in a vented enclosure with two openings. They observed that maximum cooling effect is achieved if both inlet and outlet are kept near the bottom wall. Behzadmehr et al. [7] studied mixed convection of air in a vertical tube with uniform wall heat flux has been conducted for low Reynolds numbers over a wide range of Grashof numbers $Gr \leq 108$ laminar and turbulent models. The results define three critical Grashof numbers for each Reynolds number to know the transition flow from laminar to turbulent.

2. PHYSICAL MODEL

A schematic of five configurations is shown in Figure 1(a-e). Each is a cylinder cavity, with its bottom disk submitted to a uniform temperature Th, while the other parts are adiabatic (flux q = 0). The hollow cylinder presented in Figure 1 is subjected to an external flow entering the enclosure from the bottom of the insulated sidewall and leaves from the top of the opposite vertical one. The second case is a rotating top disc at the positive direction (Ω+). For brevity's sake, this configuration will be referred to as TR+ from now on. The third case is the opposite

of rotating top disk (Ω-); this configuration will be referred to as TR-. Similarly, for the bottom wall, two other configurations will be referred to as BR+ and BR-, respectively.

The values that were chosen originally for the geometric parameters are as follows: aspect ratio of the cylinder, H/D = 1, and the ratio of the size of ports, d1 = d2 = 0.2H. Air injection through the inlet opening is horizontal with velocities u = u_0, v = 0, and a uniform temperature T_0. The outflow is assumed to have zero diffusion flux for all variables (outflow boundary condition).

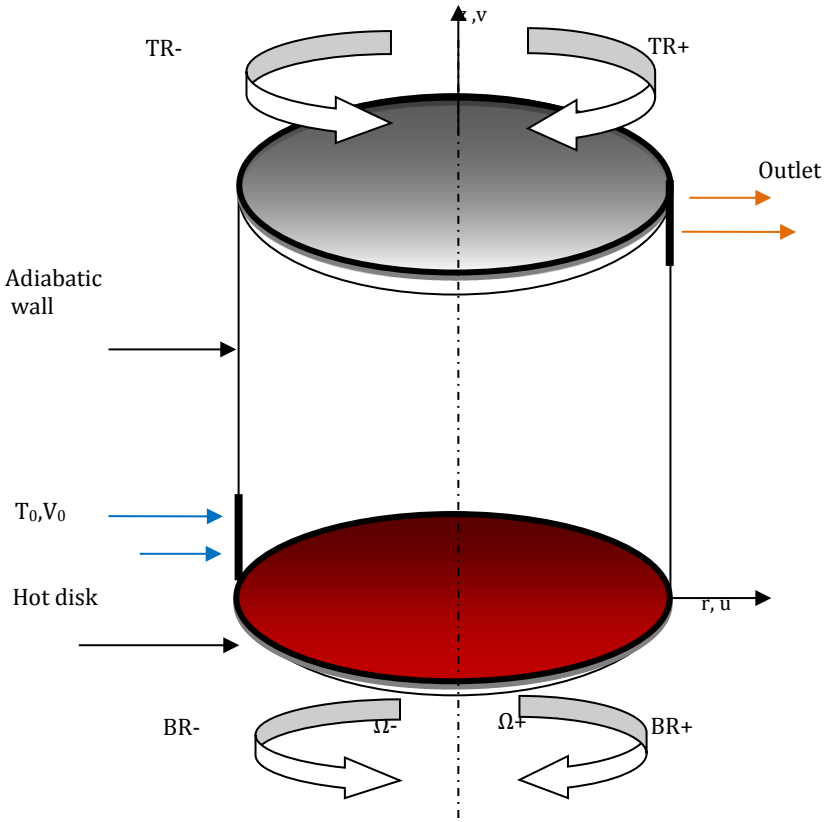


Figure 1: Schematic flow configuration of the studied enclosure.

3. MATHEMATICAL MODEL AND NUMERICAL PROCEDURE

The governing equations were solved by a software package Fluent 6.3.26. The power law scheme was used to evaluate the diffusive and convective fluxes at the interface of each control volume. The SIMPLE algorithm is used to treat the coupling pressure-speed. The discretization grid is obtained for uniform elements of 5184 nodes.

4. CODE VALIDATIONS

The results are compared with Mohamed et al. [3] (Figure 2) for the case of isothermally heated cylinder cavity, where the comparison regarding the effect of Richardson number on the average of Nusselt number.

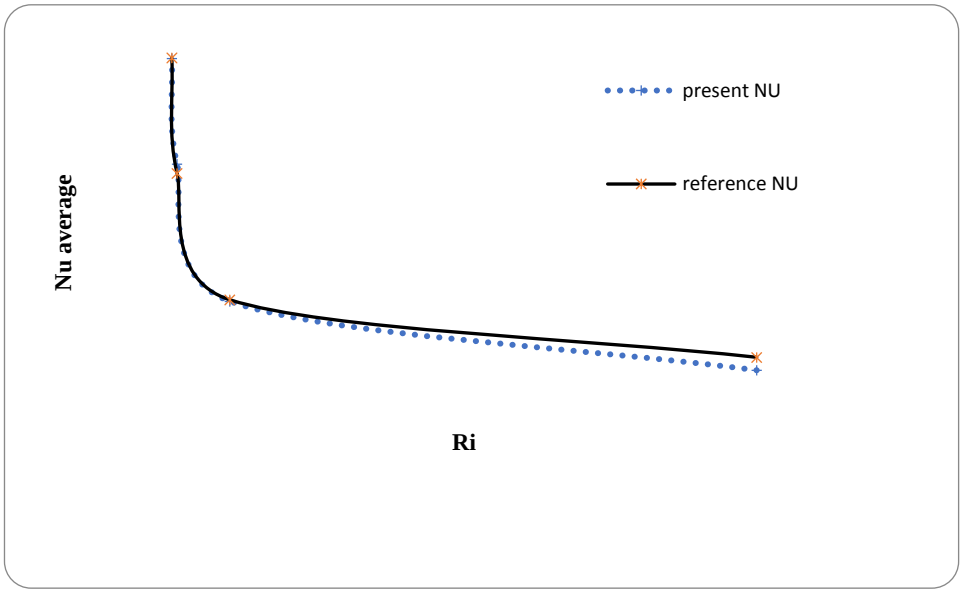


Figure 2: Variation of the average Nusselt for different Richardson numbers.

5. RESULTS AND DISCUSSION

In the present work, results were obtained for mixed convective flow for Pr = 0.71 and Gr = 105, using a uniform rectangular mesh. The Richardson number, in the range $0.1 \leq Ri \leq 20$ at different rotating disk configurations.

5.1. Effect of Richardson number (Ri)

The effect of different Richardson number (Ri) on isotherms and streamlines are shown in Figure 3. For Ri = 5, a slight variation in the thermal field prior to below Richardson numbers, where the thermal stratification in the enclosure is absent. The little cell located at the top left corner is lost by the effect of increased buoyancy forces. This leads to a significant change in the shape and size of the big central cell, while the isotherms are expanded, occupying a considerable portion of the cylinder. This is the onset of natural convection to be dominant, for large Richardson numbers. From Ri = 10, the natural convection becomes important, the size of the vortex becomes increasingly important, while the high temperatures are localized in narrow spaces near the hot wall, which correspond to the thickness of the thermal boundary

layer, that means, the effect of natural convection on the temperature distribution is characterized by the displacement of the isotherms front throughout the enclosure.

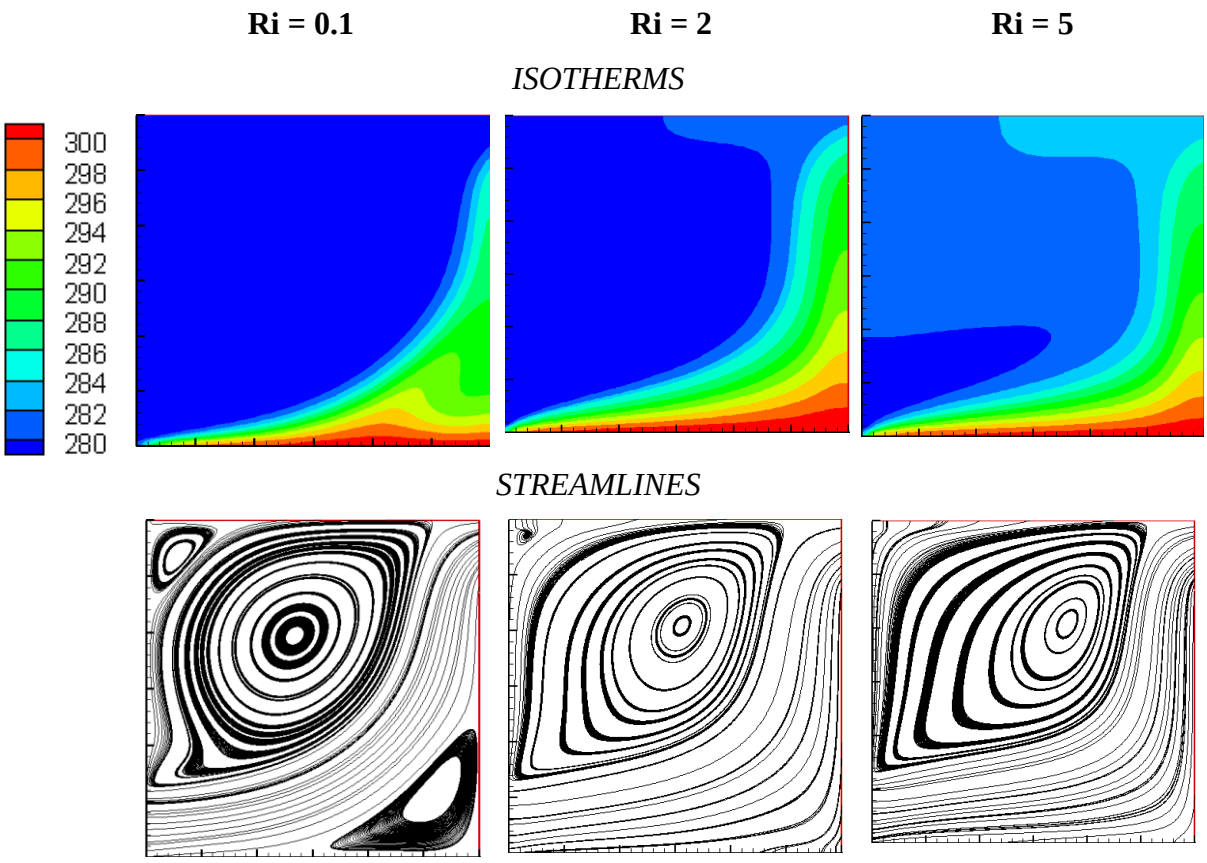


Figure 3: Effect of Richardson number for the first configuration

5.2. Effect of the rotating upper disk

Figure 4 presents the thermal and flow fields as a function of the Richardson number (Ri) and rotational Reynolds number (Re_w). The top disc is rotating around the axis (y) in the positive direction. It shows in TR+ configuration. For very low Ri and Re_w, the bulk induced fluid flow throughout the cavity, and two small cells are formed at the left top corner and the opposite one, where the conduction and forced convection effects are dominant. The isotherms are almost linear and distributed inside the cylinder at low Re_w. At low Ri and Re_w = 20, the recirculation started to grow, which indicates natural convection is sprouted. For Re_w > 20, the flow pattern is changed drastically. The upper recirculation zone spreads on the big cell, indicating a sign of the supremacy of natural convection in the upper part of the cylinder. But since the induced flow sweeps over the heat source, the forced convection acts as a driving

force for the major heat removal. For Ri = 5 and low Re_w, a big recirculation formed near the top disc, induced flow from the opening to the exit and a large vortex of higher speed. The isotherms are stratified throughout the cavity, indicating the diffusion heat transfer. Here induced natural convective current is dominant even at low Re_w.

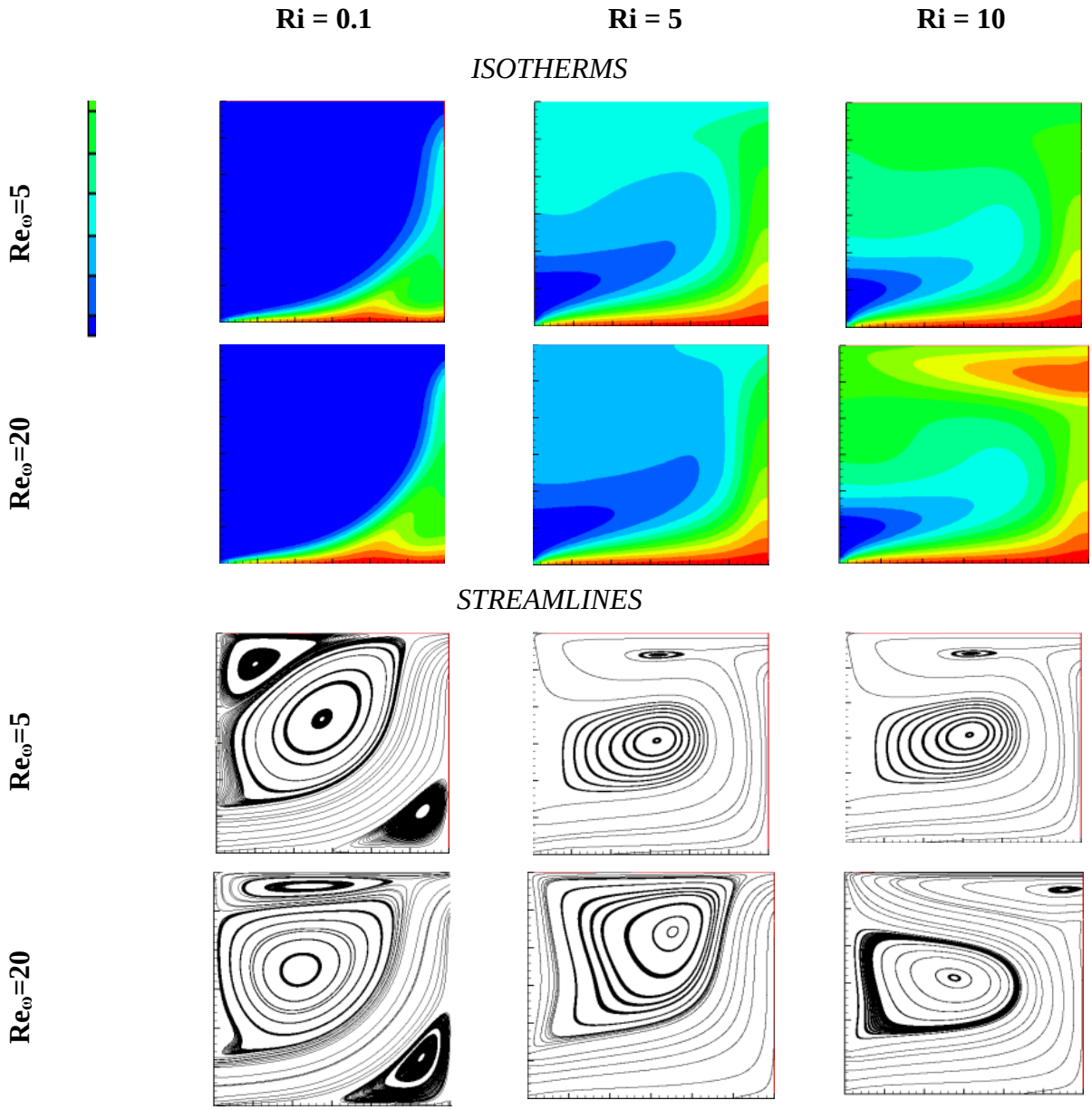


Figure 4: Isotherms and Streamlines for configuration TR+

TR- configuration presents the rotation of the bottom disc around the axis (y) in the negative direction. Isotherms and streamlines illustrating the effect of Reynolds number and Richardson numbers are presented in Figure 5. For Ri = 0.1 and low *Re*, the bulk induced fluid flows

throughout the enclosure, forming a pocket of fluid at the lower part of the right insulating wall. Here the force convection effects are dominated.

5.3. Effect of the rotating lower disk

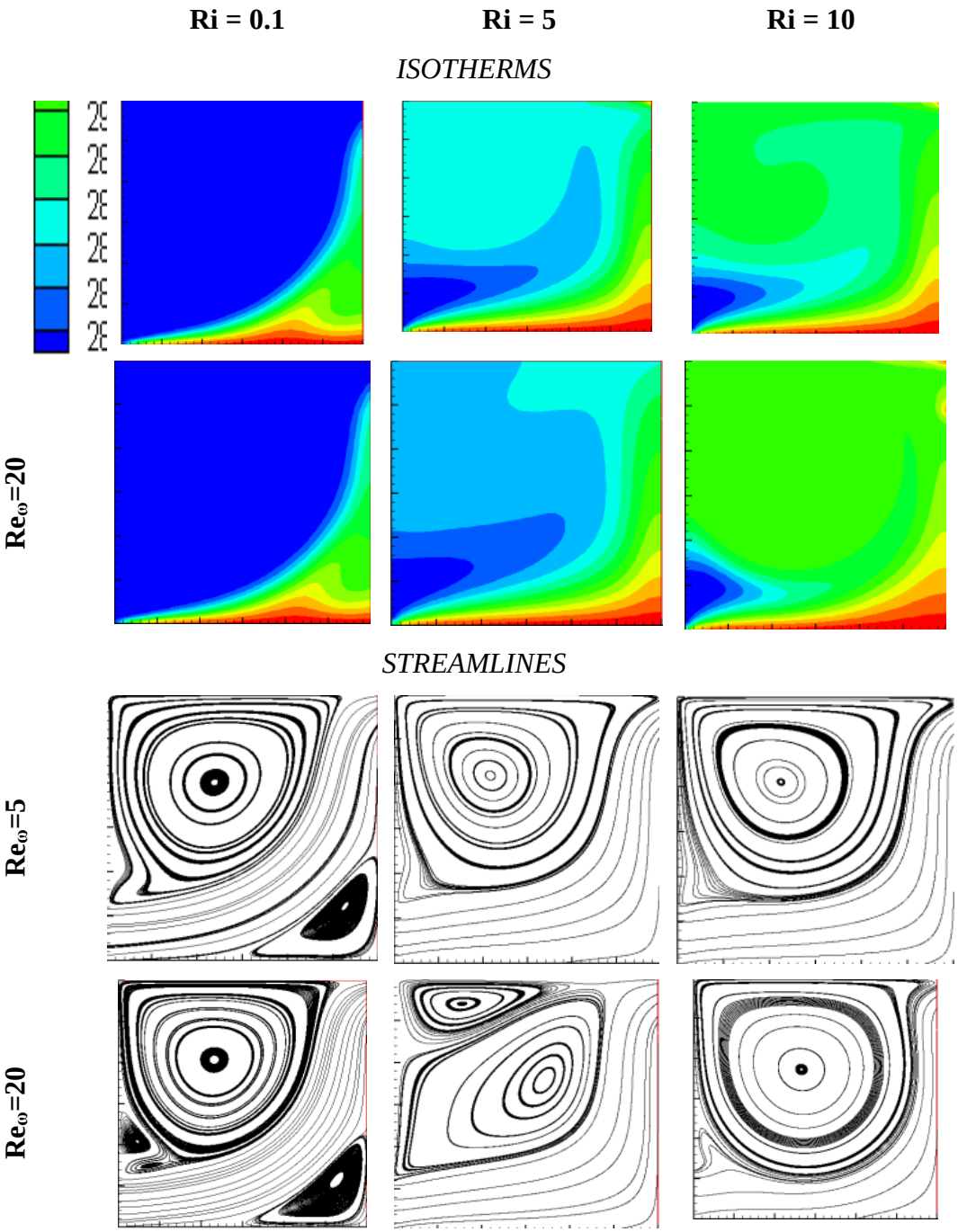


Figure 5: Isotherms and Streamlines for configuration TR-

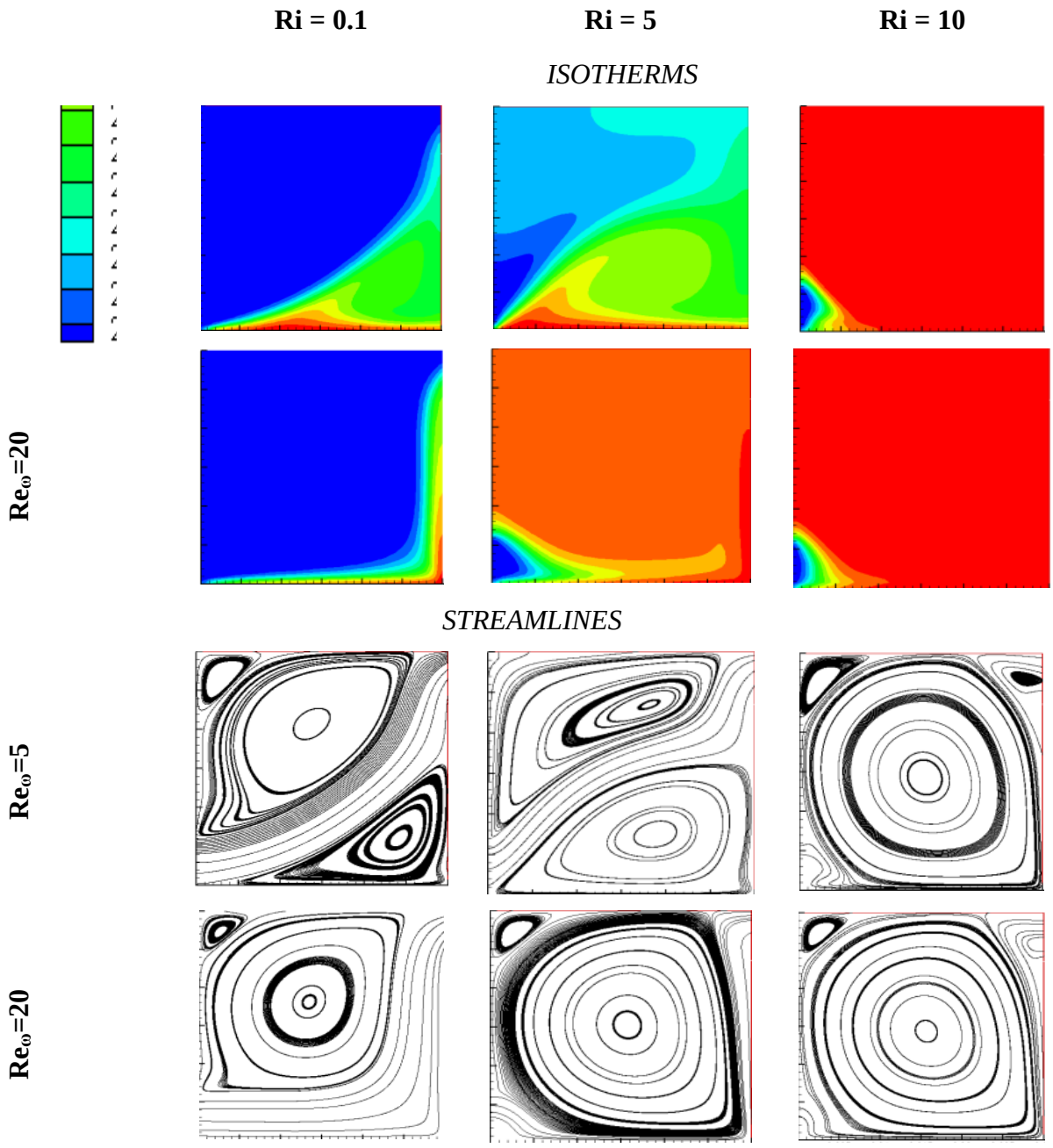


Figure 6: Isotherms and Streamlines for configuration BR+

For low values of Ri and Re_ω, the thermal field tends to go out, while two different vortexes are formed at the upper midsection of the cylinder and the lower part of the heat source, its result from weak flow velocity. When Re_ω is increased, the lower isotherms go away from the exit when Ri is still low, which means the natural convection is dominant.

The effect of the opposite rotation direction on the isotherms and streamlines is presented in Figure 7. For low Ri and Re_ω, some portions of the induced flow spread within the cavity and other ones flow diagonally from the inlet port to the exit, that's similar to (a) configuration due to the low rotational velocity. So two rotating vortices are respectively formed at the top left

corner and at the bottom right corner of the cavity. When Ri increases to 10, the rotating vortex becomes more significant.

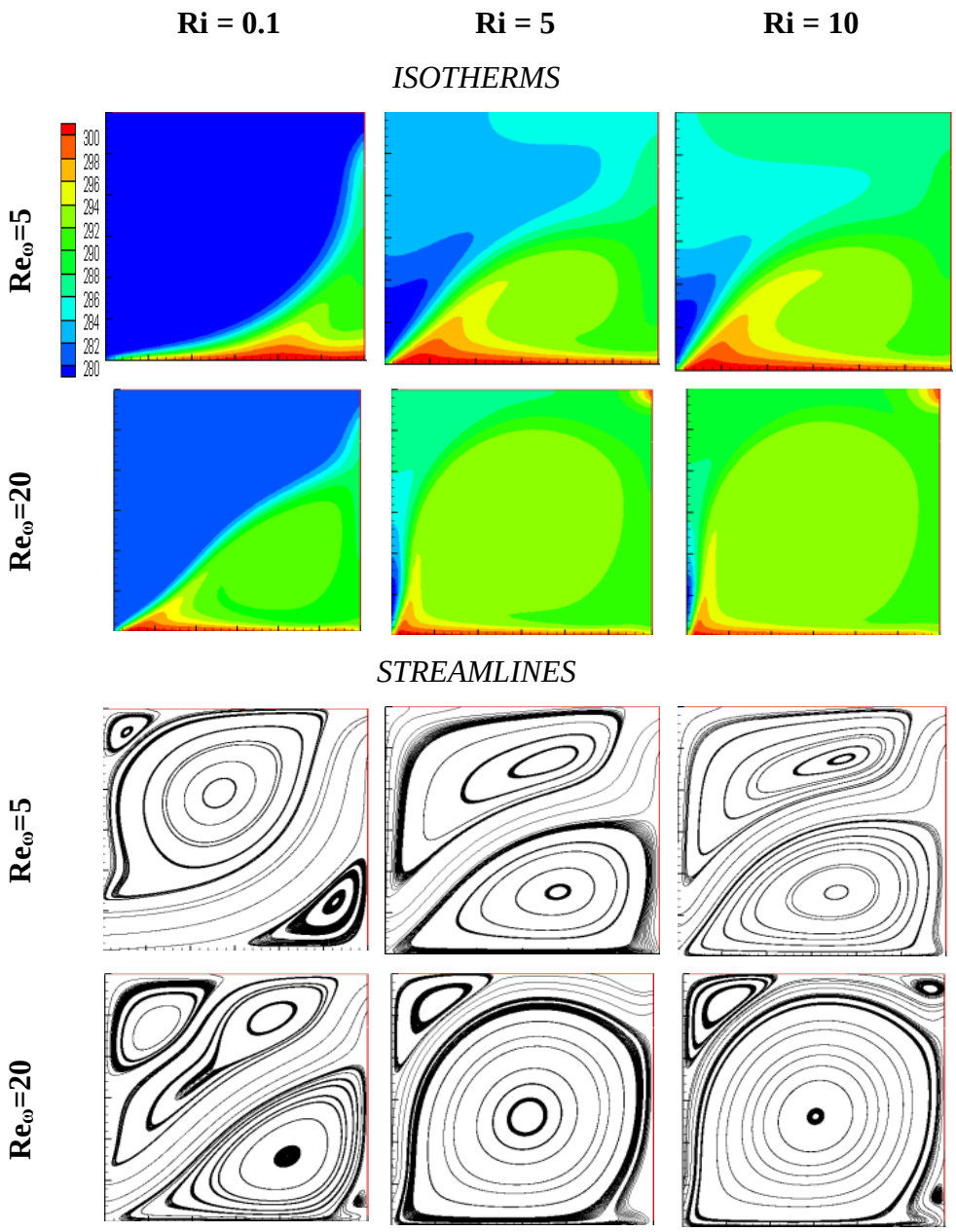


Figure 7: Isotherms and Streamlines for configuration BR-.

6. CONCLUSION

The effects of mixed convective flow on the thermal phenomena in an enclosure have been investigated. This study presented important fundamental aspects of mixed convection in an enclosure. The numerical results explained the importance of the orientation of the rotating upper and lower disks. Both Re_ω and buoyancy parameter Ri primarily affected the thermal

characteristics. At a higher value of Re_{ω}, the value of Nu was independent of the variation of Ri for the preferable BR-configuration compared to the other three configurations. On the other hand, similar heat transfer performance existed for TR- and BR+ configurations.

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