Chapter 5

CONCLUSIONS

5.1 Introduction

The study of heat transfer and fluid flow in porous medium pertaining to the square and vertical annulus is performed to analyze the effects of geometrical and physical parameters. The study focused on the convective heat transfer in porous medium, which is relevant to many industrial applications such as for thermal insulation, oil refinery and microelectronic cooling systems. The effect of combined heat and mass transfer was also studied to determine the significant factors where thermosolutal transport is important, such as in the petroleum industry, drying of vegetables and insulation of nuclear reactors.

The following conclusions have been drawn through the in-depth analysis of heat transfer and fluid flow in a porous annulus. The conclusions are presented in the same chronological orders as they were discussed in previous chapters.

5.2a Investigation of heat transfer in square porous-annulus subjected to outside wall heating

1. It was found that the fluid moves in two symmetrical cells due to the isothermal heating and cooling of outer and inner walls of the duct respectively.
2. The upper section of the duct is dominated by the conduction mode of heat transfer due to weak fluid movement in that region.
3. A separate fluid circulation region is seen at the bottom section of the duct at increased Rayleigh numbers.

4. The local Nusselt number is higher at the bottom wall of the duct as compared to the other three walls.
5. The Nusselt number oscillates in a wavy form at the bottom wall when the width ratio is $W=0.5$ and the amplitude of oscillation increased with the Rayleigh number.
6. The average Nusselt number increased with the duct width ratio.

5.2b Investigation of heat transfer in square porous-annulus subjected to inside wall heating

1. It was observed that the Nusselt number is generally higher at the bottom and lowest at the top hot wall of the annulus.
2. The local Nusselt number for the major part of the hot wall is found to be equal at width ratio $W=0.75$.
3. The convection mode of heat transfer dominated at the bottom section and conduction at the top section.
4. The total Nusselt number is found to be almost equal to the Nusselt number of right or left vertical hot walls.
5. The effect of viscous dissipation is resulted in to reduced heat transfer rate from the hot walls to the porous medium.
6. For the case of thermal non-equilibrium, the Nusselt number for fluids is higher than solids at the left/right and bottom hot surface. However, the Nusselt number is higher for solids than fluids at the top surface.

5.3 Study of conjugate heat transfer in porous annulus

1. It was observed that the temperature along the interface layer increased with decrease in the solid wall thickness.
2. The increased conductivity ratio influenced enhancement of the temperature in the solid-porous interface.

3. The temperature gradient at the hot surface was found to be decreasing with increase in the solid wall thickness and conductivity ratio.
4. It was found that the increased wall thickness led to reduced fluid velocity.
5. The isothermal lines indicated that the conduction mode of heat transfer was prominent when the solid wall thickness was increased.
6. The Nusselt number was found to be decreasing with increase in the solid wall thickness.
7. The enhancement in the thermal conductivity ratio resulted in the increased heat transfer rate.

5.4 Analysis of conjugate heat transfer in porous annulus fixed in between the solid walls

1. It was found that there was not much temperature variation inside the inner solid wall for the lower value of wall thickness.
2. The temperature at solid porous interface $r_{sp1}$was found to be increasing along the height of the cylinder.
3. At solid porous interface $r_{sp2,}$ the temperature was increasing gradually for most of the cylinder height until almost *Ar*=75 % and then rapidly decreasing in the upper section.
4. It was also observed that the temperature along r_{sp2} was higher for increased outer wall thickness.
5. The average Nusselt number was found to be decreasing with increase in the wall thickness *DL* for thin outer wall thickness. However, for higher outer wall

thickness, the $\overline{N}u$ initially decreased with respect to *DL* and then increased with further increase in *DL*.

6. The increase in the conductivity ratio *Kr* reduced the heat transfer rate.
7. The effect of *Kr* was found to be diminished, as the solid wall thickness *DL* was increased. It is observed that the heat transfer rate decreased with increased *Krs.*

5.5 Study of conjugate double diffusion in a vertical porous cylinder

1. It was found that there was an increasing temperature trend along the solid porous interface, as the height of cylinder was increased for assisting flow.
2. Temperature along the domain in the radial direction was found to be increased with solid wall thickness.
3. Temperature gradient at the inner surface decreased with an increase in the solid wall thickness.
4. The concentration was increased along the height of the cylinder for assisting flow and decreased for opposing flow. However, the concentration was almost equal for assisting and opposing flows for *D*=75%.
5. At low conductivity ratio, the Nusselt number was decreased with increase in the solid wall thickness. However, at high conductivity ratio, Nusselt number was found to be increased with the thickness of the wall.
6. The average Sherwood number was initially decreased with increase in solid wall thickness until a certain thickness and then it increased with further increase in *D*.

5.6 Study of the effect of length and location of heater in a porous annulus: thermal non-equilibrium approach

1. The increased heater length at the bottom section of the annulus had a stronger effect on the fluid than the solid phase.
2. The average Nusselt number found to be decreased initially with an increase in *Kr* and then gradually increased at higher values of *Kr* for all the three lengths of the heater when it was placed at the center portion of the annulus.
3. The fluid moved in two separate segments when the heater length was 20% and placed at the top portion of the annulus.
4. The fluid cell moved from the lower part to occupy the whole annulus as the length of the heater was increased.
5. The average Nusselt number for 20% of heater length was found to be greater than that of 35% and 50% heater length, when placed at the centre of the annulus.

5.7 Investigation of mixed convection in a porous cylinder

1. It was observed that for aiding flow and 20%HL at the bottom of the annulus, the solid Nusselt number is higher than the fluid Nusselt number for Peclet numbers 0.1, 0.5 and 2.
2. For lower conductivity ratio, the heat transfer rate was higher with the Peclet number, whereas this trend reversed when thermal conductivity ratio was increased.
3. It was observed that distinctive trend of Nusselt number variation, for the heater placed at the middle of the annulus, compared to the heater placed at the bottom section of the annulus.

4. For the case of the heater placed at the top region of hot wall of the annulus, the heat transfer is dominated due to an increase in the applied velocity where as it is dominated by a buoyancy force when the heater placed at the bottom and middle section of a hot wall of the annulus.
5. It was observed that the applied velocity in the downward direction, in case of an opposing flow, does not allow the thermal energy to reach from a hot to a cold surface.

5.8 Achievements

The applicability of the current research in designing and optimizing air-conditioning ducts is an important finding that can be useful for the efficient thermal insulation of the thermally-sensitive space. With the results obtained, key factors such as enhancement and retardation of heat transfer rate can be achieved effectively in some specific industrial and research and development applications, such as overall thermal management of nuclear reactors, performance analysis and design optimization of heat exchangers and the thermal cooling system management in microelectronic cooling. Moreover, the various parametrical analysis pertinent to the mixed convection with segmental heating are key findings to understand better similar processes, such as that which occur in cooling towers in power plants and open lakes exposed to the atmosphere.

5.8 Recommendations for future work

- In future, the work pertaining to the porous media analysis can be extended to include conjugate heat transfer as well as conjugate heat and mass transfer in complex or irregular geometries fixed with a saturated porous medium.
- The magneto hydrodynamic effect on the heat transfer rate in various shapes and geometries embedded with saturated porous medium could also be explored.
- The viscous dissipation effect on the heat transfer rate in the case of forced convection and mixed convection, would add important knowledge to carry out various practical applications this area.
- The study of turbulent fluid flow under forced convection would help in understanding fluid behaviour in the human organs under varying temperatures and pressures
- The study of the moving porous material within the biomass gasifier would help in understanding the nature of the exothermic reactions in the gasifier.

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LIST OF PUBLICATIONS

1. **Salman Ahmed N.J**, Irfan Anjum Badruddin, Jeevan Kanesan, Z.A. Zainal, K.S. Nazim Ahamed. Study of mixed convection in an annular vertical cylinder filled with saturated porous medium, using thermal non-equilibrium model International Journal of Heat and Mass Transfer, Volume 54, Issues 17–18, August 2011, Pages3822-3825.(Q1)
2. Irfan Anjum Badruddin, Abdullah A.A.A. Al-Rashed, **Salman Ahmed N.J.** Sarfaraz Kamangar, K. Jeevan Natural convection in a square porous annulus International Journal of Heat and Mass Transfer, Volume 55, Issues 23–24, November,2012, Pages7175-7187. (Q1)
3. Irfan Anjum Badruddin, Abdullah A.A.A. Al-Rashed, **Salman Ahmed N.J**, SarfarazKamangar, Investigation of heat transfer in square porous-annulus International Journal of Heat and Mass Transfer, Volume 55, Issues 7–8, March 2012, Pages,2184-2192. (Q1)