Study of conjugate heat transfer for a magneto hydrodynamic fluid in a rectangular cavity with sinusoidal corrugation

A Thesis
By

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DEPARTMENT OF MECHANICAL ENGINEERING

SONARGAON UNIVERSITY

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The thesis entitled Study of conjugate heat transfer for a magneto hydrodynamic fluid in a rectangular cavity with sinusoidal corrugation was submitted by Md. Abu Horayra (ME-2002021029), MD.Nazrul Islam (ME2002021167), MD Mamun Hosen(BME2001020479) Md.Mehedi Hasan (BME2001020547) Md.Safiqul Islam(ME-2002021015)) Session: 2023-2024, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of B. Sc. in Mechanical Engineering on January 2024.

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DECLARATION

The complete description of the product that is submitted on this report is only organized by a group consisting of Md. Abu Horayra, Md. Nazrul Islam, Md. Mamun Hosen, Md. Mehedi Hasan and Md. Safiqul islam and it's far actual. Excerpts from others' work had been truly identified, their work stated in the textual content and indexed with inside the listing of references. The whole work such as all the Comsol Software, Techplot software ,Set up time Reduction, Cavity, pc programs, formulations, calculations, layout paintings, assumption and examined reviews on this record also are real and organized with the aid of using the equal institution of students.

Md. Abu Horayra MD.Nazrul Islam MD Mamun Hosen

Md.Mehedi Hasan Md.Safiqul Islam

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Keywords:

Comsol Software, Tecplot software, Set up time Reduction, Cavity, Manufacturing System

List of Tables and Figures

Chapter 1
Introduction

Conjugate natural convection heat transfer for an MHD fluid in rectangular cavity, with sinusoidal corrugation is a useful research prototype to deepen our insight into many important practical applications, such as solar energy collectors. But surprising, until now there is no open literature on it. The work is validated by three benchmark tests. we investigate the effects of heating ratio and Rayleigh number on conjugate natural convection heat transfer for an MHD fluid in rectangular cavity with sinusoidal corrugation for the first time. It is found that these factors all influence the patterns of flow field and temperature field significantly. Especially, there exist some critical values. A small offset from them will cause a substantial change of heat and mass transfer. Sometimes the change trends are completely reversed. The present results may provide useful theoretical guides for the relevant practical applications.

1.2 Conjugate Heat Transfer

Conjugate heat transfer involves simultaneously analyzing heat transfer in interacting solid and fluid domains. It's crucial in scenarios where temperature distribution in one medium affects the other. The analysis requires solving heat transfer equations in both the solid and fluid regions.

1.3 Magneto hydrodynamic Fluid

Magnetohydrodynamic (MHD) fluid refers to a conductive fluid, such as plasma or liquid metal, that interacts with a magnetic field. The movement of the conductive fluid induces electric currents, leading to complex interactions between fluid dynamics and electromagnetic forces. This phenomenon is studied in astrophysics, geophysics, fusion research, and certain engineering applications.

1.4 Darcy Number

The Darcy number is a dimensionless quantity used in fluid mechanics to characterize the permeability of porous media. It is defined as the ratio of the permeability of a substance to its viscosity.

$$Da=\frac{k}{d^2}$$

Where ,

K is the permeability of the medium.

D is the characteristic length of the particle.

1.5 Rayleigh number

Rayleigh Number: The Rayleigh number is defined as the ratio of buoyancy forces to viscous forces and is given by:

Da=$\frac{g\beta\Delta T L^3}{v\alpha}$

Here,

υ g is the acceleration due to gravity,

β is the thermal expansion coefficient,

ΔT is the temperature difference,

L is a characteristic length (related to the dimensions of the cavity),

ν is the kinematic viscosity, and υ α is the thermal diffusivity.

1.6 Nusselt number

The Nusselt number is the ratio of conductive resistance to the convective resistance.

Nu=$\frac{\text{RConduction}}{\text{RConvectio}}$

1.7 Hartmann Number

The Hartmann number (Ha) is the ratio of electromagnetic force to the viscous force.

Ha=BL $\sqrt{\frac{\sigma}{\mu}}$

where

B is the magnetic field intensity,

L is the characteristic length scale,

σ is the electrical conductivity,

μ is the dynamic viscosity.

1.8 Height Ratio

The height ratio of a semicircular cavity refers to the ratio of the height (vertical distance) of the cavity to the radius of the semicircular shape. In a semicircle, the height ratio is typically expressed as the height (h) divided by the radius (r).Mathematically, the height ratio (h/r) can be represented as:

Height Ratio (h/r) = $\frac{h}{r}$

1.9 Velocity Streamlines

The velocity streamlines in a semicircular cavity refers to the path traced by fluid particles within the cavity as they move with the flow. In a steady state situation, the streamline represents the direction and magnitude of the fluid velocity at different points within the cavity.

1.10 Isotherm in semicircular cavity

Isotherms in a semicircular cavity represent lines connecting points with the same temperature within the cavity. These lines provide a visual depiction of the temperature distribution. The specific pattern of isotherms depends on factors like the initial conditions, heat sources or sinks, and the thermal properties of the material.

Chapter 2

Literature Review

Natural convection in cavity is an important research prototype in thermal science and engineering as it can be used to deepen our insights into many practical applications, such as solar thermal receivers, building ventilation and energy saving [1], [2], [3]. Until now there have been numerous publications on this topic. On experimental exploration, recently Montiel-Gonzalez et al. [4] revealed the effects of natural convection and thermal radiation on a solar open rectangular cavity-type receiver. The authors observed that variable thermophysical properties of working fluid would influence the results significantly. Natural convection in a horizontal open-ended axisymmetric cavity was investigated experimentally by the holographic interferometry technique [5]. The investigators mapped the isotherms as a function of the temperature on the hot wall and the cavity spacing. Heat transfer in an open-ended vertical eccentric enclosure was reported in [6]. Through analyzing their experimental data, the authors found that the heat transfer coefficient did not change monotonically with the eccentric ratio. Meanwhile, numerical efforts were also carried out. Natural convection of Al_2O_3-water nan fluid in an open-ended enclosure was numerically investigated in [7]. The purpose of [7] was to reveal the influence of magnetic force on heat transfer of nan fluid in an open-ended cavity. Marangoni convection in an open-ended cavity was numerically simulated by Saleem et al. [8]. The authors discussed the effect of thermo capillary forces on natural convection. They also carried out entropy generation analysis. Mohamad et al. [11] studied the influence of aspect ratio on natural convection in open-ended cavities. The numerical results showed the rate of heat transfer deceases asymptotically against increasing of aspect ratio. In [9], the authors considered the scenario where an open-ended cavity was completely filled by porous media. The effects of porosity and permeability of porous media on natural convection were investigated numerically. Botcher and Sparrow [10] compared some available numerical techniques and stressed the importance of appropriate boundary conditions. Only a few latest studies on this topic are cited here as the total number of the relevant literature is very huge. Through the above literature survey, it is clear that until now there is no open publication on conjugate natural convection heat transfer in for an MHD fluid rectangular cavity, with sinusoidal corrugation although it is important in energy engineering and Mechanical engineering. The purpose of the present work is to bridge such gap.

Chapter 3
Methodology

3.1 Comsol Software: The COMSOL Multiphysics approach starts with first principles like transport phenomena, electromagnetic field theory, and solid mechanics as the basic fibers of the software. Then, we can weave these fibers together in a self-consistent way to solve our particular simulation needs. The Model Builder in COMSOL Multiphysics® provides us with a complete simulation environment and a consistent modeling workflow from start to finish, regardless of the type of design or process we wish to analyze and develop. The modeling workflow encompasses: Geometry and CAD. Physics-based modeling.

3.2 Techplot software : It's essential that we have the right tools to handle large data sets, automate workflows, and visualize parametric results. Integrate XY, 2D, & 3D plots and get them looking exactly the way we want. Communicate our results with brilliant images and animations. Data files read by Tecplot may be binary or ASCII. The following sections describe the format of ASCII data files. Reading an ASCII data file into Tecplot can be much slower than reading a binary data file, as binary data files take up less disk space and Tecplot must convert from ASCII to binary.

Data Import and Compatibility: Tecplot supports a wide range of data formats, allowing users to import data from various sources such as simulation codes, CAD software, and experimental measurements.

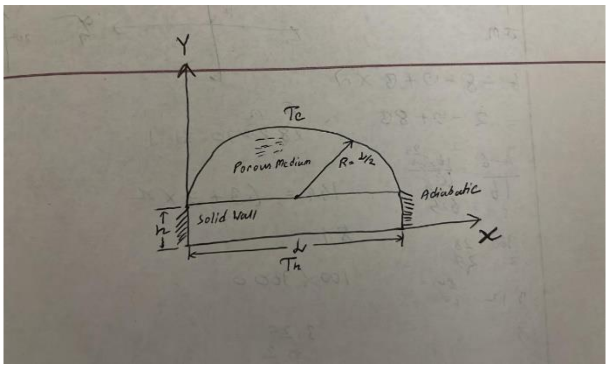
2D and 3D Plotting: Users can create high-quality 2D and 3D plots to visualize scalar and vector field data. This includes contour plots, surface plots, vector plots, streamline plots, and more.

Data Analysis Tools: Tecplot offers tools for analyzing and manipulating data, including data extraction, averaging, integration, and filtering. Users can perform quantitative analysis to extract important information from their datasets.

Automation and Scripting: Tecplot provides scripting capabilities, allowing users to automate repetitive tasks and create custom scripts for specific analyses. This can be particularly useful for batch processing and customization.

Publication-Quality Output: Tecplot allows users to generate high-resolution, publication-quality images and animations for presentations and reports.

3.3 Description of physical problem:



Upper wall is kept at cold temp Tc, the bottom wall is kept at hot temp Th. the side walls are insulated. the cavity is full with fluid saturated porous medium, the bottom wall is a solid wall.

3.4. Governing equations

For present model, we have considered a steady, MHD, viscous, incompressible flow in xy – coordinate system. Further we are considering that channel is filled with porous medium and motion of the fluid depending upon Darcy’s law, which produce for the drag exerted by the porous medium. The viscous dissipation effect is neglected and system of governing partial differential equation depends upon continuity equation under the law of conservation of mass, momentum and energy equations:

$$\frac{\partial U}{\partial X} + \frac{\partial v}{\partial y} = 0 \quad \ldots\ldots(1)$$

$$\rho\left(\cup\frac{\partial U}{\partial X} + V\frac{\partial U}{\partial V}\right) = -\frac{\partial P}{\partial X} + \mu\left(\frac{\partial^2 U}{\partial X^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{\mu}{K}U, \quad \ldots\ldots(2)$$

$$\rho\left(\cup\frac{\partial V}{\partial X} + V\frac{\partial V}{\partial V}\right) = -\frac{\partial P}{\partial Y} + \mu\left(\frac{\partial^2 V}{\partial X^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\mu}{K}V - \sigma{\beta_0}^2 V + g\rho\beta(T^0 - T_c), \quad \ldots\ldots(3)$$

$$\left(U\frac{\partial T^0}{\partial X} + V\frac{\partial T^0}{\partial y}\right) = x\left(\frac{\partial^2 T^0}{\partial X^2} + \frac{\partial^2 T^0}{\partial y^2}\right) \quad \ldots\ldots(4)$$

Chapter 4

Validation

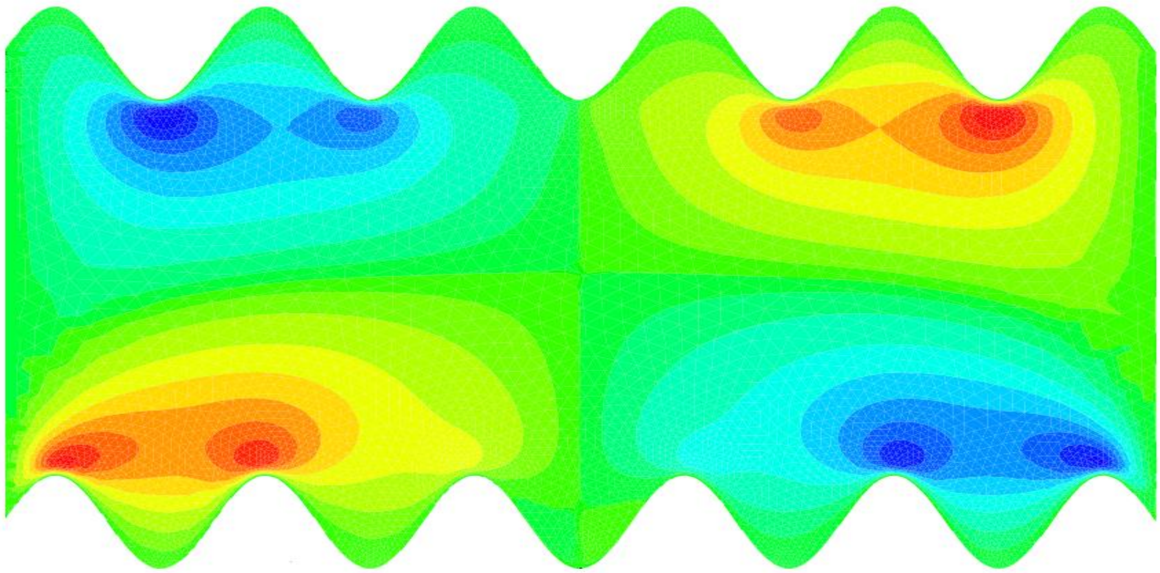


Fig. 01

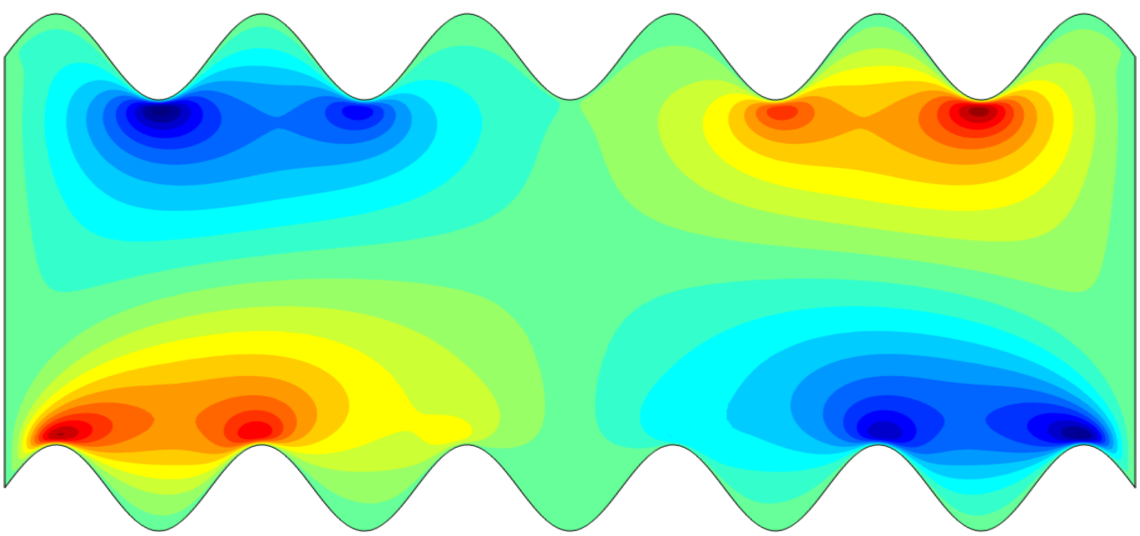
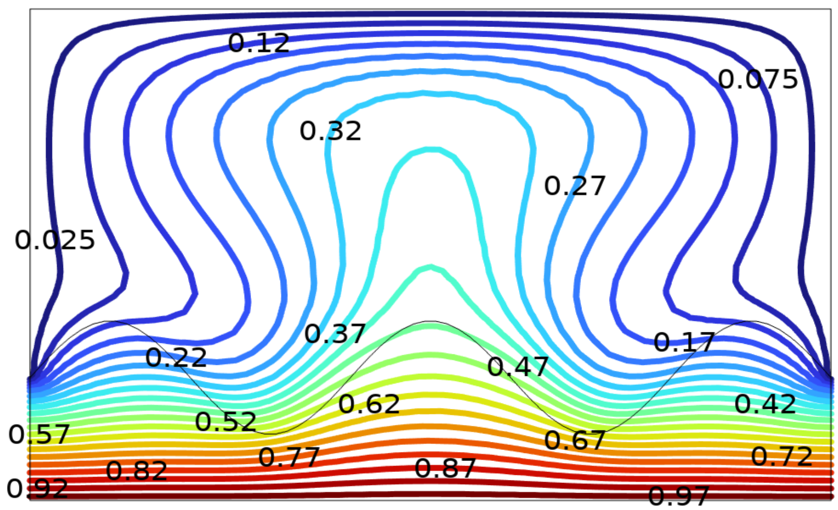


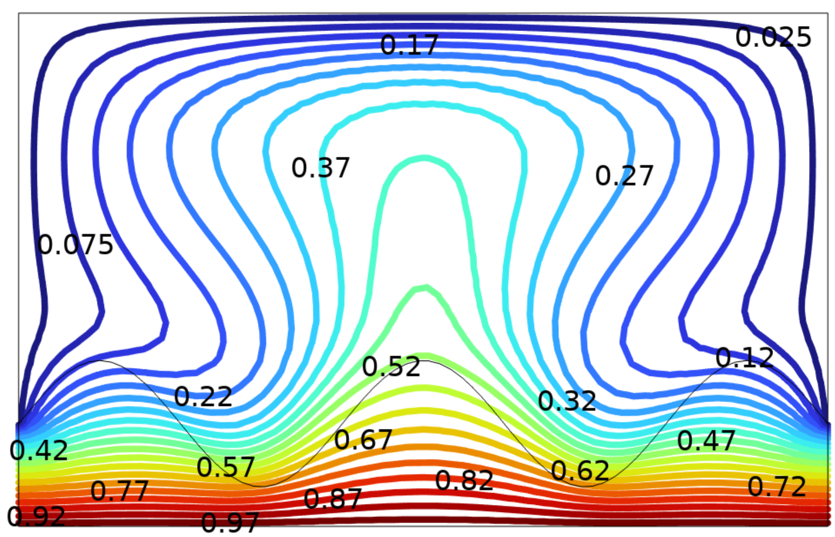
Fig.02

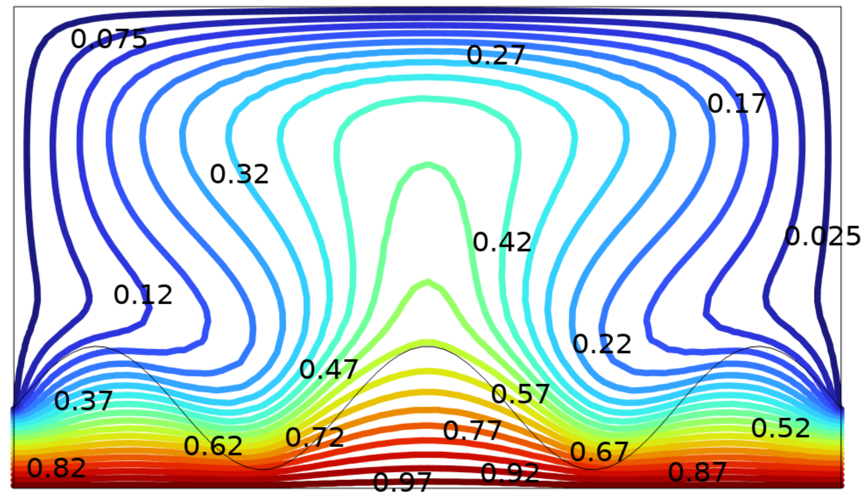
To verify the trustworthiness of any mathematical model and the associated simulation tool, any previously published studies have to be evaluated with the current simulation technique. Hence, the current methodology is validated using the results of Haq et al. [45]. From the figure 4.5.1, data suggests incredible agreement between the published result and the present methodology of work

Velocity (u) had been determined for $Ra = 10^4$ when $Pr = 6.2$, $Ha = 10$, and $Da = 10^{-4}$

Chapter 5
Results and Discussion



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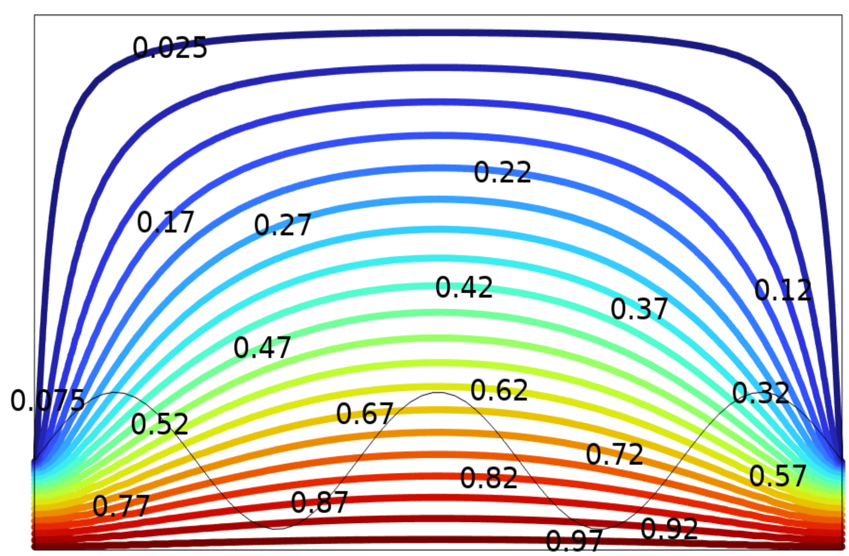
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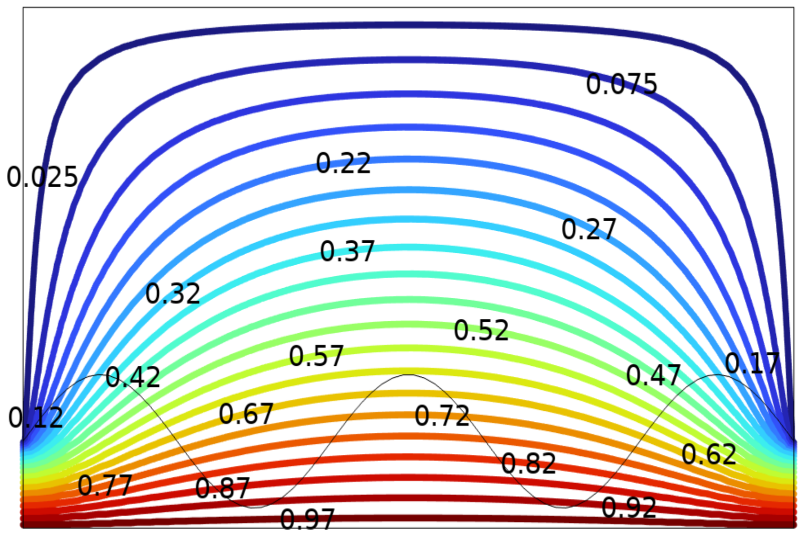
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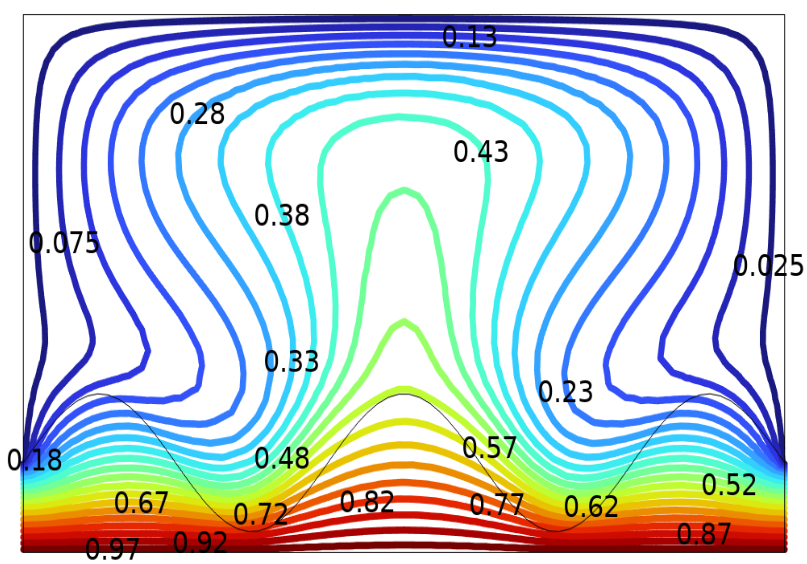
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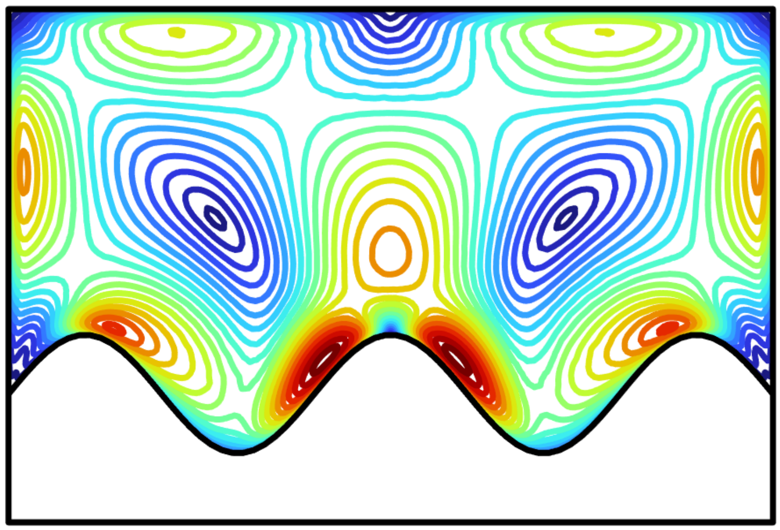

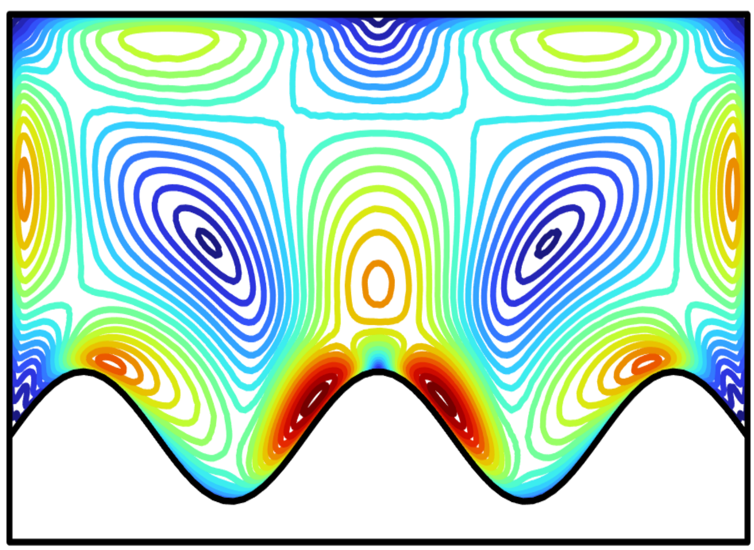

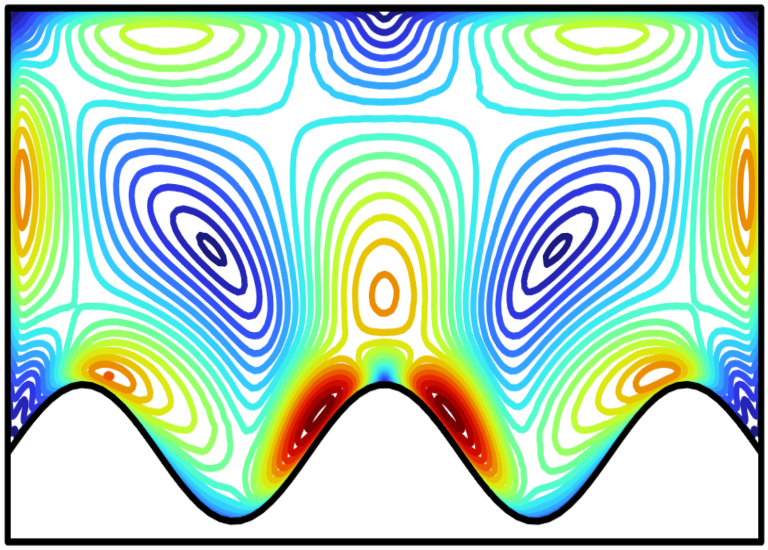

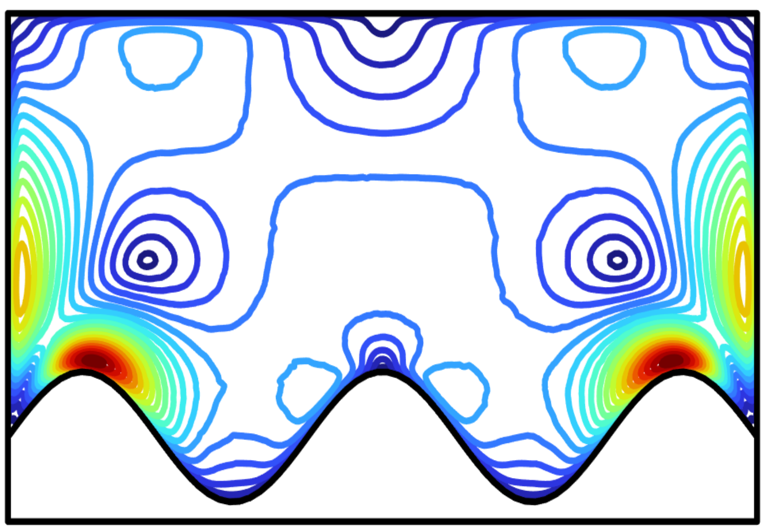

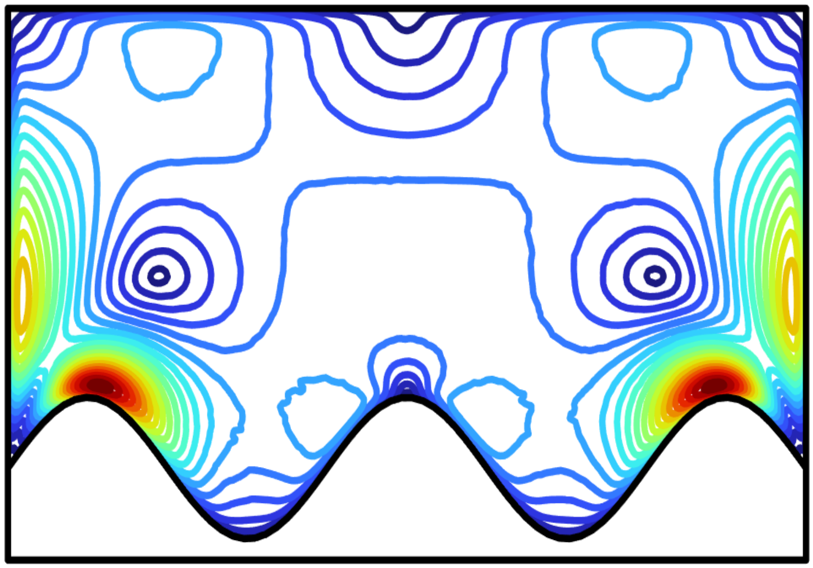

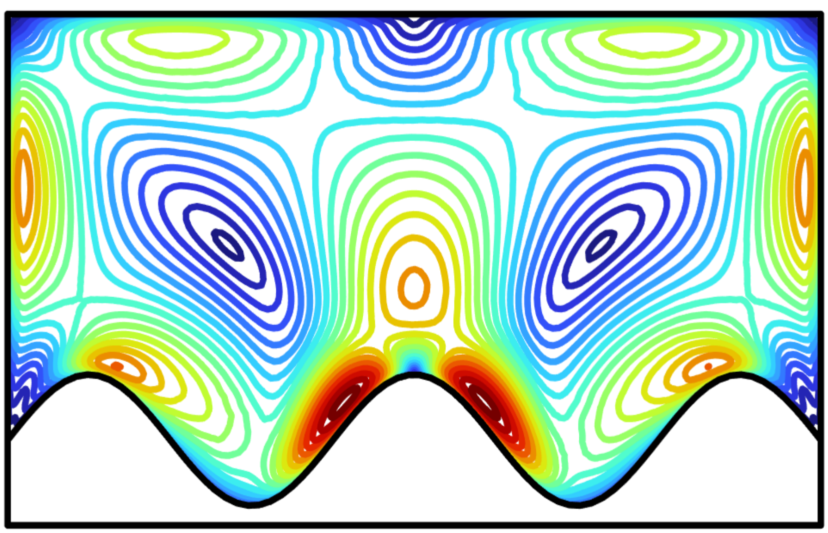

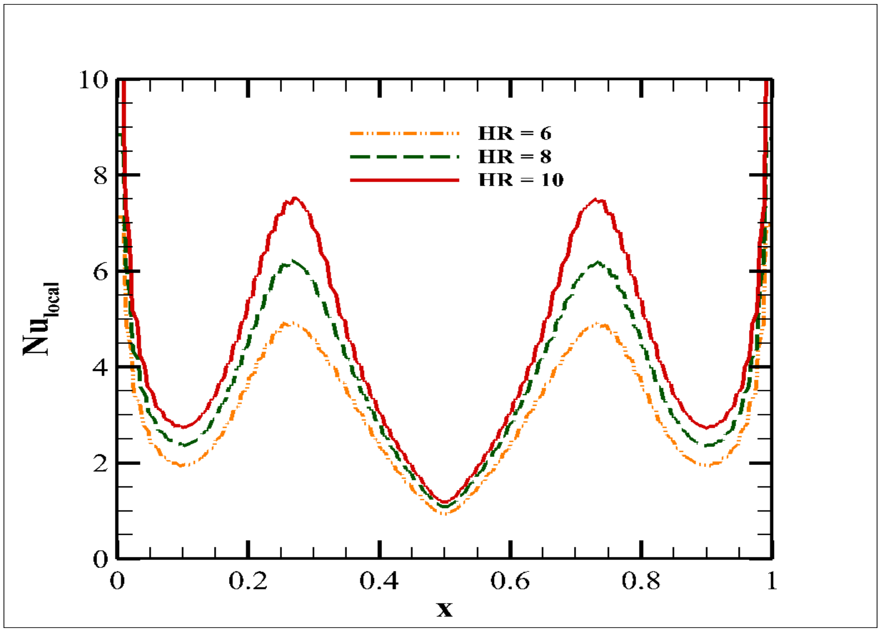

10
8
6
4
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0
0
0.2
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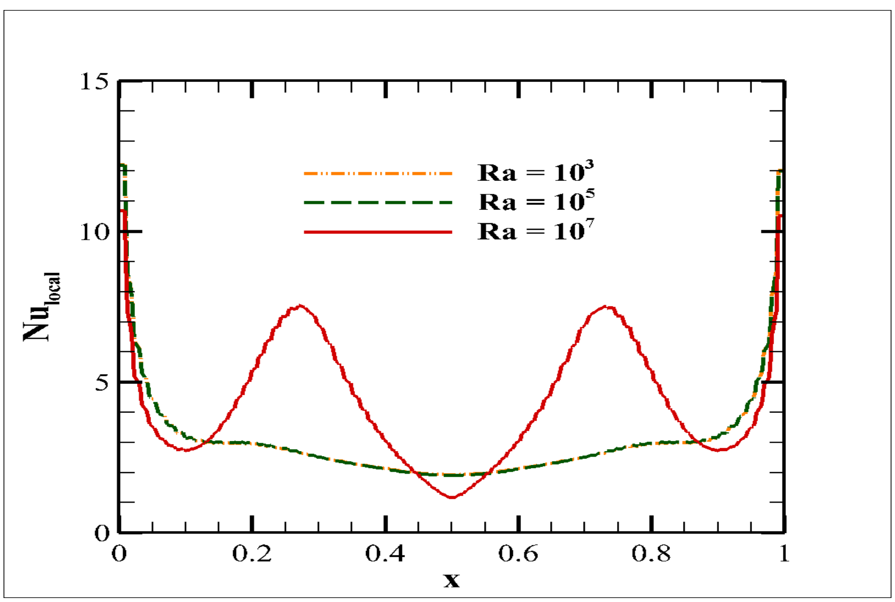
0.6
0.8
1
x
Nu_local
HR = 6
HR = 8
HR = 10



15
10
5
0
0
0.2
0.4
0.6
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1
x
Nu_local
Ra = 10^3
Ra = 10^5
Ra = 10^7

Rayleigh number: In a rectangular cavity, the relationship between heat transfer and the Rayleigh number (*Ra*) is associated with the influence of natural convection. The Rayleigh number is defined as the ratio of buoyancy forces to viscous forces and given by

$$Ra = \frac{g\beta\Delta T L^3}{V\alpha}$$

- g is the acceleration due to gravity
- β is the thermal expansion coefficient,
- ΔT is the temperature difference
- L is a characteristic length (related to the dimensions of the cavity),
- ν is the kinematic viscosity, and
- α is the thermal diffusivity

When the Rayleigh number increases in a rectangular cavity, it signifies a higher ratio of buoyancy forces to viscous forces. This higher Ra leads to more pronounced natural convection currents within the fluid inside the cavity. The fluid movement becomes more vigorous, enhancing the heat transfer process.

The increased fluid motion, driven by buoyancy forces, facilitates better mixing of the fluid and more efficient transfer of heat between the heated surfaces (such as the cavity walls) and the fluid. Consequently, the overall heat transfer rate from the walls to the fluid increases with an increasing Rayleigh number in a rectangular cavity.

In summary, as the Rayleigh number increases in a rectangular cavity, the associated enhancement in natural convection leads to increased fluid movement, resulting in improved heat transfer within the cavity.

Heat Transfer rate (HR) :The heat transfer rate through a rectangular cavity depends on various factors, including the thermal conductivity of the material, the temperature difference across the walls, and the wall thickness. According to Fourier's Law for conduction, the heat transfer rate (Q) through a wall is given by:

$$Q = \frac{k.A.\Delta T}{d}$$

- k is the thermal conductivity of the material,
- A is the cross-sectional area through which heat flows,
- ΔT is the temperature difference across the wall, and
- d is the thickness of the wall.
- Assuming other factors remain constant, a decrease in wall thickness () generally leads to an increase in the heat transfer rate (Q). Thinner walls provide less resistance to heat flow, allowing for more efficient conduction and a higher heat transfer rate.

It's important to note that this explanation holds for the scenario where conduction is the dominant mode of heat transfer through the walls of the rectangular cavity. If the cavity involves natural convection or other heat transfer mechanisms, the relationship between wall thickness and heat transfer rate can become more complex, and factors like fluid flow patterns may also come into play. In such cases, detailed numerical simulations or experiments may be necessary to fully understand the heat transfer behavior.

Chapter 6

Conclusion and Future Recommendation.

Conclusion:

Numerical Study of conjugal heat transfer for a magneto hydrodynamic fluid in a rectangular cavity with a heat conducting solid body has been performed under the influence of different orientations of the applied magnetic field. Governing equations formulated in dimensionless primitive variables with appropriate boundary conditions have been solved by finite volume method.

The simulations have revealed intricate flow patterns and temperature distributions within the corrugated cavity, highlighting the impact of both natural convection and magnetic field interactions

The inclusion of magneto hydrodynamic effects has showcased their influence on fluid flow and temperature distribution, providing a nuanced understanding of how magnetic fields alter convective heat transfer.

The numerical model has been validated against available analytical solutions or experimental data, establishing its reliability for predicting natural convection phenomena in corrugated cavities with porous media and magnetic fields.

Future Recommendations:

While this study has provided valuable insights, several avenues for future research and improvement emerge:

Extended Parametric Studies:

Conduct further parametric studies, exploring a broader range of values for parameters such as wavelength, Rayleigh number, Darcy number, and Hartmann number. This will enhance the understanding of the system's response to varying conditions.

Advanced Numerical Techniques:

Investigate the application of advanced numerical techniques or alternative simulation approaches to further improve the accuracy and computational efficiency of the model.

Experimental Validation:

Consider experimental validation to corroborate the numerical findings and provide a more comprehensive assessment of the model's accuracy under real-world conditions.

Incorporation of Nanofluids:

Extend the study to include nanofluids within the porous medium, exploring how the addition of nanoparticles influences natural convection and heat transfer.

Real-World Applications:

Explore practical applications of the research findings, particularly in the optimization of energy usage, design of efficient thermal systems, and development of sustainable technologies.

Further Magneto hydrodynamic Studies:

Delve deeper into magnetohydrodynamic effects by considering varying magnetic field strengths and orientations, offering a more comprehensive understanding of their impact.

Multiscale Modeling:

Consider adopting multiscale modeling approaches to capture finer details at the microscopic level within the porous medium, providing a more accurate representation of real-world scenarios.

This thesis lays the groundwork for further exploration and refinement in the understanding of natural convection phenomena in complex geometries, paving the way for advancements in heat transfer research and applications.

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(One or more pages as required. Make sure all references are completed, including as necessary and in the following order: last name and initials of all authors, year of the publication, title of paper or book, name of periodical, volume number, issue number, publisher, city and state or nation of publication, and inclusive page numbers. Arrange all references alphabetically)

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