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E-BOOK OF EXTENDED ABSTRACTS

MIXED CONVECTIVE FLOW OF NEWTONIAN FLUID IN CORRUGATED CHANNEL WITH MAGNETIC FIELD EFFECTS

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ABSTRACT

This paper investigates the effects of magnetic fields and undulation number on the velocity and temperature profiles of a viscous fluid in a sinusoidal-corrugated channel. The continuity equation, momentum equation, and energy equation will be transformed into their weak formulation and will be solved numerically with the help of the automated solution technique FEniCS. The velocity and temperature profiles will be plotted and discussed. It is observed that increasing the undulation number leads to a boost in the velocity and the temperature profiles. Additionally, it is found out that there is a decrease in the velocity profile with the amplification of the magnetic field. However, the amplification of the magnetic field shows no significant impact to the temperature profile.

Keywords: MHD, Wavy Channel, Undulation Number, Finite Element Method, FEniCS

INTRODUCTION

Fluid dynamics is a branch of fluid mechanics that specialised in the fluids motion. The fluids movement can be represented with the Navier-Stokes equations. Additionally, magnetohydrodynamics (MHD) has been extensively studied in fluid dynamics. MHD is a study on the electrically conducting fluid with the presence of magnetic field (Jalili et al., 2024). FEniCS is an open-source computing platform for solving partial differential equations using the finite element method. Hence, this study aims to investigate the influence of the magnetic field as well as the undulation number with the presence of a magnetic field on the velocity and the temperature profiles of a viscous fluid within a sinusoidal-corrugated channel with the help of automated solution technique FeniCS.

Alharbi et al. (2025) mentioned that amplifying the Hartmann number decreases the flow velocity due to the Lorentz force retarding the flow. Moreover, A study by Alsabery et al. (2022) reported that the increment of the undulation number of the wavy surfaces led to the formation of the recirculation zone within the channel crests. They discovered that the presence of the waviness allows the fluid to excalate and it is supported by Madlool et al. (2023). In this research, the governing equations proposed by Iwatsu et al. (1993) alongside the boundary conditions modified from Madlool et al. (2023) will be employed and will be solved numerically with the help of the automated solution technique FEniCS.

METHODOLOGY

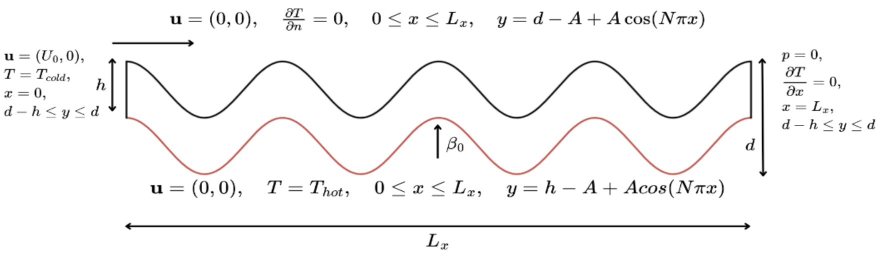


Figure 1: Configuration with Boundary Conditions

The dimensionless governing equations consisting of continuity equation (1), momentum equation (2), and energy equation (3) are:

$$\nabla \cdot u = 0 \tag{1}$$

$$(u \cdot \nabla)u = -\nabla p + \frac{1}{Re}\nabla^2 u + Ri \cdot Te - Mu \tag{2}$$

$$u \cdot \nabla T = \frac{1}{Pr\ Pr\ Re}\nabla^2 T \tag{3}$$

With boundary conditions modified from Madlool et al. (2023):

At the lower wavy surface:

$u = (0,0), \quad T = T_{hot}, \quad 0 \leq x \leq L_x, \quad y = h - A(1 - cos\ cos\ (N\pi x)\ )$

At the cold inlet left surface:

$u = (U_0, 0), \quad T = T_{cold}, \quad x = 0, \quad d - h \leq y \leq d$

At the adiabatic upper wavy surface: (4)

$u = (0,0), \quad \frac{\partial T}{\partial n} = 0, \quad 0 \leq x \leq L_x, \quad y = d - A(1 - cos\ cos\ (N\pi x\ ))$

At the adiabatic outlet right surface:

$p = 0, \quad \frac{\partial T}{\partial x} = 0, \quad x = L_x, \quad d - h \leq y \leq d$

where $u = (u_x, u_y)$ is the velocity, T is the temperature, p is the pressure, Re is the Reynolds number, Ri is the Richardson number, Pr is the Prandtl number, M is the magnetic parameter, $e = (0,1)$ is a unit vector in the direction of the buoyancy force, β_0 is the magnetic field, A is the wavy wall amplitude, and N is the undulation number or wavy surfaces.

In the pre-processing part, we import all the necessary FEniCS libraries, then we generate a mesh based on the wavy channel geometry. After that, we create a finite element space with three elements. Afterwards, we define the test functions and trial functions and identify the boundary conditions in Fig. 1. In the processing step, we will transform the equations (1), (2), and (3) into their weak formulation using the standard Galerkin method by multiplying the equations with their respective test functions and integrating over the domain, Ω (Larson & Bengzon, 2013), as follows:

$$\int_{\Omega} (\nabla \cdot u) q \, dx = 0 \tag{5}$$

$$\int_{\Omega} (u \cdot \nabla) u \cdot v \, dx - \int_{\Omega} p(\nabla \cdot v) \, dx + \int_{\Omega} \frac{1}{Re} (\nabla u \cdot \nabla v) \, dx - \int_{\Omega} Ri \cdot T(e \cdot v) \, dx + \int_{\Omega} M(u \cdot v) \, dx = 0 \tag{6}$$

$$\int_{\Omega} (u \cdot \nabla T) s \, dx + \int_{\Omega} \frac{1}{PrPr\ Re} (\nabla T \cdot \nabla s) \, dx = 0 \tag{7}$$

Equations (4), (5), and (6) will be coupled together and will be solved based on the Newton-Raphson method (Logg et al., 2012). In the post-processing part, the velocity and the temperature profiles will be plotted and discussed. The computation will be executed, and the Richardson number, Prandtl number, inlet velocity, Reynolds number, T_{cold}, and T_{hot} are set to 1, 7, (0.5,0), 100, 0.01, and 1 respectively.

RESULTS AND DISCUSSION

In Figure 2, displays the velocity (left) and the temperature (right) profiles for different magnetic parameters with constant undulation number, $N = 4$, and wavy wall amplitude, $A = 0.1$. From Figure 2(a), it can be seen that the maximum magnitude for velocity decreases as the magnetic field becomes stronger due to the Lorentz force delaying the flow. However, Figure 2(b) shows that the temperature profiles exhibit the same behavior as we increase the magnetic parameter, indicating that there is no significant impact to the flow.

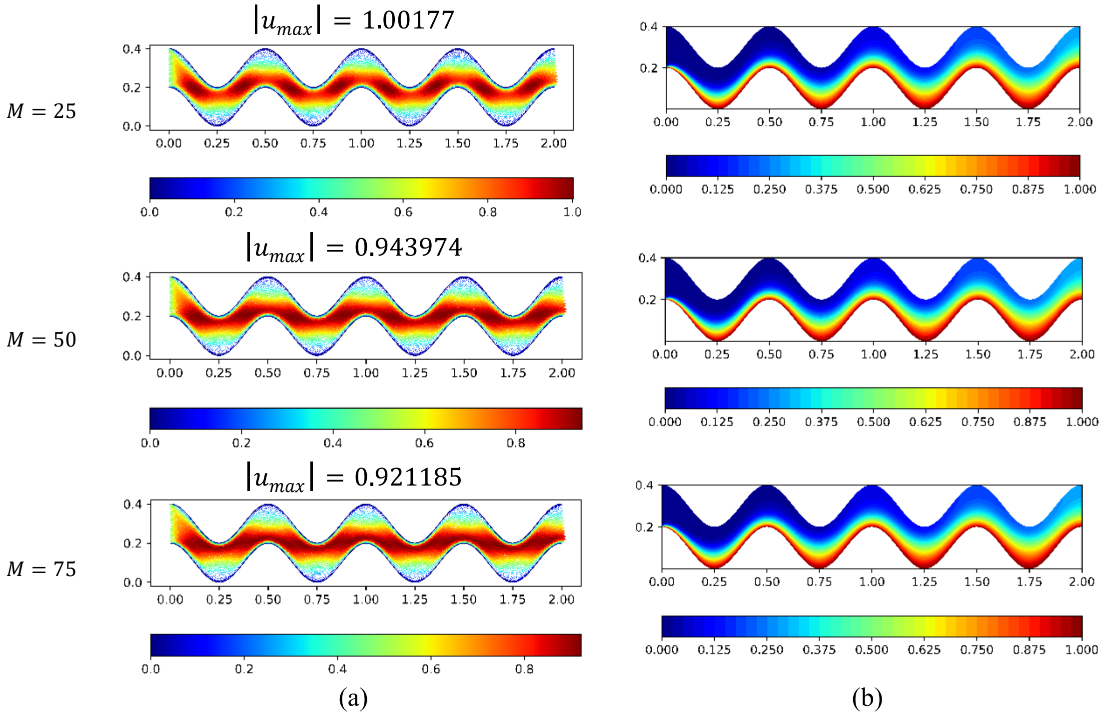
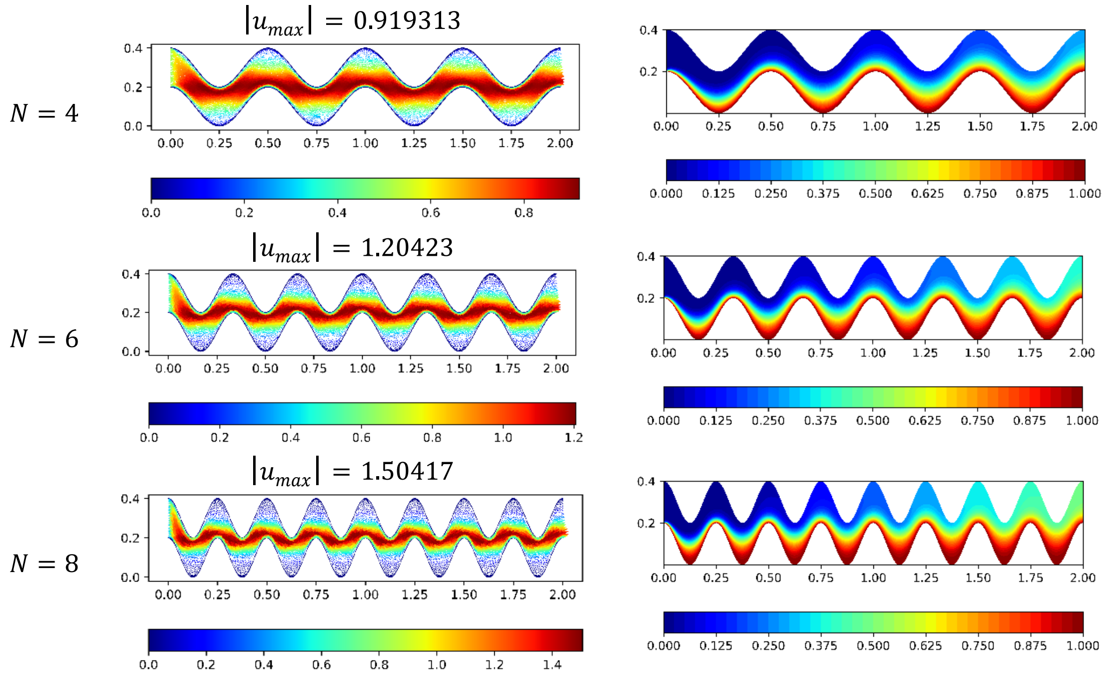


Figure 2: Velocity (a) and Temperature (b) Profiles with Different Magnetic Parameter

Figure 3 presents the velocity (left) and temperature (right) profiles with variation of undulation number with constant magnetic parameter, $M = 80$ and wavy wall amplitude, $A = 0.1$. Based on Figure 3(a), it is unveiled that the recirculation zone appeared at the wavy walls' crests, and it became larger as the undulation number increased. Moreover, the maximum value of the velocity magnitude rises as the undulation number increases. Based on Figure 3(b), it is revealed that the fluid is starting to get warmer at the right side of the channel for all N. However, at $N = 6$, the fluid starts to become warmer at around $x = 1.5$, in contrast to the flow at $N = 8$, where the fluid becomes warmer starting at around $x = 1.25$. This shows that there is a growth in the fluid-walls interaction, thus enhancing the friction between the walls and the fluid.



(a) (b)

Figure 3: Velocity (a) and Temperature (b) Profiles with Different Undulation Number of Wavy Surfaces

CONCLUSION

Numerical investigation of MHD mixed convective flow of viscous fluid in a sinusoidal-corrugated channel was performed using the finite element method with the help of the automated solution technique FEniCS. This study discovered that amplifying the magnetic field results in the reduction of the velocity profile due to the Lorentz force. However, the increment of the magnetic field shows no significant impact to the temperature profile. Moreover, the increment of the undulation number of wavy surfaces led to the enlargement of the recirculation zone at the crests of the channel and causes a boost in the velocity and the temperature profiles. A more detailed analysis including the effects of different Richardson number and wavy amplitude has been submitted for publication in Revelation and Science.

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