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Numerical investigation of PbLi17 fluid flow forced convection heating under magnetic field

Murat Erdem[1]*, Yasin Varol[2]

1 Vocational School of Technical Sciences, Firat University, Elazig, Turkey
2 Department of Automotive Engineering, Technology Faculty, Firat University, Elazig, Turkey

This study is concerned with the numerical investigation of flow characteristics of PbLi17 fluid in a pipe under a magnetic field. The magnetic field is applied perpendicularly to the pipe. Magnetic field forces have selected as B=0, 0.075 and 0.15T, but at constant Re number (1000). The temperature of the pipe is greater than the temperature of the fluid. The analysis has performed with ANSYS Fluent commercial software. The numerical results obtained are consistent with the literature. As a result, it has been observed that the magnetic field reduces the flow velocity of PbLi17 fluid, but increases the pressure and heat transfer.

Keywords: Magnetohydrodynamics, CFD, forced convection, PbLi17

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Corresponding authors: Tel.: +90 424 237 0000 ext. 7252; Fax: +90 424 236 7064

muratrdm01@gmail.com , yvarol@gmail.com

1. Introduction

Magnetohydrodynamics (MHD), associated with heat transfer and fluid flow characteristics, have received considerable attention for the last decades since there is a growing interest in understanding the underlying physical processes occurring. This is due to their wide variety of applications in engineering applications, such as crystal growth in liquid, cooling of a nuclear reactor, electronic package, microelectronic devices, and solar technology. There has been an increasing interest to understand the flow behavior and the heat transfer mechanism of enclosures that are filled with electrically conducting fluids under the influence of a magnetic field strength [1-5]. Some authors have done some studies on this.

Ellahi [6] studied some effects of MHD and temperature-dependent viscosity on the flow of a non-Newtonian nanofluid in a cylindrical channel for some analytical solutions. It has illustrated the effects of various physical parameters on velocity, temperature, and nanoparticles concentration, which have been discussed by using a graphical approach. It has been claimed that Homotopy Analysis Method (HAM) provides us with a convenient way to control the convergence of approximation series; that is a fundamental difference between the HAM and other methods for finding an approximate solution. When the flow field is under magnetic field forces, the heat transfers and fluid flow analysis in a straight channel utilizing nano-fluid have numerically been investigated by Heidary et al. [7]. They analyzed the effect of different Hartmann numbers and Reynolds numbers on the Nusselt number (Nu). It has been stated that the Ha number has increased significantly the Nu number. With relation to the subject, Rahimi - Gorji et al. [8] examined the heat transfer and fluid flow analysis for a nanofluid in a fin-shaped microchannel. Erdem [9], was studied experimentally and numerically the fluid motion and heat transfer by applying external magnetic field strength to different fluid types in a pipe. In his study, it has been tried both the cooling and heating parameters. It has been stated that the magnetic field force applied reduces the velocity of the fluid but increases the pressure and heat transfer. Erdem et al. [10] investigated the behavior of the fluid by applying an external magnetic field to liquid lithium fluid in a circular channel. Here, the liquid lithium has been cooled. Authors have stated that the magnetic field has a significant effect on fluid movement and temperature. Also, Hatemi et al. [11], Sheikholeslami et al. [12], Hatemi et al. [13] and Mahmoudi et al. [14] studied the behavior of various nanofluids under magnetic field strength.

This study aims to investigate the flow and temperature behavior of PbLi17 liquid metal during heating in a circular tube under a magnetic field. The findings obtained in this context are discussed in the graphics.

2. Experimental details

The mesh quality data of the used geometry is given in Table 1. The orthogonal quality of the mesh structure is an appropriate value. This value increases the quality as it approaches number 1. The boundary conditions of the problem are presented in Table 2. The thermophysical properties of the $Pbli^{17}$ fluid are obtained from Ref. [15].

Table 1: Mesh quality data

Mesh size (m)	0.0005
Mesh element number	280825
Orthogonal quality	0.9871
Standard deviation	3.354e-002
Size function	Uniform

Table 2: Boundary conditions

Ti (K)	573
Two (K)	773
To (K)	293
U (m/s)	0.0185

The 3D cylindrical channel (pipe) used in this numerical study has given in Figure 1. The pipe is under the influence of a magnetic field externally. Fluid temperature and pipe temperature are different. The pipe temperature is greater than the fluid temperature (Tw>Ti), and the fluid passes through the pipe in laminar conditions. Also, the pipe has a finite thickness. The mesh structure is shown in Figure 2, and the mesh type is quadratic.

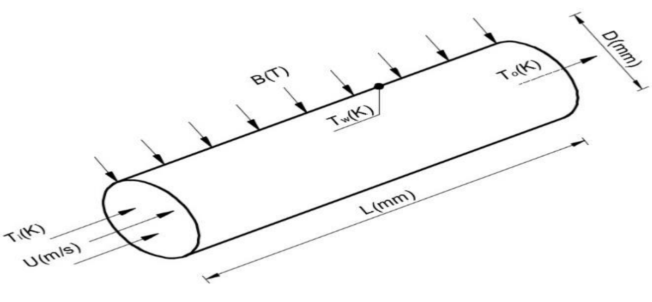


Fig. 1: The pipe model

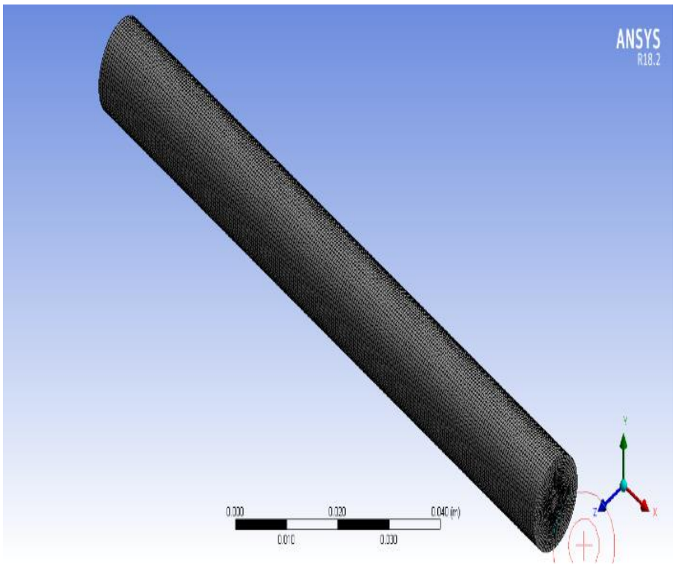


Fig. 2: Grid structure

Analysis has been performed via the momentum Eq. (1), Ohm law Eq. (2), continuity Eq. (3), and energy Eq. (4). Calculations have performed using ANSYS-Fluent commercial software programmer [16].

$$\rho * (U.\nabla)U = -\nabla P + \mu * \Delta U + [j\text{x}B] \quad (1)$$

$$j = \sigma * [E + U\text{x}B] \quad (2)$$

$$\nabla . U = 0 \quad (3)$$

$$\rho * c_p * (U.\nabla)T = k * \Delta T + \frac{j^2}{\sigma} + W_f \quad (4)$$

3. Results and discussion

In this study, the magnetic field on the $PbLi^{17}$ fluid metal effect has been investigated. The results are discussed.
Figure 3 shows local velocity profiles of $PbLi^{17}$ fluid flow along the pipe diameter. As can be seen from the figure, the magnetic field has significantly reduced the velocity of the fluid. The decrease in fluid velocity is due to the retarding effect of the Lorentz force. The maximum velocity values obtained are V = 0.029, 0.0255 and 0.0224 m/s for B = 0, 0.075 and 0.15T, respectively. Also, local velocity profiles along the pipe center (X=0–120 mm) are depicted in Figure 4. Here, the velocity changes along the tube center are similar to Figure 3. The maximum velocity values are identical to Figure 3. No fluctuations are observed in the velocity curves in both Figures.

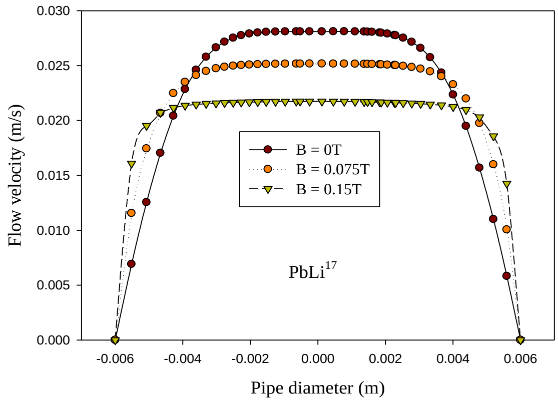


Fig. 3: Local velocity profiles of the pipe diameter

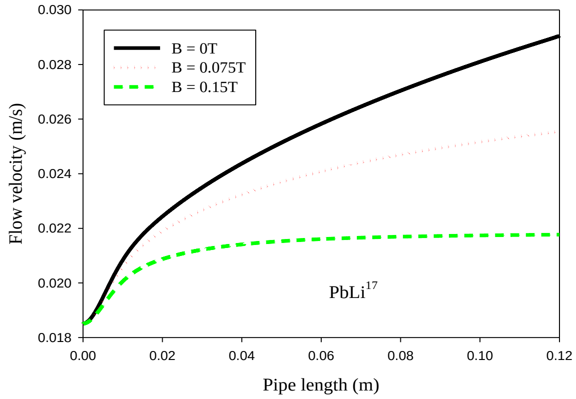


Fig. 4: Local velocity profiles along the pipe center

Pressure variations along the pipe center of PbLi[17] liquid metal are presented in Figure 5 (X = 0 – 120 mm). Values have been obtained for two different magnetic field strengths and in the absence of a magnetic field. It is clear from the Figure that the pressure values have increased with the magnetic field forces. There is no fluctuation in the pressure values along the center length of the channel. In the selected reference value (B = 0T), the pressure value is approximately P = 2.5. For B = 0.075 and 0.15T, the resulting pressure values are approximately P = 8 and 27 Pa, respectively.

Temperature variations along the pipe diameter are given in Figure 6. As can be seen from the figure, the temperature along the diameter for all magnetic field strengths has reduced.

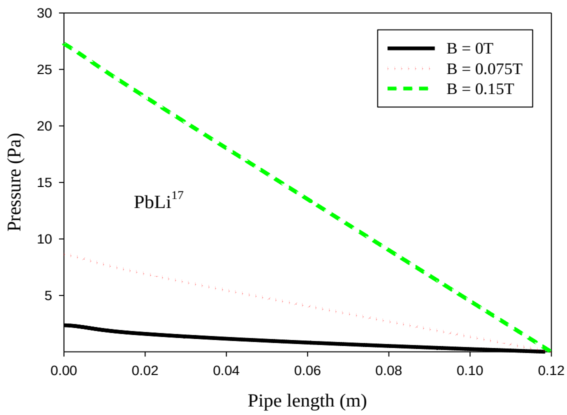


Fig. 5: Pressure changes along the pipe center

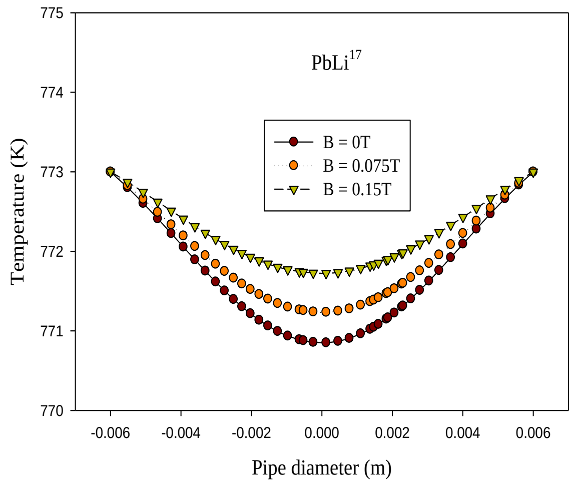
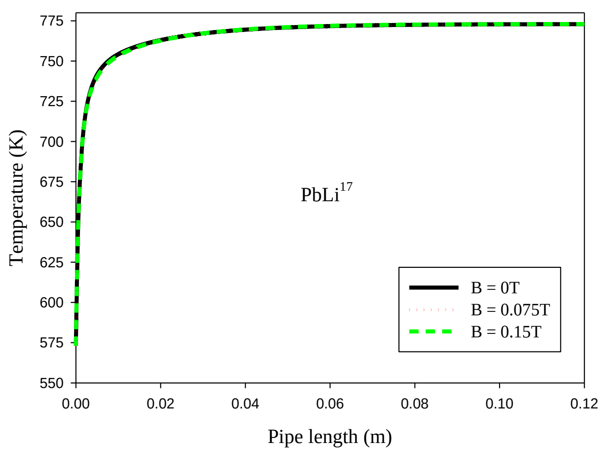


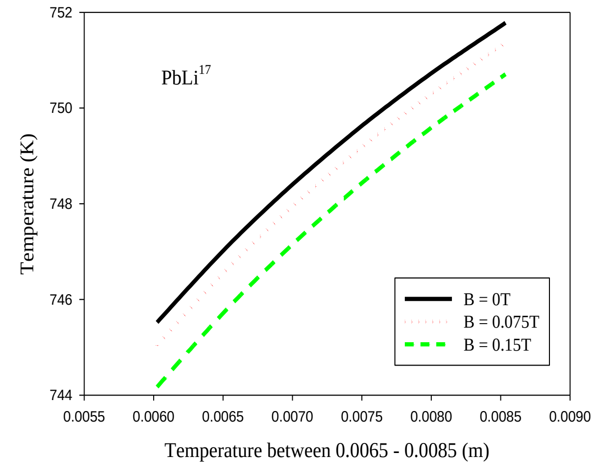
Fig. 6: Temperature changes along the pipe diameter

Temperature comparisons at a distance of 0.5 mm from the wall are shown in Figure 7 (a) and Figure 7 (b). Figure 7 (a) shows all the temperature values, but Figure 7 (b) represents a certain range to see the change more clearly (the between 0.0060 and 0.0085 m). The change in Figure 7 (a) is barely understood. However, in Figure 7 (b), the difference is much more obvious. It has been determined that from these figures the temperature values have decreased with the effect of the magnetic field force. Therefore, the difference between the pipe and fluid temperature has increased. Heat transfer has also increased.

Temperature comparisons at a distance of 0.1 mm from the wall have depicted in Figure 8 (a) and Fig. 8 (b). The temperature changes in Fig. 8 are similar to Fig. 7. Here again, the temperatures have decreased due to the force of the magnetic field. As the difference between the wall and fluid temperature increases, heat transfer has increased. It follows that the magnetic field increases heat transfer.

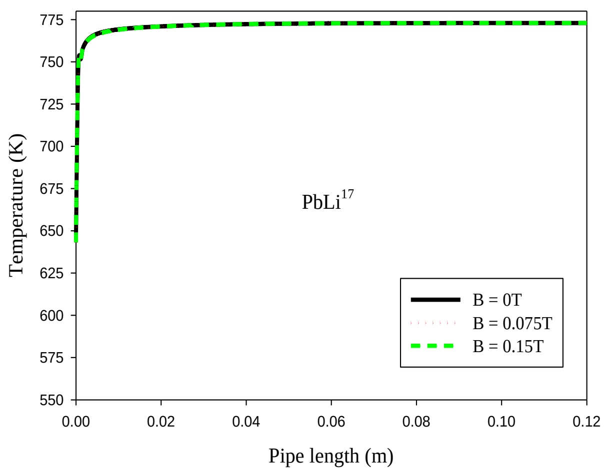


a)

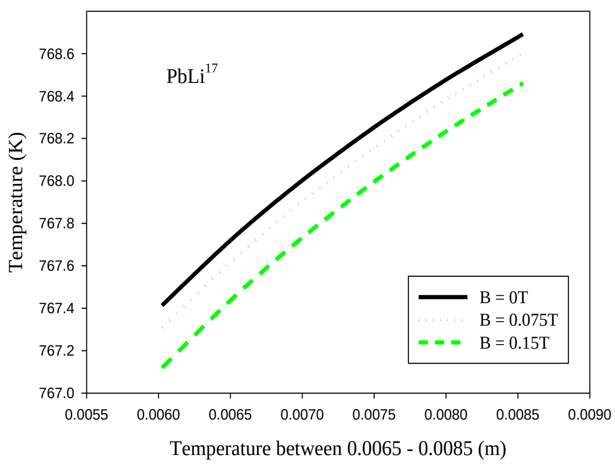


b)

Fig. 7: Temperature comparisons at a distance of 0.5 mm from the wall



a)



b)

Fig. 8: Temperature comparisons at a distance of 0.1 mm from the wall

The velocity contours of the fluid along the pipe diameter are shown in Figure 9. From the scales, it is seen that the magnetic field reduces the fluid velocity. Also, these values are shown in Figures 3 and 4. However, when the velocity field is examined, the magnetic field changes the velocity field. At B = 0T the shape is completely round, while at B = 0.075T the ellipse shape has formed. Also, at B = 0.15T, the ellipse of the shape deteriorates.

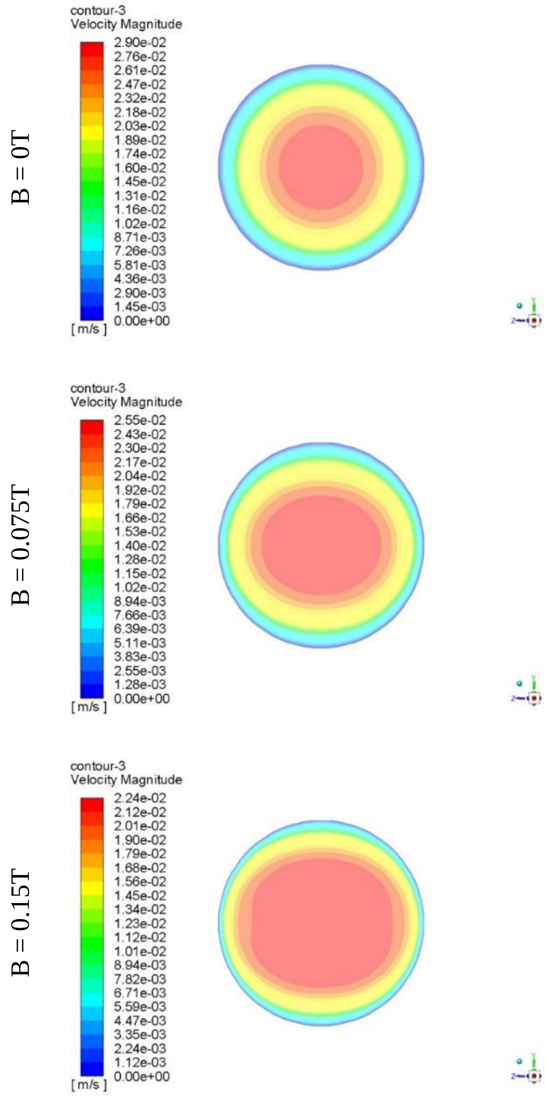


Fig. 9: pipe diameter velocity contours

Conclusion

This study has investigated numerically the magneto-hydrodynamic forced convection of $PbLi^{17}$ fluid flow. In the study, velocity, pressure, temperature profiles, and velocity contours have been presented and discussed. The important results obtained are listed below (Tw > Ti).

- Fluid velocity has decreased significantly with magnetic field strength.
- Fluid pressure has increased significantly with magnetic field strength.
- The fluid temperature has decreased significantly with magnetic field strength for distance in both 0.1 mm and 0.5 mm.
- The magnetic field significantly has changed the velocity contour area.

As a result, the applied external magnetic field has a significant effect on the flow and heat transfer of the $PbLi^{17}$ liquid metal.

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