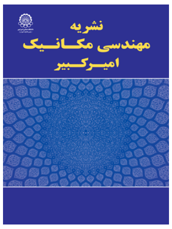

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(5) (2021) 673-676
DOI: 10.22060/mej.2020.17736.6657

Numerical Study and Investigation of the Effect of Magnetic Field on Fluid Hydrodynamic Behavior

H. Sanaei[1], F. Sarhaddi[1,*], S. Farahat[1], S. M. Javadi[2]

[1] Department of Mechanical Engineering, University of Sistan and Baluchestan, Zahedan, Iran
[2] Department of Mechanical Engineering, Quchan University of Technology, Quchan, Iran

ABSTRACT: This research represents the dual blanket structure and liquid metal fluid hydrodynamic characteristic under magnetic field. Numerical study of the flow inside the blanket which is separated by separator structure from the shell side is done. This structure is used for both thermal insulation and pressure drop reducing mechanism. As the fluid has electrical conductivity properties, magnetohydrodynamic analysis is also done. In the current study following analyses are done: magnetic field effect, wall electrical conductivity, baffle thickness and its distance from wall in on pressure drop, as well as explaining the behavior of velocity profile under magnetic field changes. According to the result increasing the magnetic field from 0.4 T to 1 T increasing the pressure drop by 4 times the initial value. Also, reducing the electrical conduction in the separating wall from 500 S/m to 5 S/m reduces the pressure drop by 35%. Studies on the different thicknesses of the separator structure in 16 different cases with constant distance between the separator and the wall does not have a significant effect on the pressure drop but by increasing the distance between the separator and the wall the pressure drop will decrease and consequently decreasing in pumping power.

Review History:

Received: Jan. 14, 202
Revised: May. 22, 2020
Accepted: Jun. 20, 2020
Available Online: Jul. 17, 2020

Keywords:

Magnetohydrodynamics
Dual blanket
Numerical study
pressure drop

1. Introduction

One of the most important parts of a nuclear fusion reactor, Tokamak, is the blanket, which has three main functions: generating cycle fuel, transmitting energy, and protecting other components of the reactor from radiation. An intense magnetic field to enclose plasma to produce fusion (bond between two hydrogen isotopes called deuterium and tritium) is a requirement of this type of reactor. One type of blanket that is being researched is the Dual Coolant Lead-Lithium (DCLL) type. The fluid used in this type of blanket is pb-17li liquid metal. Researchers have tried different methods to study fluid behavior, especially pressure drop, fluid velocity, and heat transfer The configuration of a simplified DCLL blanket channel model with a Flow channel insert (FCI) is illustrated in Fig. 1. In order to prevent induced current and magnetic field coupling, reduce Magnetohydrodynamic (MHD) pressure drop and increase the temperature of liquid metal, FCI flow channels made of silicon carbon are placed between the main body and the liquid metal (Fig. 1).

Smolentsev et al. [1] studied the velocity profiles of MHD flow in the front poloidal. However, the simulation was based on a 2D model for a fully developed flow. Kirillov, et al. [2] verified that the liquid metal flow in a rectangular duct with FCI was fully 3D flow. In fact, the DCLL blanket endures affection from both external strong magnetic fields and the large gradient neutron flux. The liquid metal, FCI structure, magnetic field and heat source constitute a coupling physical field. The high neutron flux formula from neutron analysis [3] demonstrates the relation between space location and heat magnitude. It implies that geometrical configuration of blanket would cause the variation of not only liquid metal flow but also heat transfer. The velocity field, temperature distribution and thermal-mechanical behaviors of FCI would change accordingly.

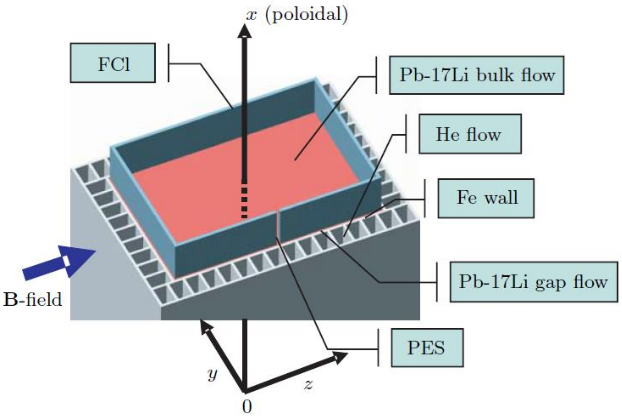

Fig. 1. Liquid metal circulation in DCLL blanket [1]

*Corresponding author's email: fsarhaddi @eng.usb.ac.ir

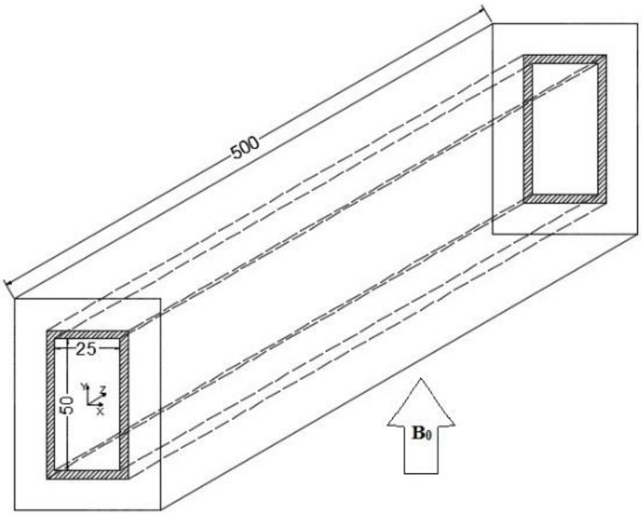

Fig. 2. Rectangular geometry

In the last 10 years, most researchers have focused on DCLL blanket, such as separating wall material, sudden expansion, bending, overall cross-sectional changes, changing the inlet velocity, and changing the magnetic field. However, examining issues such as the effect of the thickness of the separator structure and its electrical conductivity in reducing the pressure drop can be useful in improving the performance of the DCLL blanket.

2. Solution Methodology

2.1 Geometry description

Fig. 2 shows the rectangular cross-section geometry. A rectangle duct having a 25 × 50 mm cross-section, and length of 500 mm have been analyzed.

The current simulation is performed with a uniform strong magnetic field B0 parallel to the toroidal direction (y-direction), as shown in Fig. 2. The inlet velocity is 0.01 m/s for bulk flow and gap flow. Physical properties of FCI depend on the fabrication techniques, impurities, dopants, and interphase materials. The electrical conductivity of FCI varied from 5 to $500(\Omega\mathrm{m})^{-1}$

2.2 Governing equations

For a low magnetic Reynolds number liquid metal MHD flow, with steady-state, incompressible, and constant physical properties, the system governing equation of mass, momentum, conservation of charge, and Ohm's law is described as following [4]:

$$\nabla.\vec{u}=0 \tag{1}$$

$$\vec{u}.\nabla\vec{u}=-\frac{1}{\rho}\nabla p+\nabla\left(\upsilon\nabla\vec{u}\right)+\frac{1}{\rho}\left(\vec{J}\times\vec{B}\right) \tag{2}$$

$$\vec{J}=\sigma\left(-\nabla\varphi+\vec{u}\times\vec{B}\right) \tag{3}$$

$$\nabla.\vec{J}=0 \tag{4}$$

The problem given has been solved by using Ansys Fluent 19.2. The magnetic induction method has been chosen in the MHD module

2.3 Boundary conditions

Boundary conditions are given at inlet by specifying a uniform or fully developed velocity profile. A no-slip boundary condition is applied on the other walls .

At the inlet:

$$u=v=0 \quad , \quad w=w_0 \quad , \quad p_{in}=p_0 \tag{5}$$

At the outlet:

$$u=v=\frac{\partial w}{\partial n}=0 \quad , \quad \varphi_{out}=0 \quad , \quad p_{out}=0 \tag{6}$$

On wall:

$$u=v=\frac{\partial w}{\partial n}=0 \quad , \quad \varphi_{out}=0 \quad , \quad p_{out}=0 \tag{7}$$

3. Results and Discussion

According to Fig. 3, a approximately linear relationship ΔP≈40B-2 can be extracted for pressure drop in terms of magnetic field. This relationship states that the pressure drop increases with an increasing magnetic field.

Fig. 4 shows that the MHD pressure drop reduction factor reaches the highest value when the FCI thickness is 2 mm and the gap width is 1 mm. The reduction in pressure drop is quite evident with the reduction in FCI electrical conductivity. As can be seen, by reducing the electrical conductivity from 500 to 5 ohms, the pressure drop is reduced by about 35% (Fig. 5).

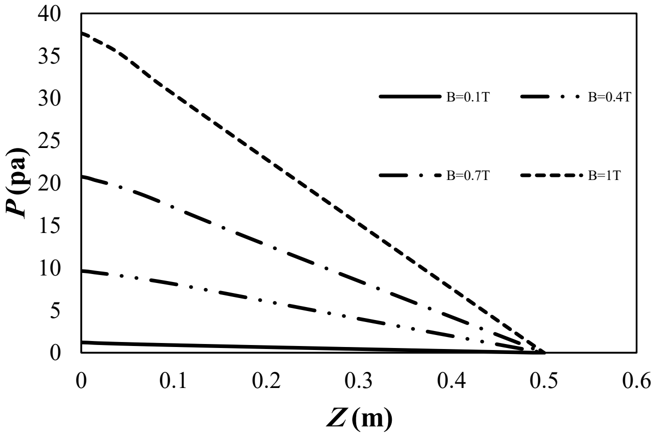

Fig. 3. The effect of magnetic field variation on pressure distribution along with the flow

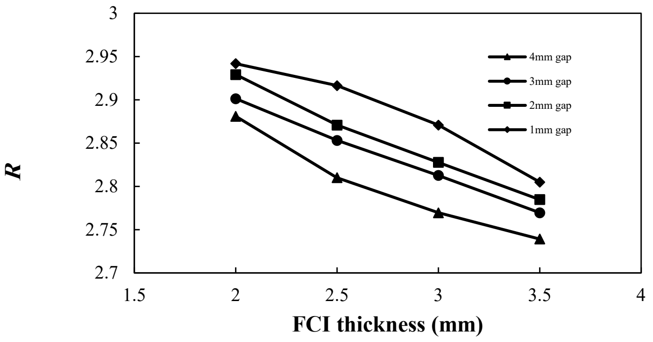

Fig. 4. Effect of the FCI thickness and the gap width on the MHD pressure drop factor (R), Ha=520

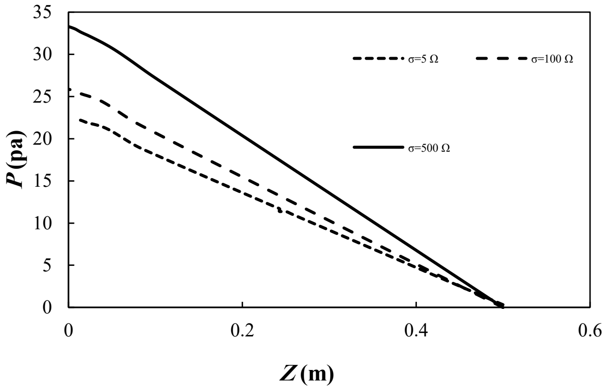

Fig. 5. The effect of changes in the electrical conductivity of FCI on pressure distribution along with the flow

4. Conclusions

* Increasing the intensity of the magnetic field from 0.4 T to 1 T increases the pressure drop.

* FCI and gap width have a relatively large effect on pressure drop in bulk flow.

* By reducing the electrical conductivity from 500 to 5 ohms, the pressure drop is reduced by about 35%.

References

[1] S. Smolentsev, N. Morley, M. Abdou, R. Munipalli, R. Moreau, Current approaches to modeling MHD flows in the dual coolant lead lithium blanket, Magnetohydrodynamics, 42(2-3) (2006) 225-236.

[2] I.R. Kirillov, C.B. Reed, L. Barleon, K. Miyazaki, Present understanding of MHD and heat transfer phenomena for liquid metal blankets, Fusion Engineering and Design, 27 (1995) 553-569.

[3] K. Starke, L. Bühler, S. Horanyi, Experimental MHD–flow analyses in a mock-up of a test blanket module for ITER, Fusion Engineering and Eesign, 84(7-11) (2009) 1794-1798.

[4] C. Soto, S. Smolentsev, C. García-Rosales, Mitigation of MHD phenomena in DCLL blankets by Flow Channel Inserts based on a SiC-sandwich material concept, Fusion Engineering and Design, 151 (2020) 111381.

HOW TO CITE THIS ARTICLE

H. Sanaei, F. Sarhaddi, S. Farahat, S. M. Javadi, Numerical study and Investigation of the Effect of Magnetic Field on Fluid Hydrodynamic Behavior, Amirkabir J. Mech. Eng., 53(5)(2021) 673-676.

DOI: 10.22060/mej.2020.17736.6657