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The MHD Pressure Drop by a Transverse Magnetic Field on a Liquid Sodium Flow

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1. Introduction

A liquid sodium coolant is being considered for use in KALIMER (Korea Advanced LIquid MEtal Reactor) such as a SFR (Sodium Fast Reactor) due to its high thermal conductivity. The KALIMER system, which is being designed for an electric output of 600 MW, is thought to employ an electromagnetic pump and an electromagnetic flowmeter for circulating and measuring the sodium coolant with a high electrical conductivity. A magnetic field is known to affect an electrically conducting metal flow by the generation of an electromagnetic pressure drop as seen in the theoretical calculation and related experiment on a nuclear fusion blanket with a lithium coolant under a high magnetic filed [1-4]. However, little experimental data is currently available for an MHD effect on sodium for a SFR even though there are several experimental MHD results on liquid metal such as lithium for a fusion reactor. Therefore, a liquid sodium metal MHD loop system for quantitatively studying an experimental characterization of a magnetic field effect on a sodium flow by using electromagnetic devices has been built up in Korea. In the present study, an MHD pressure drop by a uniform magnetic field in a rectangular test section is theoretically calculated and experimentally measured. A comparison between the theoretical prediction and experimental data is carried out to establish their agreements.

2. Theoretical Analysis

The Navier-Stokes equation and Ohm's law that describe a fluid system are :

$$\frac{\partial u}{\partial t} + u \bullet (\nabla u) = -\frac{1}{\rho}\nabla p + \nu\nabla^2 u + \frac{1}{\rho} J \times B \qquad (1)$$

$$J = \sigma(E + u \times B) \qquad (2)$$

where u denotes the flow velocity, ρ, the density of the fluid, p, the pressure, ν, the viscosity, J, the current density, B, the magnetic field σ, the electrical conductivity of the fluid, and E, the electric field strength. First of all, the liquid sodium fluid is incompressible ($\nabla \bullet u = 0$). The hydraulic pressure drop by friction with the wall is negligible in comparison with that of a magnetohydrodynamic term when a duct wall is electrically conductive [1]. The velocity is assumed to be uniform across the wall by the considerable Hartman number due to a magnetic field except for the inner wall surface which contacts with the sodium flow [2]. That is, $\nabla u = 0$ for an incompressible and uniform flow. The flow is also considered to be inviscid. And a steady state is considered. According to the above assumptions, the Navier-Stokes equation for describing a system with an electrically conductive flow under a magnetic field is reduced for an inviscid flow :

$$\nabla p = J \times B \qquad (3)$$

On the other hand, the flow system to be analyzed is seen in Figure 1. Figure 1 represents the analysis model based on the uniform current density method. The uniform magnetic field is driven perpendicular to the liquid sodium flow for a magnetohydrodynamic pressure drop by a magnetic field. When considering a flow system like Figure 1, the pressure gradient along the flow in equation (3) is extended based on Keiji Miyzaki [1, 3-4] :

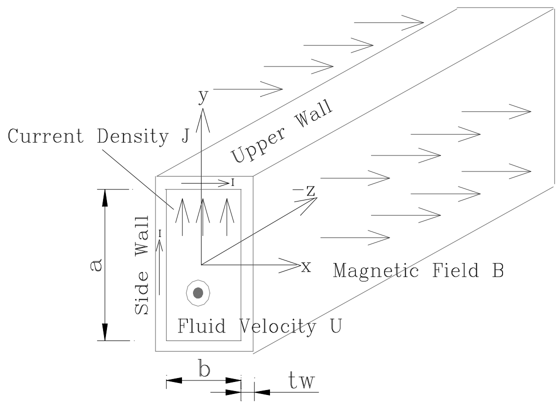

Figure 1. The 3D schematic model for an experiment on the magnetic field effect.

$$-dp/dz = Kp\ \sigma_f u B^2 \qquad (4)$$

where

Kp = C/(1+b/3a+C) (pressure coefficient)

$C = 2\sigma_w t_w / \sigma_f b$

a : The length of a side wall[m]

b : The length of an upper wall[m]

σ_w : The electrical conductivity of the stainless steel wall[mho/m]

t_w : The thickness of a wall[m]

σ_w : The electrical conductivity of the sodium fluid[mho/m]

B : Magnetic flux density[T]

J : Current density[A/m^2]

U : Fluid velocity [m/sec]

Therefore, by integrating equation (4) along the test section where the liquid sodium flows, the pressure drop is :

$$\Delta p = \int K_p \sigma_f U B^2 dz \qquad (5)$$

3. The Experiment and Results

Figure 2 shows the plots of the pressure drop (P1-P2, atm) in a uniform magnetic field according to a varying velocity (v, m/sec) with a change of the magnetic field (B, Gauss) in the rectangular test section.

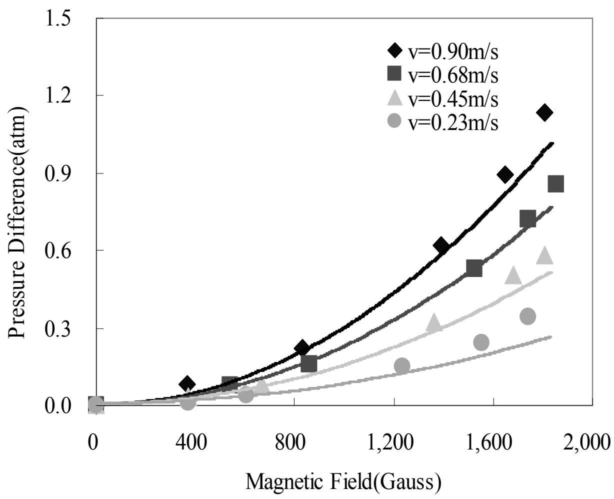

Figure 2. The pressure drop between both ends of the test section according to the varying velocity with the change of magnetic field.

The lines denote the theoretical prediction based on a uniform magnetic field and current model. The experimental plots are thought to reveal a good agreement with the respective lines in spite of some experimental deviations for some values of the velocity. In Figure 2, the experimental values of the pressure drop increase in proportion to the square of B as is revealed in the theoretical equation.

Figure 3 shows the plots of the pressure drop (P1-P2, atm) in a uniform magnetic field against a mean flow velocity (v, m/sec) in the rectangular test section, with the magnetic flux density (B, Gauss) as a parameter. The lines denote the theoretical prediction and the experimental plots fit the theoretically calculated values well except for a slight deviation in some values of the magnetic flux densities. In Figure 3, the pressure drop is proportional to the flow velocity.

4. Conclusions

The magnetic field effect on a pressure drop was measured for a liquid sodium flow when the operational variables such as the magnetic field and the flow velocity were varied. A comparative analysis between the theory and experiment was performed. The pressure drop was given by $\Delta p = \int K_p \sigma_f U B^2 dz$ and good agreements were observed except for some experimental deviations. It suggests that the results of the present study can provide a good approximation for evaluating an MHD pressure drop due to a uniform magnetic field for the design of the SFR system although the study showed some inconsistences. In the future, an experiment on an MHD pressure drop in the environment of a rippled magnetic field ($B= B_0+ B_1 \sin wt$) will be carried out to investigate the effect of a fluctuating magnetic field on a liquid sodium flow.

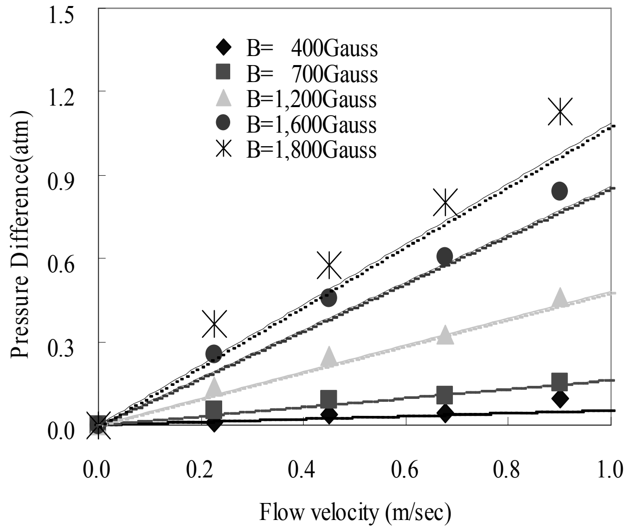

Figure 3. The pressure drop between both ends of the test section according to a varying magnetic field with a change of the velocity.

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