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Code Validation for MHD Pressure Drop with Benchmark Problems and Theoretical Comparison.

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1. Introduction

Korea have proposed and designed the Helium Cooled Molten Lithium (HCML) Test Blanket Module (TBM) for a testing in the International Thermonuclear Experimental Reactor (ITER) [1-4]. A liquid metal breeding system of the TBM such as lead lithium and lithium is circulated in the presence of strong magnetic field. The flow and heat transfer in the liquid breeder should be estimated but this magnetohydrodynamics (MHD) phenomenon in TBM is not clearly understood yet. Therefore, Numerical analysis of this liquid metal flow in the TBM requires that the code to simulate the flow be validated beforehand. In this investigation a commercial code, CFX EM module, was verified by comparison with previous experimental data and with theories about the pressure loss of the flow. The results will support the accurate analysis of the flow in TBM.

2. Methods and Results

Since a pressure loss in the liquid metal flow of TBMs is a main concern, the comparison between CFX and experimental data is performed considering the pressure drop. The code is verified by two ways. At first, CFX calculations were also compared with theoretical prediction. Then a benchmark problem with a couple of previous experimental results was used for comparison.

2.1 Formulation and CFX implementation.

The steady state fully developed MHD flow of a fluid is governed by the following non dimensional momentum equation:

$$\frac{1}{N}[\delta t+(\mathrm{v}\cdot\nabla)]=-\nabla\mathrm{p}+\frac{1}{Ha^2}\nabla^2\mathrm{v}+\mathrm{j}\times\mathrm{B} \qquad (1)$$

where v=u(x,y) z-direction is the fluid velocity and B, j, ∇p is magnetic field, current density, and pressure gradient scaled respectively. The flow is governed by two non-dimensional parameters, the Hartmann number and the interaction parameters.

$$Ha = BL\sqrt{\frac{\sigma}{\rho\nu}} \quad \text{and} \quad N=\frac{\sigma LB}{\rho\nu}$$

Ha and N mean the ratio of electromagnetic forces to viscous forces and electromagnetic force to inertia forces, respectively.

CFX EM module calculates the Lorents force which is induced by the liquid metal breeder and magnetic field as a momentum source. In calculating the pressure drop, the CFX assumes that the capacitance and inductivity are very small. This assumption means that electromagnetic phenomena have no delay, no oscillation and a faster effect than hydrodynamic one.

2.2 Comparison with theory

The CFX calculation was validated by comparison with theoretical prediction. This comparison verification could overcome the limit of the experimental data and show closely the parameters which cause pressure drop.

The comparison with theories focused on the rectangular channel flow which is suitable for the liquid metal flow in the TBM. The conditions for the calculation are Re (2,200~27,000), Ha (200~4,000) and C (0.016~0.13). According to pressure prediction by Miyazaki et. al. [5], the equation is

$$\frac{dP}{dz}=\frac{C}{(1+a/3b+C)}\sigma_f UB^2 \qquad (2)$$

where, $C=\dfrac{\sigma_w t_w}{\sigma_f a}$

The analytic solution suggests that the geometric parameter of width (a), aspect ratio (a/b), thickness (t_w) and the material properties of electrical conductivity of fluid and solid (σ_f, σ_w) contribute to the pressure drop. In the additional validation, the CFX results were compared to the theoretical prediction as the above parameters were varied.

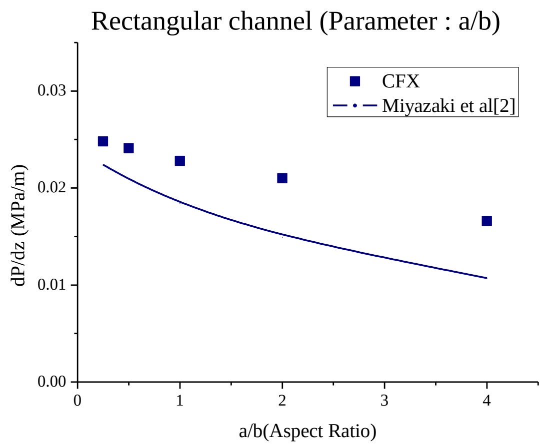

Fig. 1 Parameter Study for a/b

The tendency of pressure drop with the aspect ratio change (0.25~4) was predicted and calculated, as shown in Fig. 1. As the aspect ratio increases, the theoretical prediction shows the decrease in the pressure drop. The CFX calculation also shows the decrease of pressure drop as the increase of the aspect ratio. In the calculation with the other parameters, CFX results show the good agreements with the theoretical prediction.

Although CFX show the good calculation results, the slight difference between the CFX and theories was observed. The assumption of code and the theories is considered as a main cause of the difference. The theory [6] assumes that the electromagnetic force is the only cause for the pressure drop. As this assumption regards Ha and N as too much high, Eq. (1) can be derived

$$\nabla p = j \times B \quad (3)$$

As the electromagnetic effect increase relatively, the CFX calculation show a good agreement with the theory, Eq. (2) and (3). Because the flow is more stabilized and fit with theoretical prediction [8], the results strongly support the accurate calculation by CFX.

2.3 Comparison with experimental data

There are many experimental studies about MHD in simple geometries and strong magnetic field. The code was benchmarked with those results [5-7]. The geometries selected were a rectangular channel, a circular pipe and a sudden expansion. And each cases has a wide range of magnetic field (0~2T) and flow velocity of liquid metal flow (0.01~15m/s).

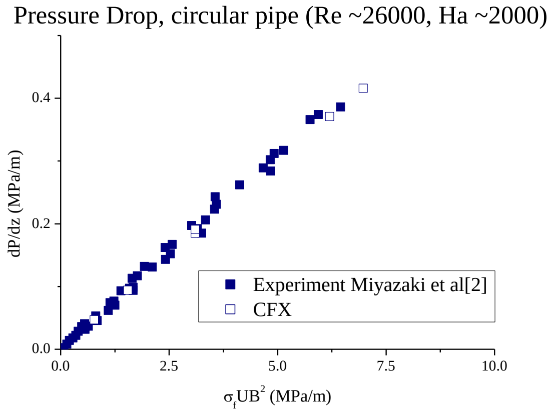

Fig. 2 Pressure drop in circular pipe

Figures 2 and 3 show the pressure drop results from the experiment and CFX calculation in the circular pipe, and the pressure drop results along the flow in the sudden expansion geometry, respectively. The calculation results show a good agreement with the experimental data.

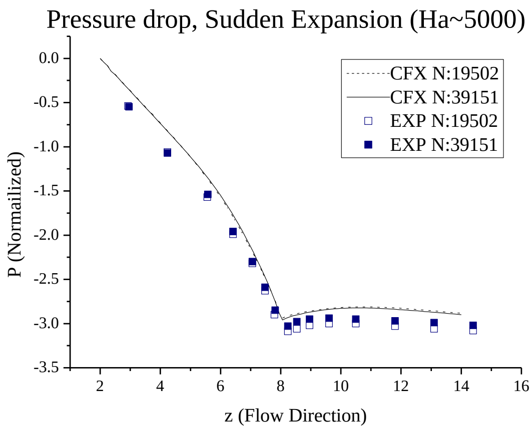

Fig. 3 Pressure drop in Sudden Expansion

3. Conclusions

The comparison validation with experiments and theoretical tendency show that the CFX EM module can predict the hydrodynamics of the liquid metal flow well and its calculation is very reliable. In the next step, the validation about heat transfer in the flow will be performed.

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