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CFX validation for the fully developed 2D laminar steady MHD flow

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1. Introduction

One of the key objectives of the ITER experiment is to test and validate the design concepts of tritium breeding blanket modules, called the Test Blanket Modules (TBM). Tritium breeding blankets are expected to be essential component for D-T reaction based fusion power reactors, as tritium self-sufficiency is crucial for their commercial utilization. However, for Pb-Li based blankets, one of the greatest burdens in maintaining a desired flow rate is the MHD pressure drop. Within the TBM, the Pb–Li will be moving in rectangular channel crossed by the strong magnetic field of the confinement magnets. Motion of the Pb–Li in the high magnetic field generates currents, and interaction of this current with the imposed magnetic field results in Lorentz affecting the motion. These forces modify the velocity profile of the flow, and develop a motion-opposing Lorentz force, so that a much higher pressure drop now needs to be maintained across the channel to maintain the desired mass flow rate. Reduction of these current through proper insulation of the duct wall is desired for lowering the MHD pressure drop and enhancement of efficiency of the blanket. In this regard, fully developed laminar steady state flow driven by a constant axial pressure gradient in long rectangular ducts is a classical 2D MHD problem for flows of electrically conducting fluids in channels subject to a uniform transverse magnetic field [1]. In this paper two cases with different wall conditions are studied by using CFX program. First case is considered with insulating duct walls (C_w=0) and in the second case, insulating side walls (C_w=0) and conducting Hartmann walls (C_w=0.01) has been considered.

2. Geometry and Properties

Schematics and duct cross section are shown in Figure 1 and 2.

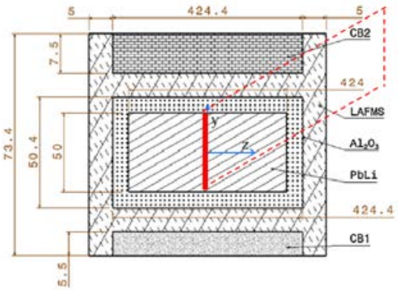


Figure. 1 Shematics of 2d laminar steady flow

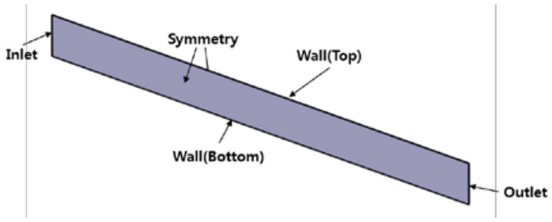


Figure. 2 2d cross section laminar steady flow

Material Properties**:**
ρ_w = 8000 Kg/m^3 ,
C_{pw} = 502.1 J/Kg-K,
λ_w = 16 W/m-K.

Pb-Li properties	
Dynamic Viscosity of Pb-Li,μ (Pa-sec)	0.0018
Electrical Conductivity of Pb-Li,σ (ohm-m)$^{-1}$	0.77616×10^6
Density of Pb-Li ,ρ(Kg/m^3)	9401.8
Thermal Conductivity of Pb-Li, λ(W/m-K)	14.16
Specific Heat Pb-Li ,Cp (J/Kg-K)	189.32

Table. 1 Pb-Li properties

3. Results and Discussion

Numerical analysis has been performed using CFX software. For simulating fully developed laminar MHD flow, 2D approach has been used where flow rate is estimated using specified value of the pressure gradient. We have solved Hunt's case[2] for several Hartmann numbers from Ha = 0 to Ha = 10. The obtained results are shown in Table 2. The numerical results are compared with the analytical solution using the dimensionless flow rate (relative velocity from the center to the wall), which is shown as 'reference' in diagrams. Results for velocity along the transverse coordinate z for Shercliff flow A1 are shown in Figure 2 (left) for various Hartmann numbers Ha. A perfect agreement with the analytical solution is found for all the considered Hartmann numbers, Ha □ 20000, and deviations from analytically obtained pressure gradients k are all smaller than 1%, which is a quite remarkable result considering the fact that we have only 50×50 points in 0 < y < 1 and 0 < z < 1. By using a finer grid 100×100 in a quarter of the channel the relative error becomes significantly smaller as shown in Table 2.The numerical results we have obtained are in a very good agreement with the analytical values for every Hartmann number.

Case 2		
m=0(Hartmann Number) Steady State Defined Electromagnetic Model V_{in} = 0.0001 [m/s] P_{in} = 1 [atm] P_{out} = 0 [Pa] Pres. Profile Blend = 0.05 Pressure Averaging = Average Over Whole Outlet None(Laminar) model Single phase flow Fluid : PbLi Solid : Al_2O_3 Time Factor = 1.0 Convergence Criteria = 1e-04 V_{max}/V_{avg} = 1.499 Converged in solver	<<Referred Case 2.1>> m=5(Hartmann Number) Electric Potential Electric Field Model = None $\text{Magnetic Field}_{External}$ = 0.01926(Z) $\text{Magnetic Field}_{x,out}$ = Normal to Boundary Condition V_{max}/V_{avg} = 1.232 Converged in solver	<<Referred Case 2.2>> m=10(Hartmann Number) $\text{Magnetic Field}_{External}$ = 0.01926(Z) V_{max}/V_{avg} = 1.128 Converged in solver

Table. 2 Summary of case I

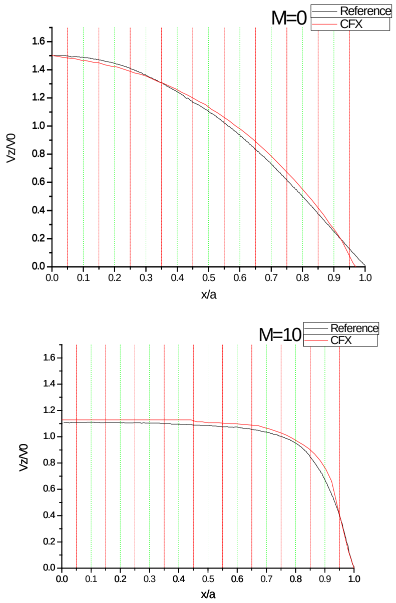
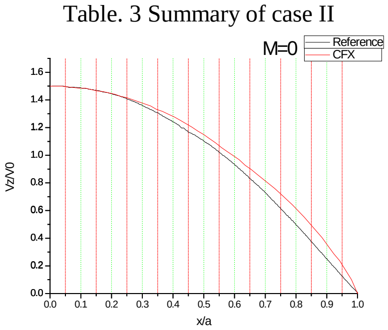


Figure. 3 case I: Flow in a non-conducting square duct

We have also solved Hunt's case considering that the Hartmann walls (top and bottom) have a finite wall conductivity Cw=0.01. In order to simulate this problem, we have used a computational domain consisting of two materials, a solid and a fluid. The fluid part is the same than in the previous example and the solid part simulates the top and bottom channel walls with finite conductivity

Case 2		
m=0(Hartmann Number) Steady State Defined Electromagnetic Model V_{in} = 0.0001 [m/s] P_{in} = 1 [atm] P_{out} = 0 [Pa] Pres. Profile Blend = 0.05 Pressure Averaging = Average Over Whole Outlet None(Laminar) model Single phase flow Fluid : PbLi Solid : Al_2O_3 Time Factor = 1.0 Convergence Criteria = 1e-04 V_{max}/V_{avg} = 1.499 Converged in solver	<<Referred Case 2.1>> m=5(Hartmann Number) Electric Potential Electric Field Model = None $\text{Magnetic Field}_{External}$ = 0.01926(Z) $\text{Magnetic Field}_{x,out}$ = Normal to Boundary Condition V_{max}/V_{avg} = 1.232 Converged in solver	<<Referred Case 2.2>> m=10(Hartmann Number) $\text{Magnetic Field}_{External}$ = 0.01926(Z) V_{max}/V_{avg} = 1.128 Converged in solver

Table. 3 Summary of case II



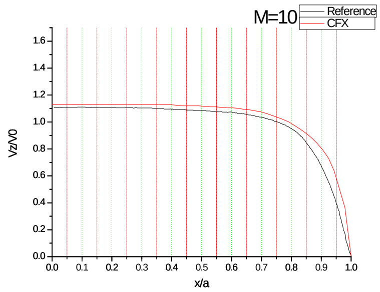


Figure. 4 case II: Flow in a square duct with two non-conducting walls parallel to the magnetic field and two conducting walls perpendicular to the magnetic field

Table 3 summarizes the results obtained for the benchmark case A2 (cH = 0.01, cS = 0). Same

number of nodes has been used in the layers for all considered Ha. In Figure 3 the velocity

profiles in the symmetry plane y = 0 of the duct cross section are plotted for the MHD flows at

Ha = 5000 and 15000. A perfect agreement with the analytical solution is found. It should be

noted that in Table 3 the number of points #S in the side layers are those distributed only in the

region 1-□S □ z □ 1 with □S = Ha-1/2 and therefore the full boundary layer is resolved by a much

larger number of points. The location of grid points is shown in Figure 3 by symbols.

3. Conclusion

Numerical analysis for simulating fully developed laminar MHD flow has been performed using CFX software.

References

[1] K.S. Goswami, "Preliminary studies on MHD simulation and heat transfer analysis for LLCB TBM", Fusion Engineering and Design 85 (2010) 1371–1375
[2] J.C.R. Hunt, Magnetohydrodynamic flow in rectangular ducts, J. Fluid Mech., 21 (4), 577-590 (1965).