FLUIDCHEN ELECTRO-MAGNETIC SOLVER

(Project Done as a Part of CFD Lab Course)



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1. Introduction

In a special type of nuclear reactor called sodium fast breeder reactor, liquid sodium is used as a coolant. However, normal pumps cannot operate at such high temperatures and thus an electro-magnetic pump is required. In this project, we have extended the *Fluidchen* solver developed as a part of the CFD Lab course, with the goal of simulating an electromagnetic pump. The solver also uses *preCICE* library to couple the energy equation solver already developed for *Fluidchen* with the *Electromagnetic Solver* developed as a part of this project.

2. Accessing The Code

The repository can be accessed at: https://gitlab.lrz.de/durganshu/group-i-cfd-lab/-/tree/master

The merge request can be accessed at: https://gitlab.lrz.de/durganshu/group-i-cfd-lab/-/merge_requests/25

3. Governing Equations for Electromagnetism

Electric Potential (ϕ): $$\nabla^2\phi = 0 \quad (1)$$

Electric Field (***E***): $$\vec{E} = -\vec{\nabla}\phi \quad (2)$$

Electromagnetic Force (***F***): $$\vec{F} = \sigma V\left(\vec{E} \times \vec{B}\right) \quad (3)$$

where, ***B*** is magnetic field, σ is electrical conductivity and V is volume.

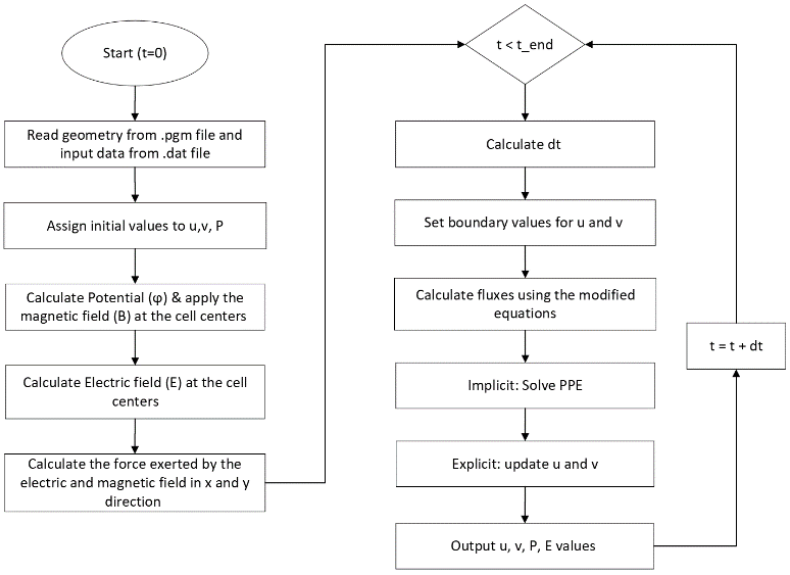
4. Implementation

- Electric Potential distribution is solved using Successive Over-Relaxation (SOR) method from equation(1).
- Electric field is calculated from electric potential using forward difference scheme using equation(2).
- Electromagnetic force is calculated from electric field using equation(3).
- The x and y momentum equations are modified to add the electromagnetic force component:

$$\text{x-momentum flux: } f(u,v) = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} + \nu\nabla^2 u + \frac{F_x}{\rho} + g_x \quad (4)$$

$$\text{y-momentum flux: } g(u,v) = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} + \nu\nabla^2 v + \frac{F_y}{\rho} + g_y \quad (5)$$

u: x-velocity, v: y-velocity, ν: kinematic viscosity, F_x: Electromagnetic Force in x-direction, F_y: Electromagnetic Force in y-direction, g_x: gravity in x-direction, g_y: gravity in y-direction, ρ: density of fluid



- We implemented a ramped force approach to have a faster convergence of pressure SOR iterations at start of simulation. The user can specify the ramped time. Force increases linearly from zero to maximum in this time interval.

5. Example Case

For the example case, we have simulated an electromagnetic pump and coupled it with energy equation solver using *preCICE*. We have used a finer mesh for the electromagnetic pump since we noticed a sudden jump in electric potential at the boundary. The case files can be found in the *EMHD_Energy-Coupling* Folder in *EMHD_precice* branch.

5.1. Domain Information

Property	Electromagnetic Pump		Fluid Channel	
	x	y	x	y
Length	5	2	10	2
Cells	100	20	100	20

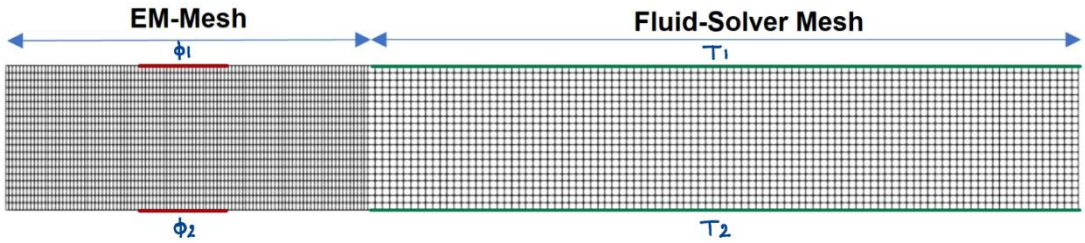


Figure 1. Mesh and Boundary Conditions

5.2. Fluid Properties

We have used the properties of liquid sodium at 500°C. However, we have increased the thermal diffusivity by order of 10^3 since our simulation time was very low to have any significant temperature evolution.

Property	Density (kg/m^3)	Electrical Conductivity ($\Omega^{-1}m^{-1}$)	Kinematic Viscosity (m^2/s)	Thermal Diffusivity (m^2/s)
Value	828	3.5×10^6	27.42	6.87×10^{-2}

5.3. Boundary Conditions

Property	ϕ_1 (V)	ϕ_2 (V)	B_z^* (T)	T_1 (K)	T_2 (K)	T_{in} (K)
Value	10	-10	-1×10^{-4}	748	752	750

*B_z is the magnetic field in z-direction.

5.4. preCICE Configuration

Property	Coupling Scheme	Dimensions	Max Time (End Time)	Time Window Size
Value	Serial-Explicit	2	0.5s	0.0005s

5.5. Results

5.5.1. Electric Potential

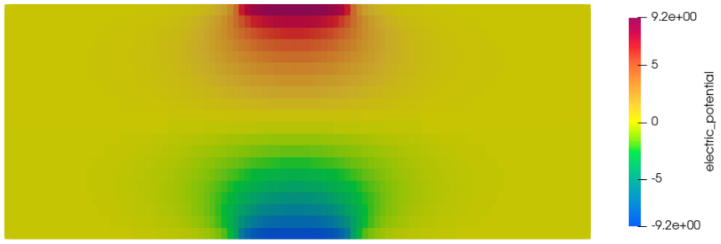


Figure 2. Electric Potential

5.5.2. Electric Field

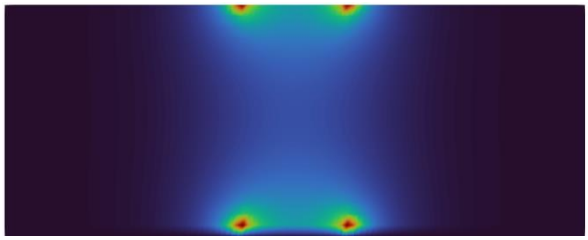


Figure 3.a. Electric Field

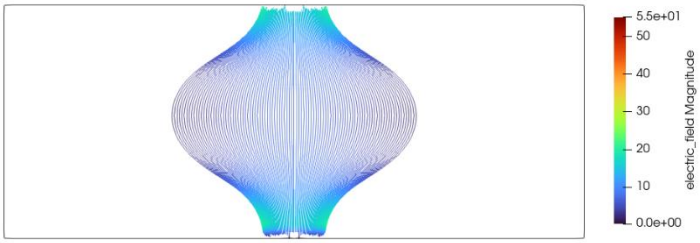


Figure 3.b. Electric Field Streamlines

5.5.3. Electromagnetic Force

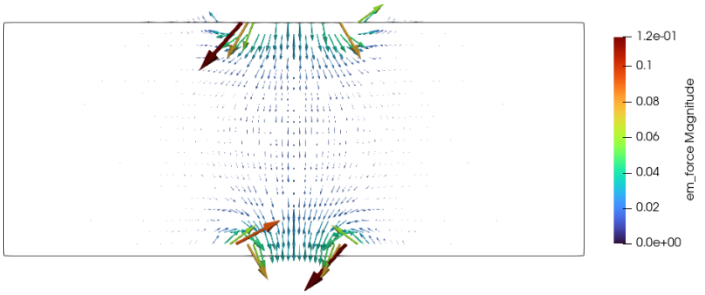


Figure 4. Electromagnetic Force Vectors

5.5.4. Velocity

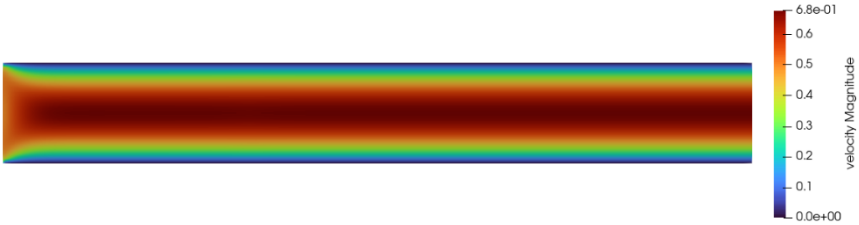


Figure 5. Velocity at $t=t_{end}$

5.5.5. Pressure



Figure 6. Pressure at $t=t_{end}$

5.5.6. Temperature

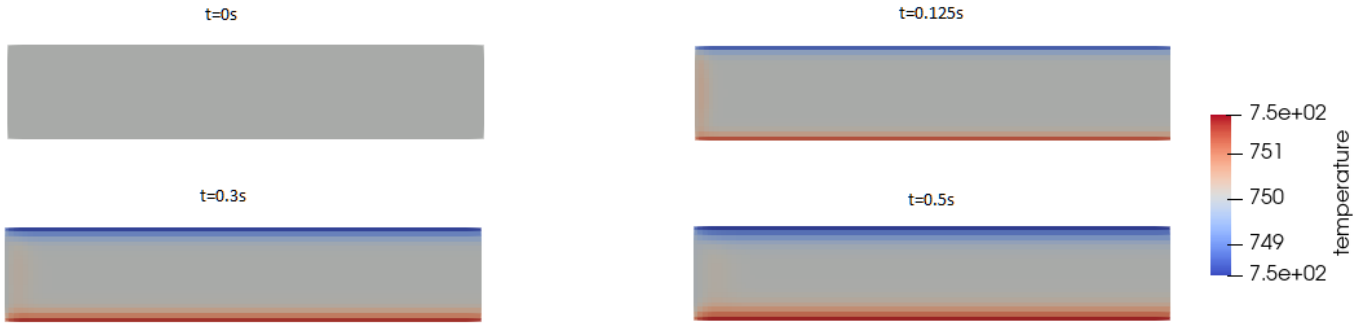


Figure 7. Temperature Evolution with Time

6. Conclusion

From the results, it is evident that the electromagnetic solver is working as expected. The velocity and pressure plots show the coupling is working as expected as well. The code currently only handles outflow and inflow on vertical edges. As a future development, outflow and inflow can be generalised. The code can also be extended to include microfluidic flows.