Analytical Method to Calculate EMF Induced in Ionic Liquid by Magnetic Field

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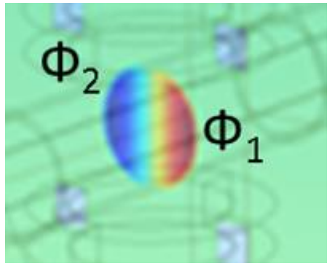

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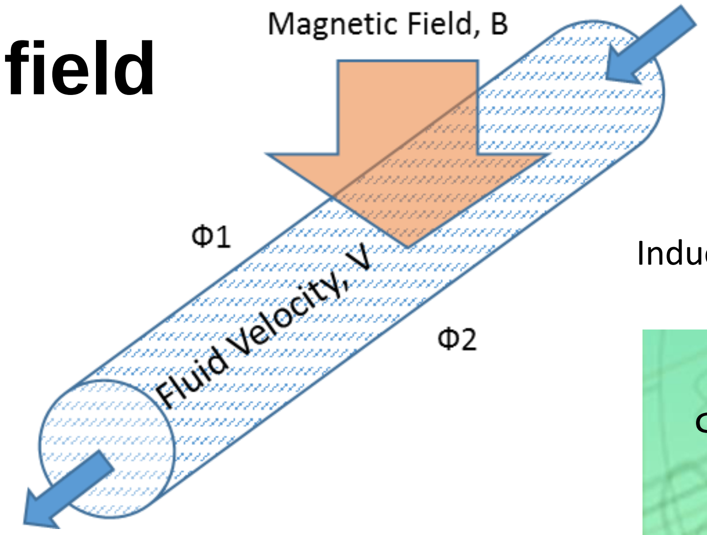
Induced EMF in Fluid: 1D Analytical Calculations

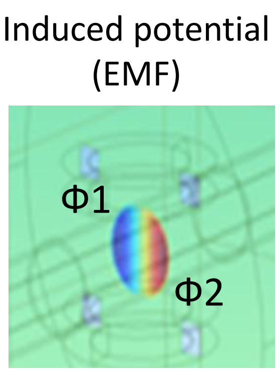
Induced EMF in fluid flowing past magnetic field

Analytical Expression (*Electrically Insulated Pipe*)

Induced EMF: Φ2 – Φ1 = BVD

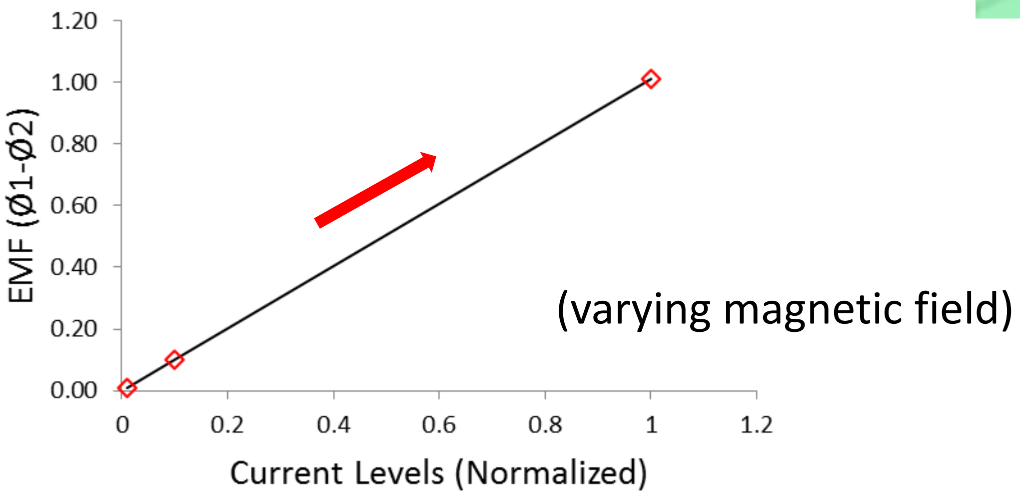
B: Magnetic Field, V: Average Velocity, D: Diameter





Assumptions:

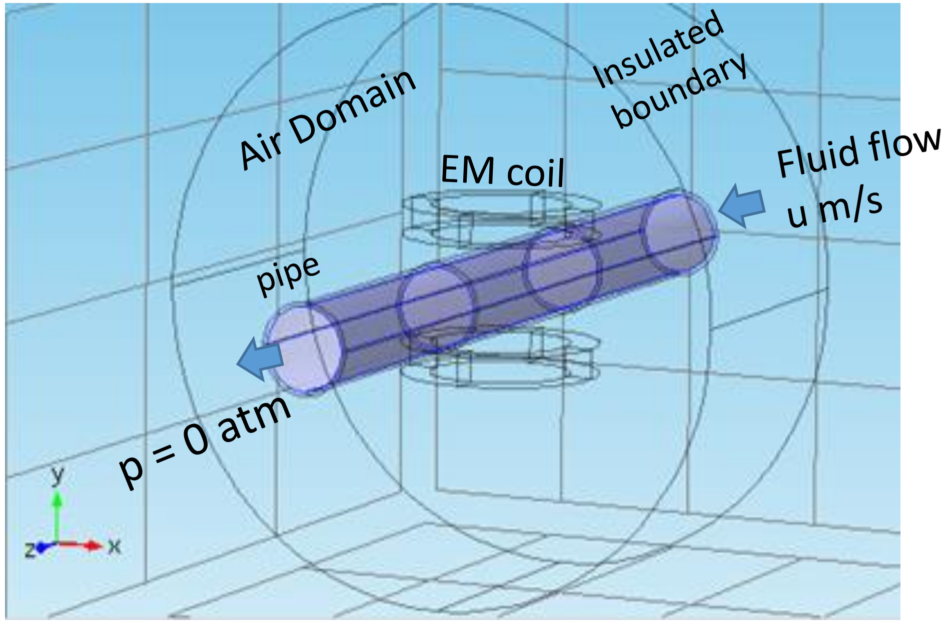
- Insignificant 3D effects
- Uniform magnetic and flow fields
- *Insulated pipe wall*



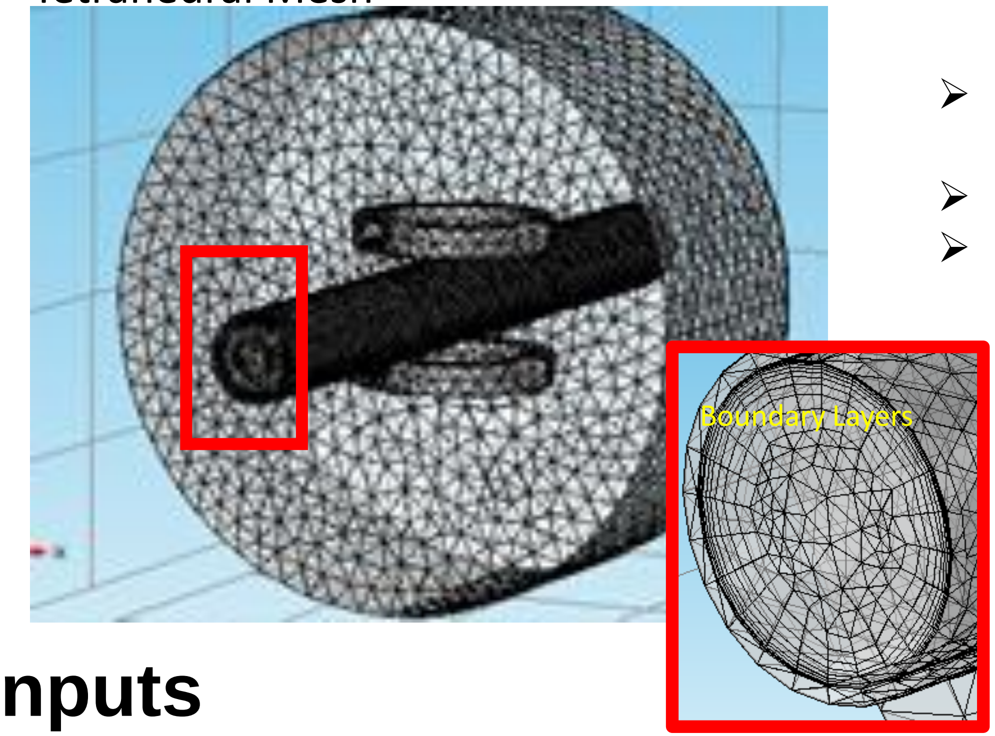
Analytical Calculation of Induced EMF

Induced EMF in Fluid: COMSOL Multiphysics 3D Model Prediction

Geometry and Meshing

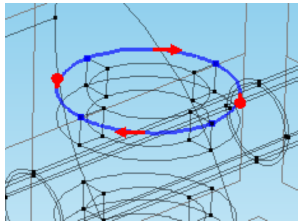


Tetrahedral Mesh



- ➢ Model in COMSOL meshing module
- ➢ Tetrahedral meshing
- ➢ Boundary layers: Resolve near wall physics

Multi-turn coil



Boundary Conditions and Inputs

Fluid Flow

- ➢ inlet velocity = u m/s
- ➢ outlet pressure = 0 atm
- ➢ no slip wall (u = 0 m/s)

Electromagnetics

- ➢ Insulated air domain $\nabla \times A = 0$
- ➢ DC current and number of coil turns
- ➢ *Pipe wall conductivity* ~ 0 S/m

Induced EMF in Fluid: COMSOL Multiphysics 3D Model Prediction

Physics Coupling and Governing Equations

Method Highlights
- Multi Turn Coil
- Segregated Solvers
- AMS solver for electromagnetics

Laminar Flow Module

Fluid Flow

Continuity:

$$\nabla . u = 0$$

Momentum:

$$\rho u \nabla u = -\nabla . p + \mu \nabla^2 u$$

u

Magnetic and Electric Fields Module

Electromagnetics

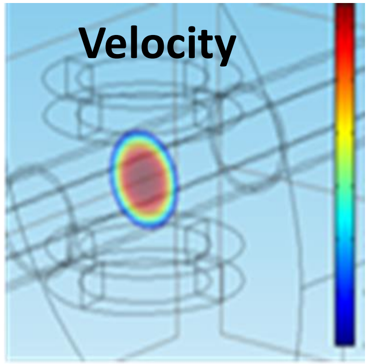
Ampere's law

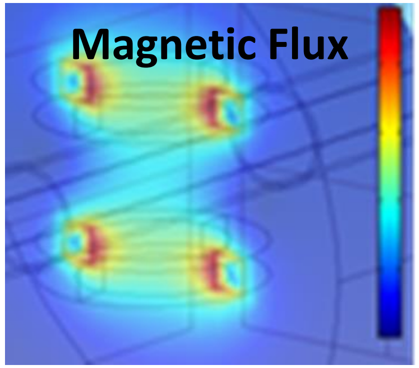
$$\nabla \times \mu_0^{-1} \mu_r^{-1} B = J$$

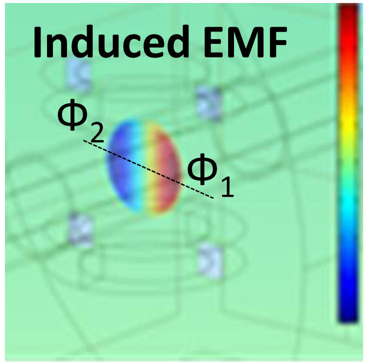
Ohm's law:

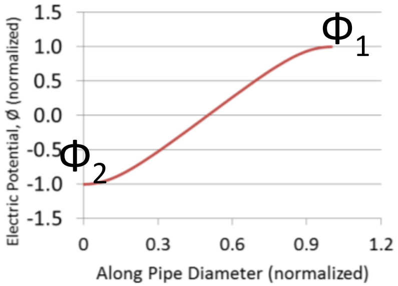
$$J_i = \sigma E + \sigma u \times B$$

p - pressure
u – velocity
μ - viscosity
μ_o-vac. permeability
μ_r-rel. permeability
B-magnetic flux density
J-current density
E-induced electric field
σ-conductivity



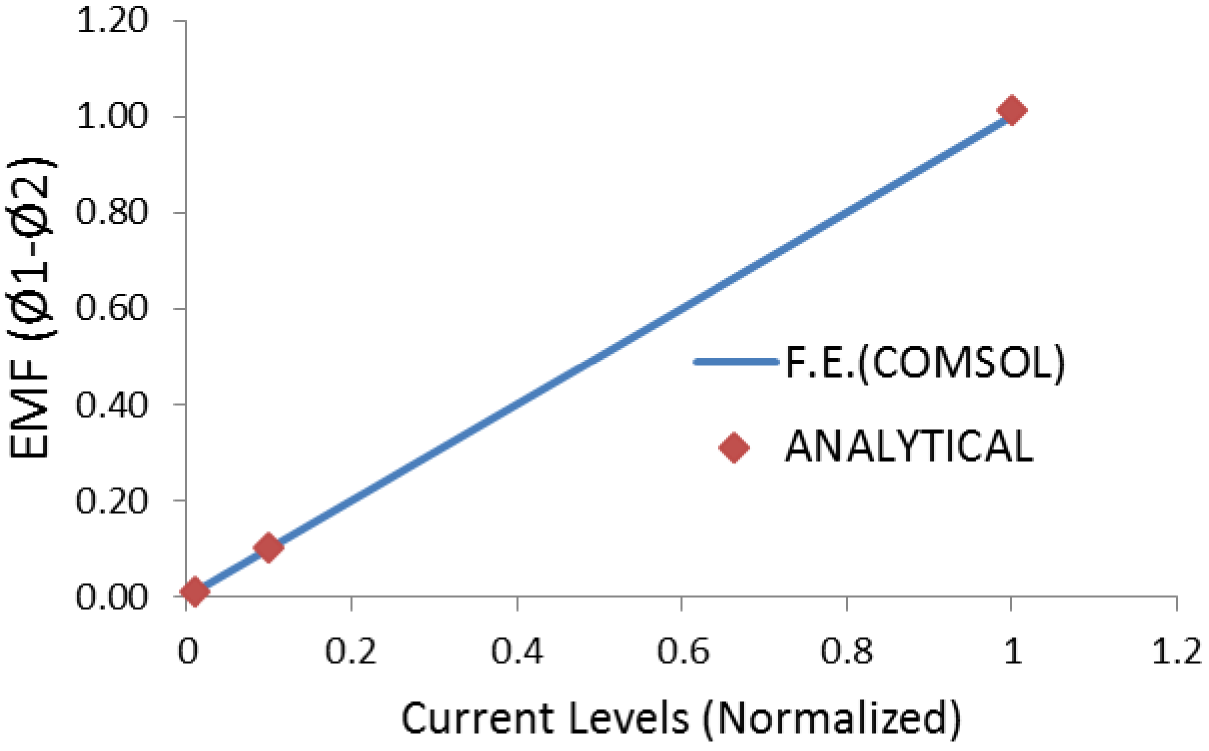


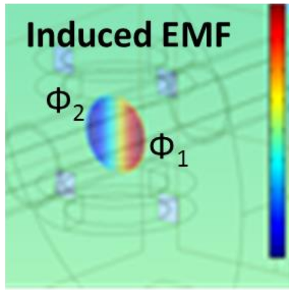


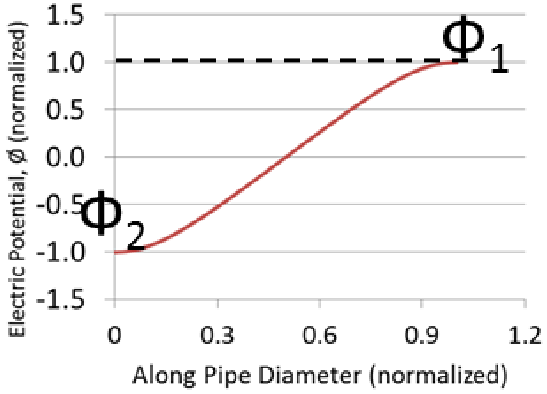


EMF = Φ_1-Φ_2

Comparison of 1D Analytical with 3D F.E. Results (Case 1: Electrically Insulated Pipe Wall)

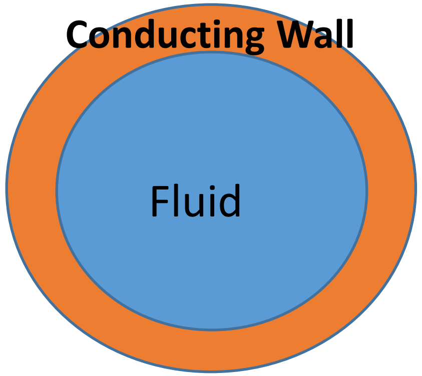






- **Analytical Calculations: Almost 1% Deviation F.E. Results**
- **Case: Electrically Insulated Pipe**
- **Analytical calculations useful in investigations**

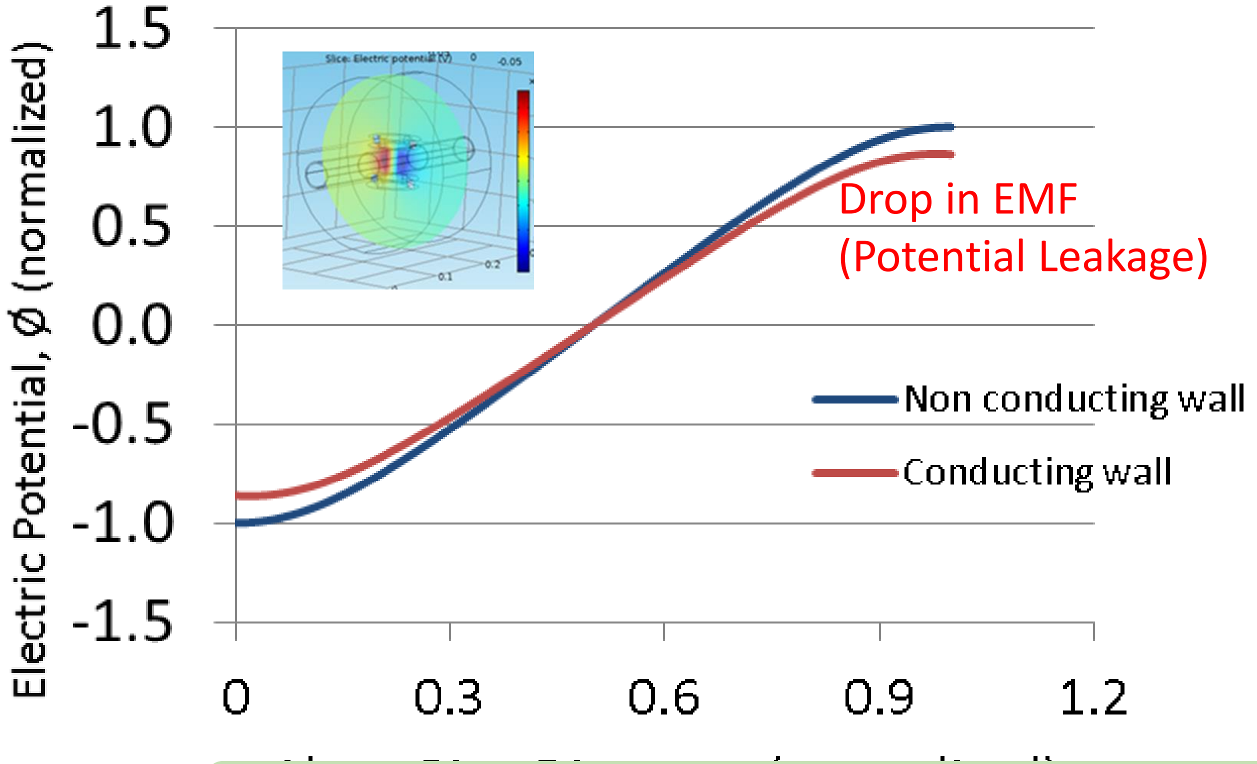
Comparison of 1D Analytical with 3D F.E. Results (Case 2: Electrically Conducting Pipe Wall)

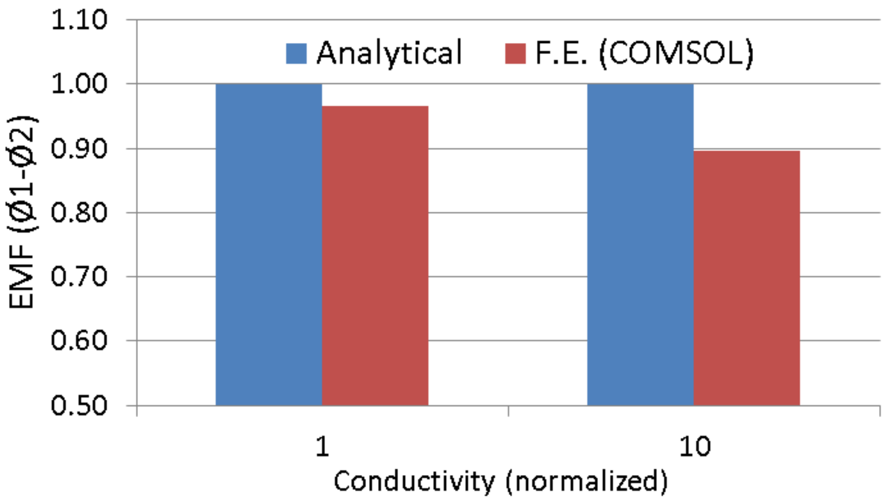


Induced EMF

$$\Phi_1 - \Phi_2 = BVD\left(1 + \frac{t\tau}{r\sigma}\right)^{-1}$$

B-Magnetic flux density
V-Average Velocity
D-Diameter
t-tube thickness
r-tube radius
σ-fluid conductivity





Analytical Calculations: Almost 1-10% Deviation with F.E. Results

Conclusions

- Simplistic cases: ID calculations useful in understanding MEHD phenomenon
- Complicated cases: 3D F.E. calculations necessary, Realistic Estimation using COMSOL Multiphysics
- Future Scope: 3D calculations can improve 1D results by incorporation of correction factor