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Calibration of MHD Flowmeter Using COMSOL Software

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Outline

- Introduction
- Flow meter description
- Usage of COMSOL
- Results
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- Calibration of Flow meter
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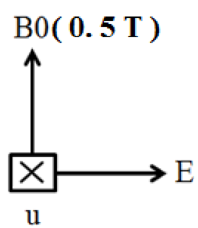
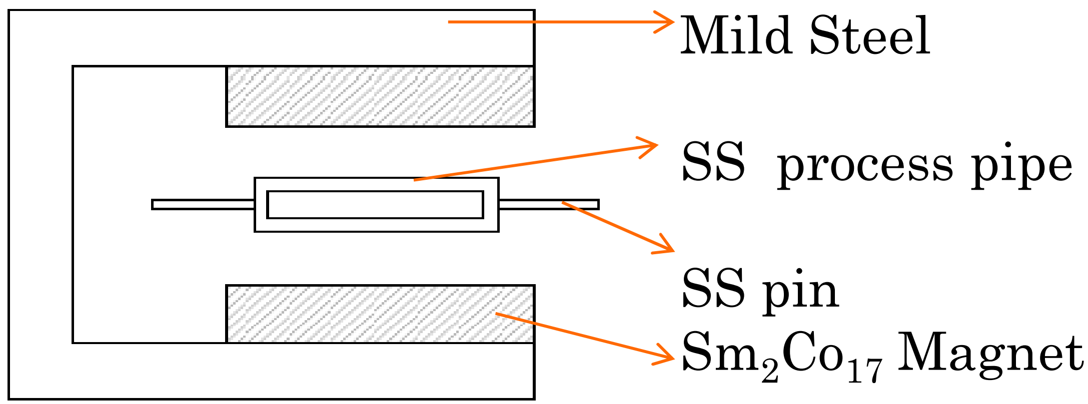
INTRODUCTION

- Nuclear reactors use Liquid metal as coolant
  - Fission (Pb, Pb-Bi, NaK)
  - Fusion (Pb-Li, Li)
- Reactor efficiency depends upon process parameters: flow rate, pressure
- Non-intrusive flow meter is indispensible for accurate flow measurement
- Liquid metals pertaining to nuclear applications have high melting point (Upto 500 ^oC)
- High temperature flow meters are not off the self items
- An economic way is to measure the induced voltage when the liquid metal flows in an applied transverse magnetic field

Flow meter Description

Principle: An induced voltage is developed, when a liquid metal moves in a transverse magnetic field, which is perpendicular to both the flow and magnetic field direction.





$E = K\,U$

E is the emf developed , U is the flow rate , K is the calibration coefficient

- ❖ Emf developed depends : magnetic field, dimension of the flow meter, thermo-physical properties of LM like, conductivity and viscosity as well as upon the conductivity of the process pipe
- ❖ Flow meter calibrated at one temperature with some liquid metal will not behave the same with other liquid metal or at another temperature
- ❖ Flow meter has to be calibrated each time with operating liquid metal and temperature which increase the cost of usage

Usage of COMSOL

- CFD and AC/DC module has been used
- Constitutive relation $\boldsymbol{B} = \mu_0 \mu_r \boldsymbol{H} + \boldsymbol{B}_r$
- Reynold's averaged Navier Stoke's equation

$$\rho(\boldsymbol{u}.\nabla)\boldsymbol{u} = \nabla[p\boldsymbol{I}+(\mu+\mu_T).(\nabla\boldsymbol{u} + (\nabla\boldsymbol{u})^T) - 2/3.\ \rho k\boldsymbol{I}] + \boldsymbol{J}\times\boldsymbol{B}$$

- Continuity equation $\rho\nabla.\boldsymbol{u} = 0$
- Generalized Ohm's Law $\boldsymbol{J} = \sigma(\boldsymbol{E} + \boldsymbol{u}\times\boldsymbol{B})$
- Ampere's Law $\nabla\times\boldsymbol{B} = \mu_m \boldsymbol{J}$
- Current conservation equation $\nabla.\boldsymbol{J} = 0$
- Maxwell's equations $\boldsymbol{E} = -\nabla\boldsymbol{V}$

Assumptions

- Liquid metal is a Newtonian fluid
- No slip at the wall
- Incompressible liquid metal
- Steady state equations

Boundary Conditions

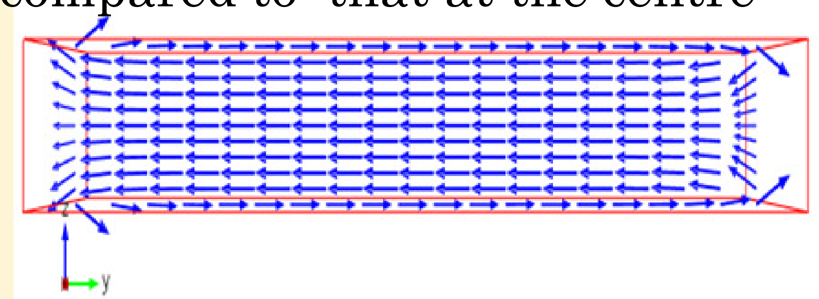
- As the flow rate is constant inlet velocity is made equal to outlet velocity
- For current at different boundaries

$\boldsymbol{n}\times\boldsymbol{J} = 0$

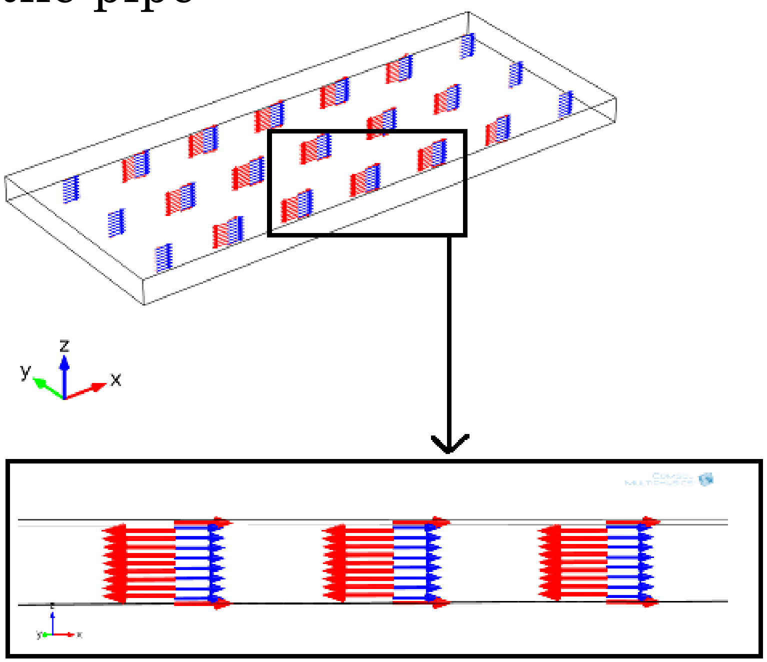
$\boldsymbol{n}.\boldsymbol{J}=0$

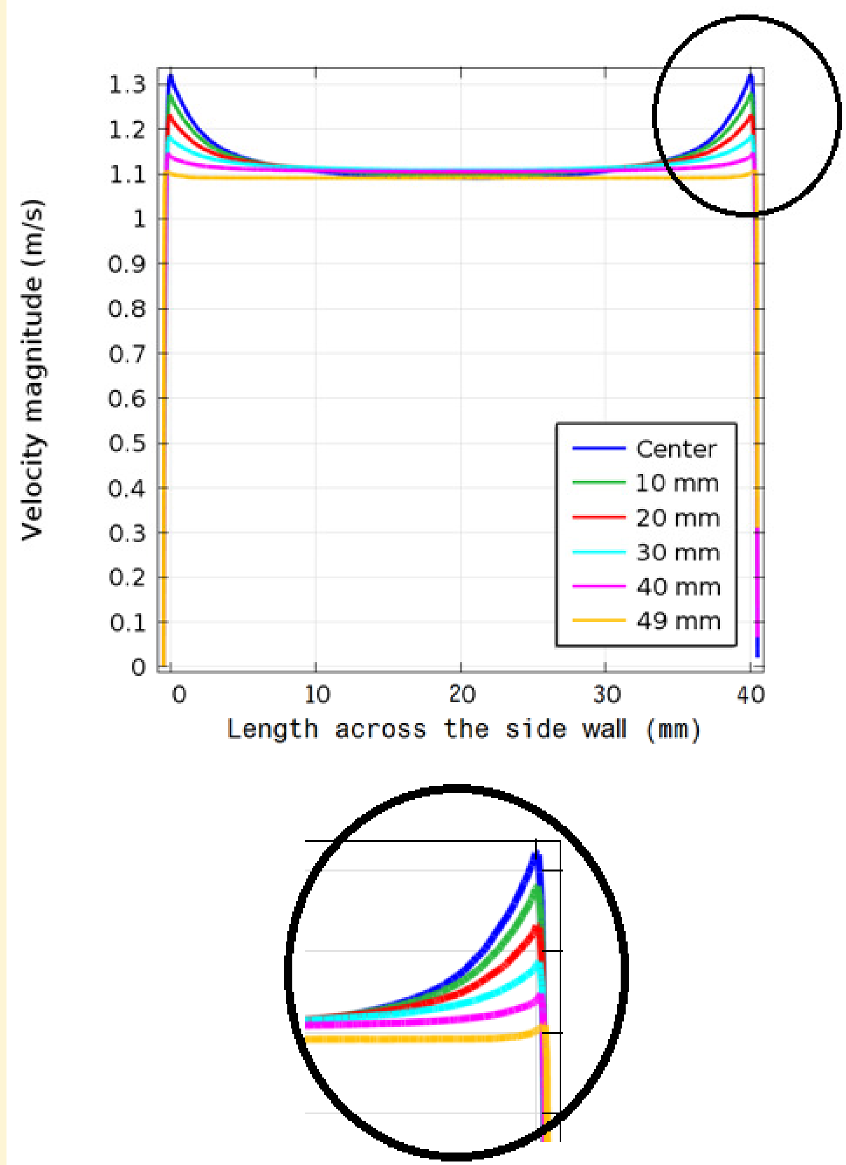
VELOCITY PROFILE

The induced current in the liquid metal is opposite at the wall as compared to that at the centre



The Lorentz force helps the flow at the wall and opposes at the centre of the pipe





Development of velocity profile as the LM proceeds in the magnetic field

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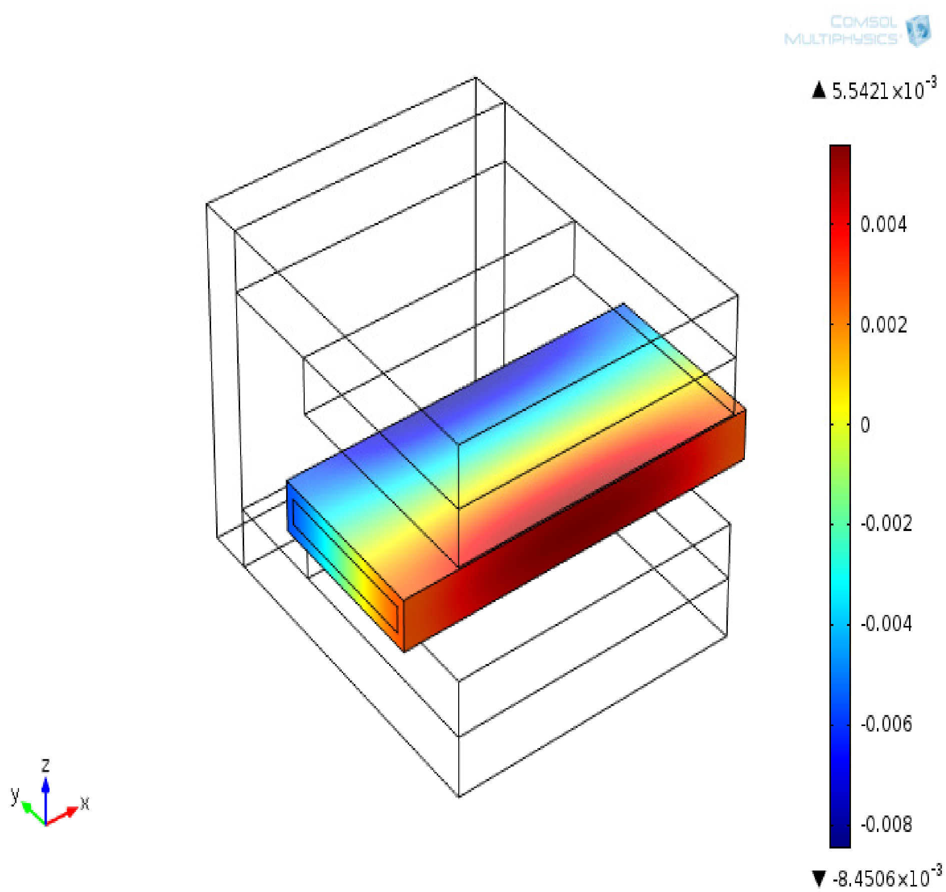
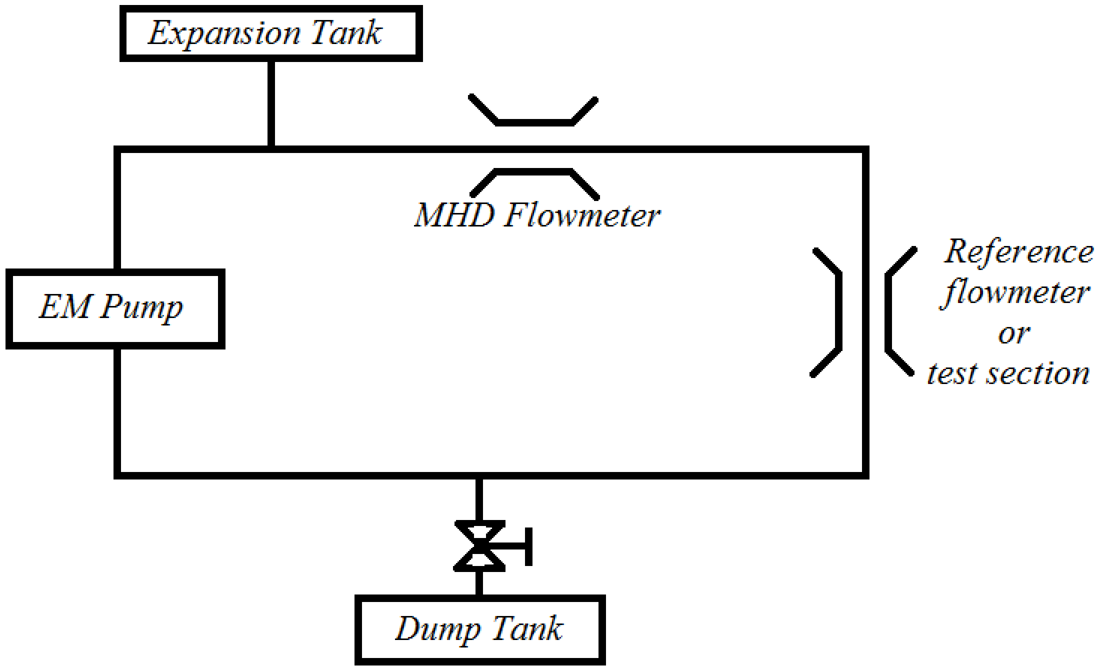
Induced Voltage



- Force experienced by the charge particles in the liquid metal generated the induced voltage
- The voltage induced is asymmetric with the pipe axis which may be due to the slight asymmetry in the magnetic field at one side
- The induced voltage in the LM is directly proportional to the LM flow velocity

The induced voltage developed at the pipe wall is the indicator of liquid metal flow rate

CALIBRATION OF THE FLOW METER

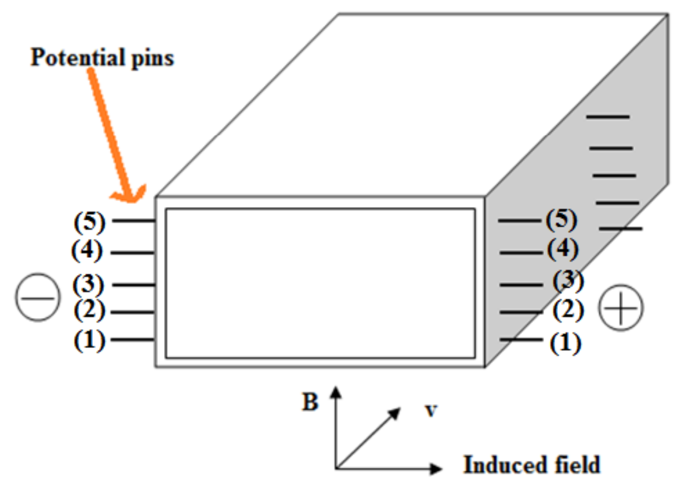


- Flow meter is calibrated by comparing the flow velocity obtained by a reliable source in a closed loop
- Reliable source was a venturimeter in case of Hg and a rectangular test section placed in a 4 T magnetic field in case of Pb-Li
- Various flow rate were obtained by changing the rpm of the EM pump

Flow rate Measurement

- In case of Mercury
  - A simple venturimeter was used
  - Venturimeter measures the flow rate by measuring the pressure drop at the constrictions present in the flow meter

- In case of Pb-Li
  - A rectangular test section placed in a 4 T magnetic field was used [Ref 9]
  - There is theoretical relation available for voltage developed [Ref 8]



(1).... (5) are the five pairs of potential pins

G_i be theoretical voltage obtained at i^{th} location

$$G_i = \varphi_{(-a/2,\, i))} - \varphi_{(a/2,\, i)}$$

and corresponding voltage obtained from the experiment be $\Delta\varphi_i$.

The average velocity at the i^{th} location

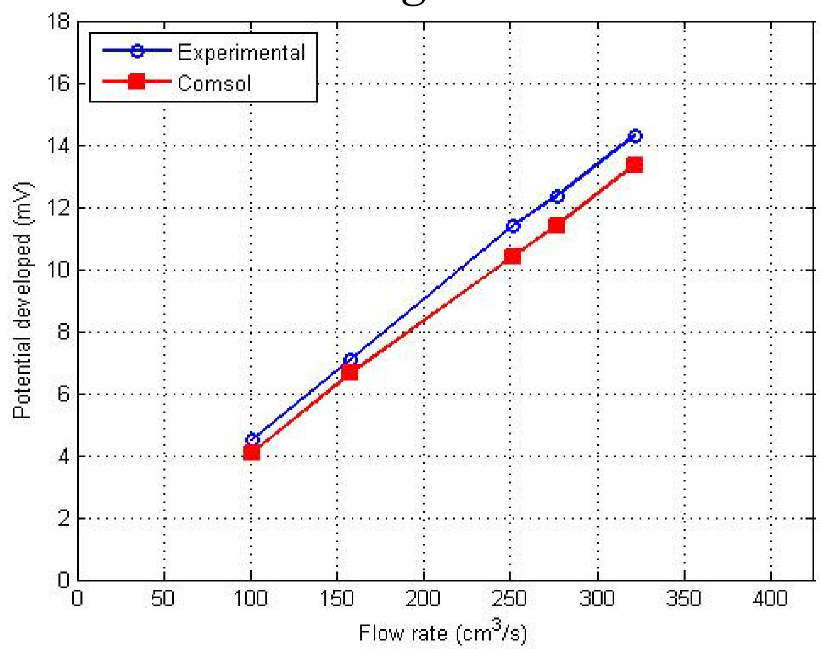
$$\bar{u}_i = \frac{\Delta\varphi_i}{B_0\, a\, G_i}$$

The average velocity in the channel cross section

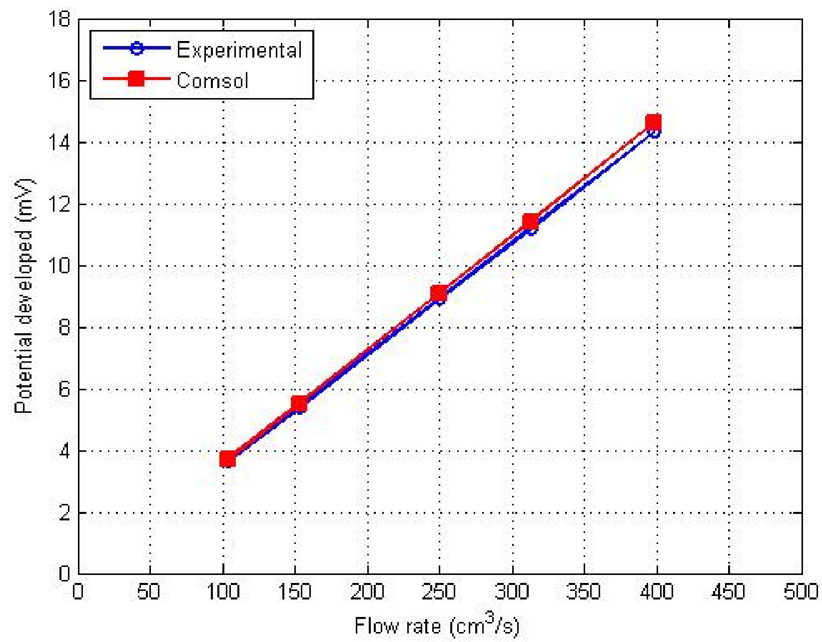
$$\bar{u} = \sum_{i=1}^{5} \frac{\Delta\varphi_i G_i}{a B_0 \sum_{k=1}^{5} G_k^2}$$

Comparison of Calibration Result

For Hg



For Pb-Li



Calibration coefficient for the flow meter

$$K = E / U$$

-There is slight mismatch of results in case of Hg which may be due to the fact that Hg does not wet the SS 316L surface

-There is good agreement in experimental and COMSOL result in case of Pb-Li

K	Experimental($mV.s/cm^3$)	COMSOL ($mV.s/cm^3$)	Error (%)
For Hg	0.0447	0.0418	6
For Pb-Li	0.0362	0.0357	2

Summary

- A technique for high temperature liquid metal flow measurement has been discussed.
- The flow meter calibration at high temperature using COMSOL has been discussed.
- There is a fairly good agreement between the experimental and COMSOL results for the calibration coefficient.
- The flow meter calibrated at one temperature and liquid metal can be calibrated at other temperature and liquid metal using COMSOL.
- The usage of COMSOL can reduce the cost of the repeated calibration work needed for the flow meter.

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Thank You