Analytical Method to Evaluate EMF Induced in Ionic Liquid By Magnetic Field

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Abstract

In the interest of computational time and resources, simplistic analytical calculations are often used to evaluate magneto hydrodynamic flow characteristics [1, 3]. However, given the assumptions in analytical calculations, like consideration of average values of input parameters and neglect of three dimensional effects, it is necessary to validate analytical calculations with Finite element (FE) tools to establish accuracy of the calculations. In this study an analytical approach was used to calculate emf induced in a flowing ionic liquid under the influence of a magnetic field perpendicular to the direction of flow. Subsequently, an FE element model built in COMSOL Multiphysics® [4] was used to check validity of the calculated emf.

Analytical: When a magnetic field traverses a flowing liquid, Lorentz forces act on the moving ions causing separation of the positive and negative ions and results in an induced emf. The emf is directly proportional to the cross product of velocity and magnetic flux density. If the tube wall is electrically and magnetically insulated (simplest case), the emf or potential difference across the diameter is calculated as [2, 3]:

$\Phi_{Analytical}=BVD$ (1)

Where B is magnetic flux density, V is fluid velocity, D is tube diameter. In the analytical calculations average values of water velocity (V) across an insulated pipe and magnetic field (B) traverse to the direction of flow were considered to determine Φ Analytical using eq. 1.

Finite Element Method: A FE model built in COMSOL Multiphysics (Figure 1) was used to check the accuracy of the analytical emf, Φ Analytical. The flow and magnetic field modules were enabled to simulate the interaction between the flow and magnetic fields to yield the resulting emf within the liquid:

$J=\sigma(E+v\times B)$ (2)

where J is internal current, E is induced electric field (gradient of electric potential, Φ) and $v\times B$ is the cross product giving the interaction between the magnetic and flow fields. The velocity term in equation (2) above was obtained by solving the flow equations of mass and momentum. The induced emf, ΦFE, across the pipe diameter perpendicular to the flow was obtained from the model to check the accuracy of Φ Analytical.

Results: Figures 1 (a) and (b) show water flowing through a pipe at an average value of V, used in the analytical calculations. Coils around the tube generate the magnetic field, B (Figure 2). Figure 3 shows the voltage field induced within the tube as a result of the flow-magnetic field interaction. The induced emf, ΦFE, across the pipe diameter perpendicular to the flow was obtained from the model. Φ Analytical was found to be 13-21% above ΦFE depending on the

current value (Figure 4). While this is a significant error, the analytical value is found to be realistic and the approach can be used for a rough estimation of the induced emf. The cause of error could be due to assumption of uniform magnetic field and velocity across the pipe which in reality varies across the domain.

Reference

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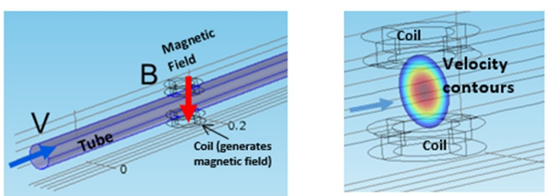
2. Shercliff J.A., 1987. The Theory of Electromagnetic Flow Measurement, Cambridge University Press, pp. 10-47.
3. Yamasaki H., Honda S., Jin D, Akiyama C., 2001. A Magnetic Flowmeter with Conducting Pipe Wall. Trans. of the Society of Instrument and Control Engineers, Vol. 1, 20/26.
4. COMSOL Multiphysics Ltd. Version 5. Burlington. MA.

Figures used in the abstract



(a) (b)

Figure 1: Figure 1: (a) FE model in COMSOL Multiphysics (b) Velocity contours of water in circular pipe (FE model)

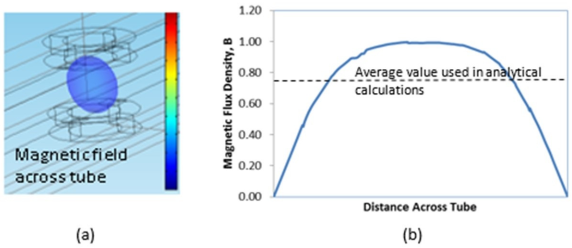


Figure 2: Figure 2: (a) Magnetic field contour across tube cross section, (b) Magnetic flux density (normalized with respect to maximum value) across tube cross section generated by FE model.

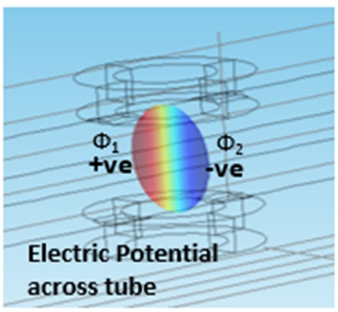


Figure 3: Figure 3: Electric Potential contours developed across tube due to interaction between velocity and magnetic fields (FE model). Computed potential difference (emf), ΦFE = Φ1 – Φ2

	Induced EMF		
Coil Current	Analytical	FE (COMSOL)	%error
0.2	9.60E-09	8.50E-09	13
1	4.90E-08	4.20E-08	17
10	5.10E-07	4.20E-07	21
100	4.90E-06	4.30E-06	14

Figure 4: Figure 4: Comparison between EMFs obtained using analytical and finite element (COMSOL) simulation. Coil current varied in each case.