Three Dimensional Numerical Study of the Flow Past a Magnetic Obstacle

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Introduction: The influence of inhomogeneous magnetic fields in MHD flows has been barely studied despite the fact that these fields are widely used in industry to manipulate molten metals, for example, in the continuous casting of steel they are used to brake and stir the melt. In this work, we use COMSOL to study the flow of a liquid metal past a localized magnetic field (a magnetic obstacle)[1] in a rectangular duct and compare with some experimental results [2].

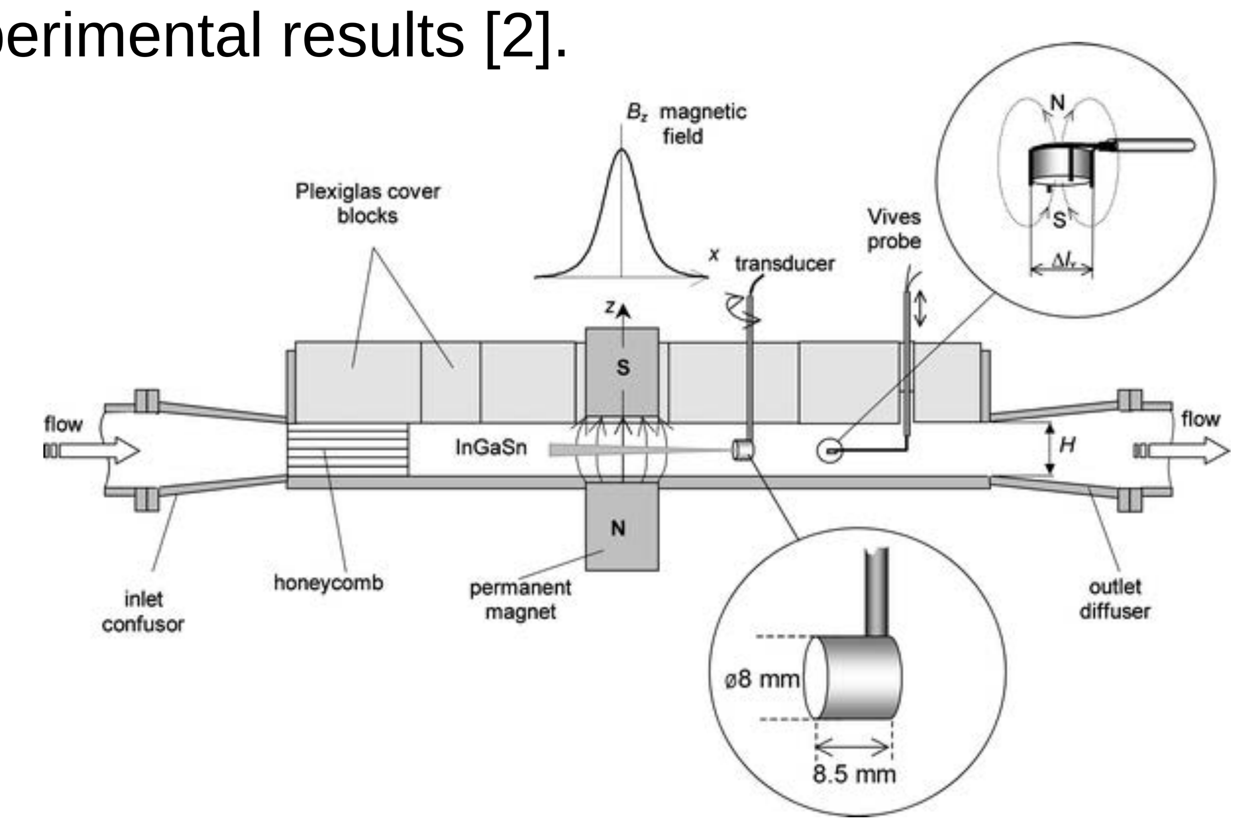


Figure 1. Sketch of the experimental test section[2].

Computational Methods

Navier-Stokes Eqs. (CFD) ⟷ Maxwell's Eqs. (AC/DC)

$$\rho(\boldsymbol{u}\cdot\boldsymbol{\nabla}) = \boldsymbol{\nabla}\cdot\left[-p\boldsymbol{I} + \eta(\boldsymbol{\nabla}\boldsymbol{u} + (\boldsymbol{\nabla}\boldsymbol{u})^T) - \frac{3}{2}\eta(\boldsymbol{\nabla}\cdot\boldsymbol{u})\boldsymbol{I}\right] + \boldsymbol{j}\times\boldsymbol{B}$$

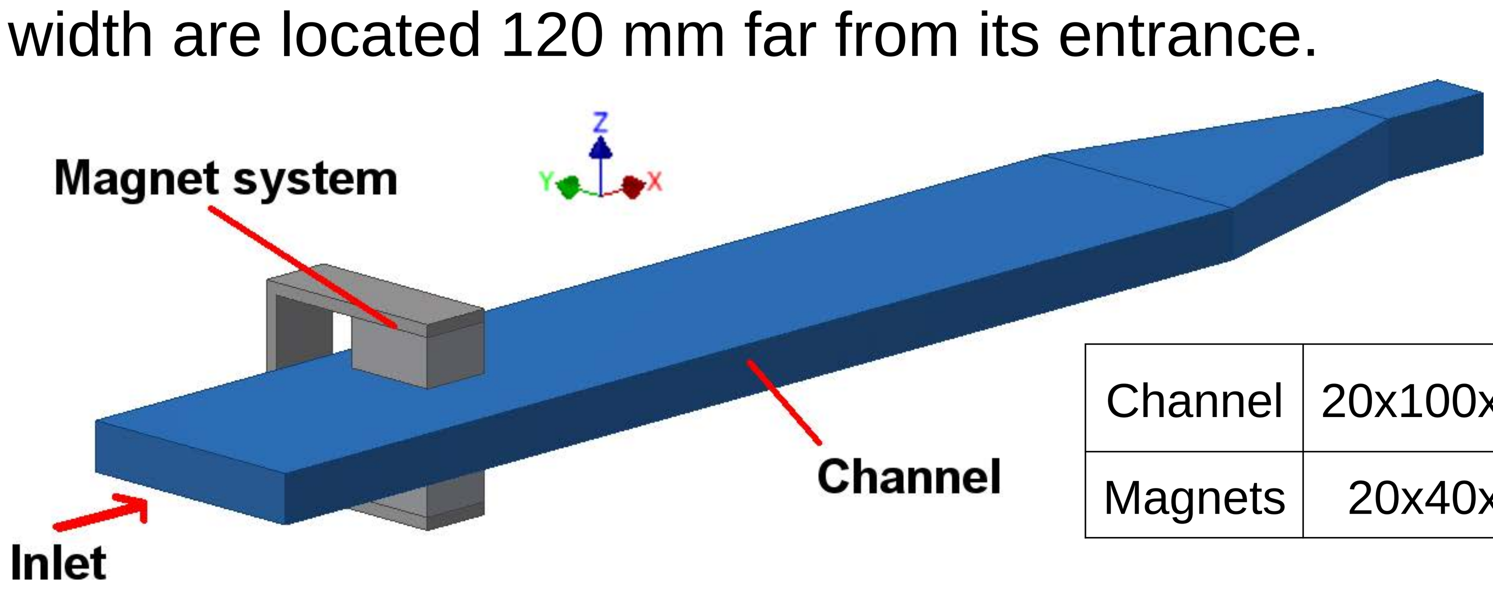
$$\boldsymbol{\nabla}\cdot(\rho\,\boldsymbol{u}) = 0$$

$\boldsymbol{u}$ ↓ ↑ $\boldsymbol{j}$

$$\boldsymbol{\nabla}\cdot\boldsymbol{j} = \boldsymbol{\nabla}\cdot(\sigma\boldsymbol{u}\times(\boldsymbol{\nabla}\times\boldsymbol{A}) - \boldsymbol{\nabla}V) = 0$$

$$\boldsymbol{\nabla}\times\left(\frac{\boldsymbol{\nabla}\times\boldsymbol{A}}{\mu_r\mu_0}\right) = \sigma(\boldsymbol{u}\times(\boldsymbol{\nabla}\times\boldsymbol{A}) - \nabla V) \qquad \boldsymbol{B} = \boldsymbol{\nabla}\times\boldsymbol{A}$$

Formulation of the problem: Liquid metal (GaInSn) flows in a rectangular channel. A pair of magnets smaller than the channel width are located 120 mm far from its entrance.



Channel	20x100x500	mm³
Magnets	20x40x30	mm³

Figure 2. Geometry of the flow past a magnetic obstacle. Air is not plotted.

Magnetic filed computation: The distribution of the magnetic field plays a key role in the flow. The calculated field was validated with a different magnetic system[3], where the same kind of magnets were used.

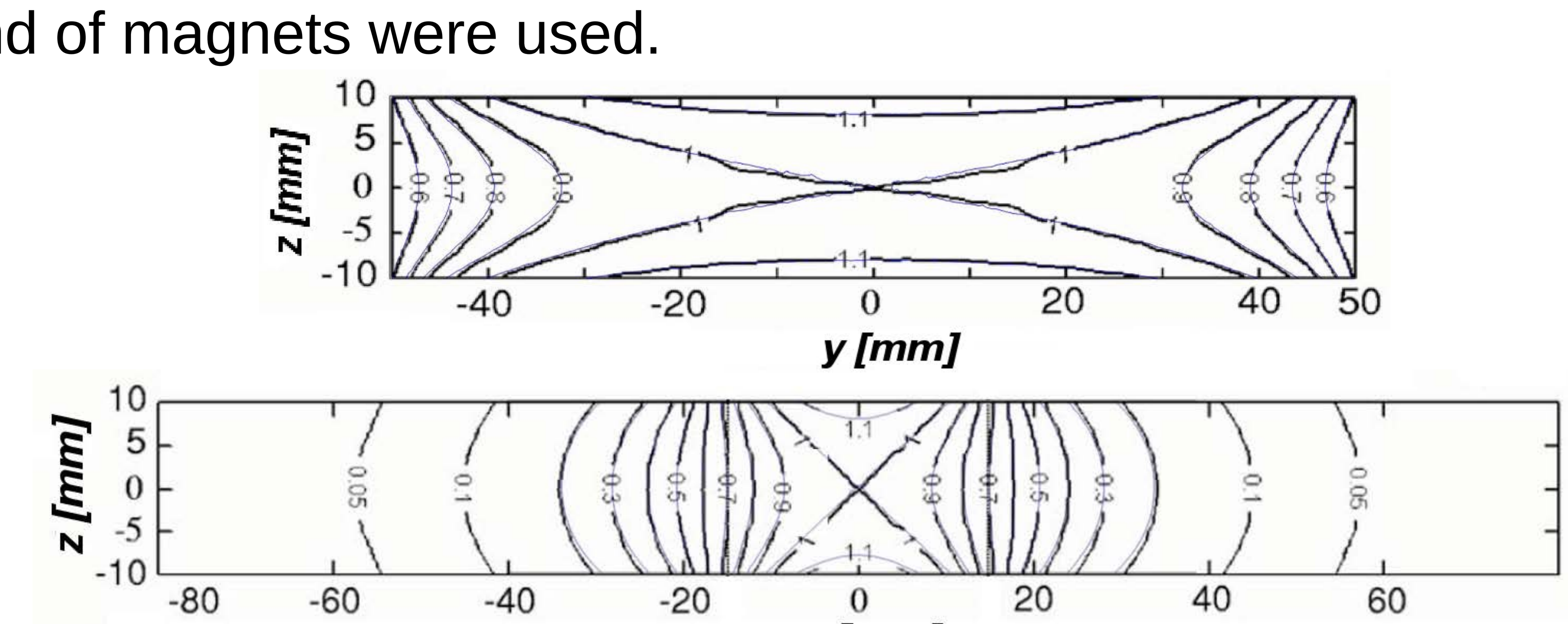


Figure 3. Comparison of experimental data[3] and numerical simulation (thin blue line).

Experimental results: Different steady vortex patterns were observed as Re=U*l*/h is varied.

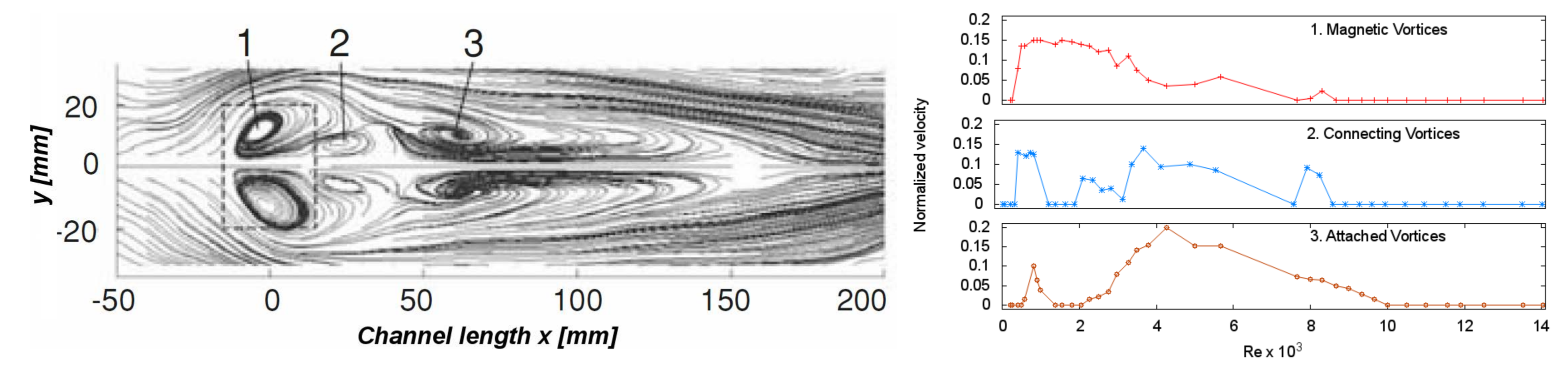


Figure 4. Streamlines for Re=4000[2] (left) and local maximum normalized velocity as function of Re[4] (right).

Results

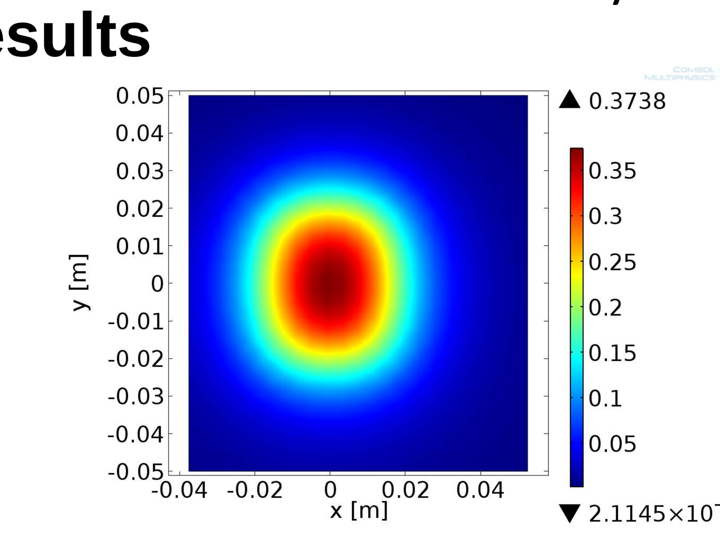


Figure 5. Calculated **Bz** in *xy* plane.

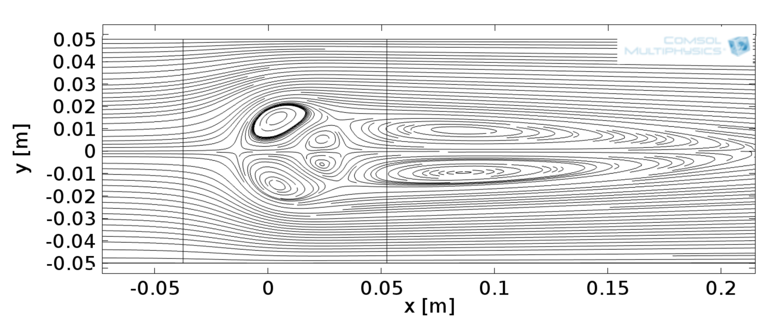


Figure 6. Calculated streamlines for Re=4000.

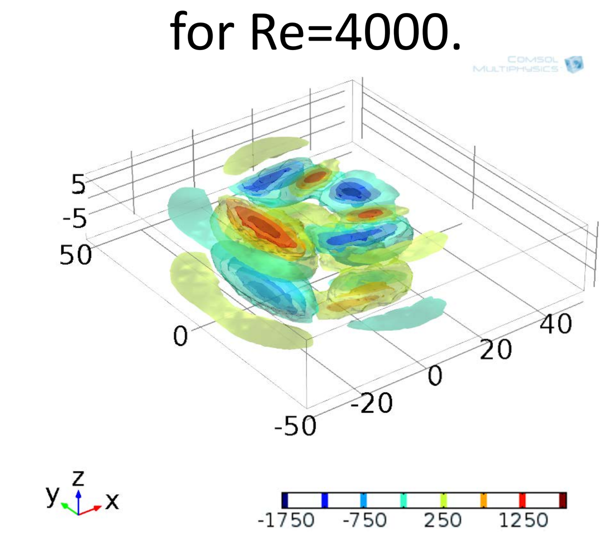
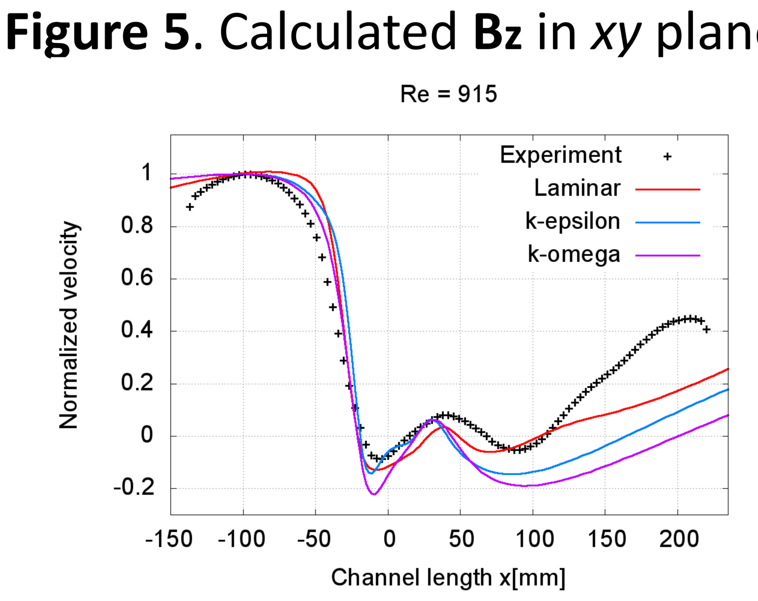


Figure 7. Isosurfaces of **Fz**.



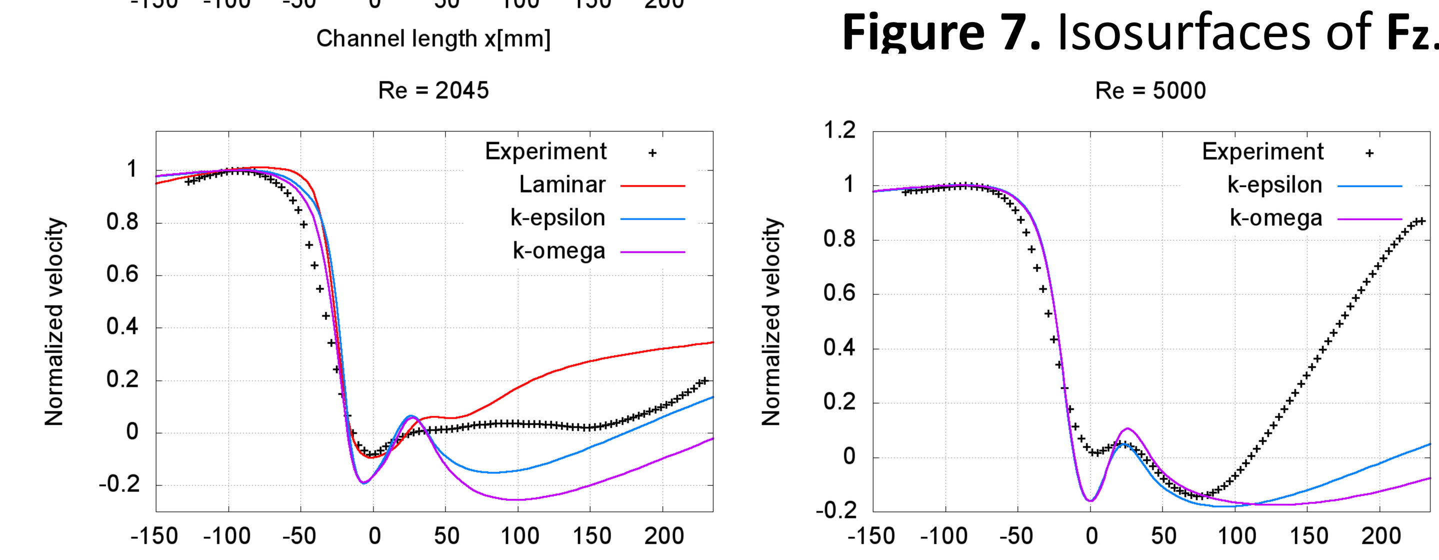


Figure 8. Comparison of numerical results obtained with COMSOL for the central axial velocity and experimental data.

Conclusions: Comparison of different fluid dynamic models (laminar, k-epsilon and k-omega) with experiments has been done. For Re < 2050, the laminar model fits better to the experimental data than turbulent models, while for Re > 2050 the turbulent models present a better agreement but still do not reproduce the behavior accurately in the whole region. Nevertheless, results suggest that the dynamics of vortex patterns as Re is increased may be due to the transition from a laminar to turbulent regime.

Even though simulations capture the essential physics of the flow, COMSOL models may need to be improved when used for simulations of liquid metal flows. In a future analysis the transient flow will be studied and modified wall functions suited for MHD problems will be implemented.

References:

1.S. Cuevas et al., *On the flow past a magnetic obstacle.* Journal of Fluid Mechanics, 553,227–252 (2006).
2.O. Andreev et al., *Application of the ultrasonic velocity profile method to the mapping of liquid metal flows under the influence of a non-uniform magnetic field*, Experiments in Fluids, 46 (2009).
3.O. Andreev et al., *Experimental study of liquid metal channel flow under the influence of a nonuniform magnetic field*, Phys. Fluids 19, 039902 (2007).
4.M. Rivero et al., *Experimental study of flows past a magnetic obstacle* on 8th PAMIR International Conference on Fundamental and Applied MHD (2011).