Three Dimensional Numerical Study of the Flow Past a Magnetic Obstacle

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Excerpt from the Proceedings of the 2013 COMSOL Conference in Boston
MOTIVATION

The influence of inhomogeneous magnetic fields in MHD flows has been barely studied despite the fact that these fields are widely used to manipulate, brake, stir or characterize show flows.


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MAGNETIC OBSTACLE

The interaction of the fluid flow and the externally applied magnetic field induces a force that brakes the flow.

On the analogy between streamlined magnetic and solid obstacles. E. Votyakov et al., Physics of Fluids (2007)
MAGNETOHYDRODYNAMIC EQUATIONS

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

\[ \nabla \cdot (\rho \, u) = 0 \]

\[ \nabla \cdot j = \nabla \cdot (\sigma u \times (\nabla \times A) - \nabla V) = 0 \]

\[ \nabla \times \left( \frac{\nabla \times A}{\mu_r \mu_0} \right) = \sigma (u \times (\nabla \times A) - \nabla V) \quad B = \nabla \times A \]
PROBLEM DESCRIPTION

Experimental setup.

Simulated geometry.

Channel: 20x100x500 mm³
Magnets: 20x40x30 mm³
Neodymium-Iron-Boron
Bmax ~ 0.4 T
Fluid: GaInSn
Melting temperature ~10 °C
Electrical conductivity ~ 3.46*10⁶ S/m
Density = 6360 kg/m³

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UDV MEASUREMENT

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STEADY VORTEX PATTERNS

Magnetic Vortices

Connecting Vortices

Attached Vortices

$Re = \frac{U_0 \ell}{\nu}$

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Comparison of numerical results for the axial velocity and experimental data.

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COMPARISON

Streamlines for the time averaged flow over a magnetic obstacle

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Vertical component of the Lorentz force
LORENTZ FORCE DISTRIBUTION

Instability of the Hartmann layer

BL thickness

Flow over a flat plate

\[ \delta_{Re} \sim \frac{\ell}{Re^{1/5}} \sim 0.016 \ m \]

\[ \delta_{Ha} \sim \frac{\ell}{Ha} \sim 0.07 \ mm \]

\[ Ha = B_0 \ell \sqrt{\frac{\sigma}{\nu \rho}} \]

Vertical component of the Lorentz force

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CONCLUSIONS AND FURTHER WORK

Simulations capture the essential physics of the flow.
• For $Re < 2050$, the laminar model fits better to the experimental data than turbulent models,
• $Re > 2050$ the turbulent models present a better agreement but still do not reproduce the behavior accurately in the whole region.
• Results suggest that the dynamics of vortex patterns as $Re$ is increased may be due to the transition from a laminar to turbulent regime.

★ Implementation of wall functions suited for MHD problems.
★ Transient flow.
★ Multiphase flow (Gallium oxides).
Thanks for your attention!

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*Also in poster session
O. Andreev et al., Experimental study of liquid metal channel flow under the influence of a nonuniform magnetic field, Phys. Fluids 19

Vertical magnetic field at the midplanes of the channel.

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