Presented at the 2011 COMSOL Conference

A Study of Fluid Flow and Heat Transfer in a Liquid Metal in a Backward-Facing Step under Combined Electric and Magnetic Fields

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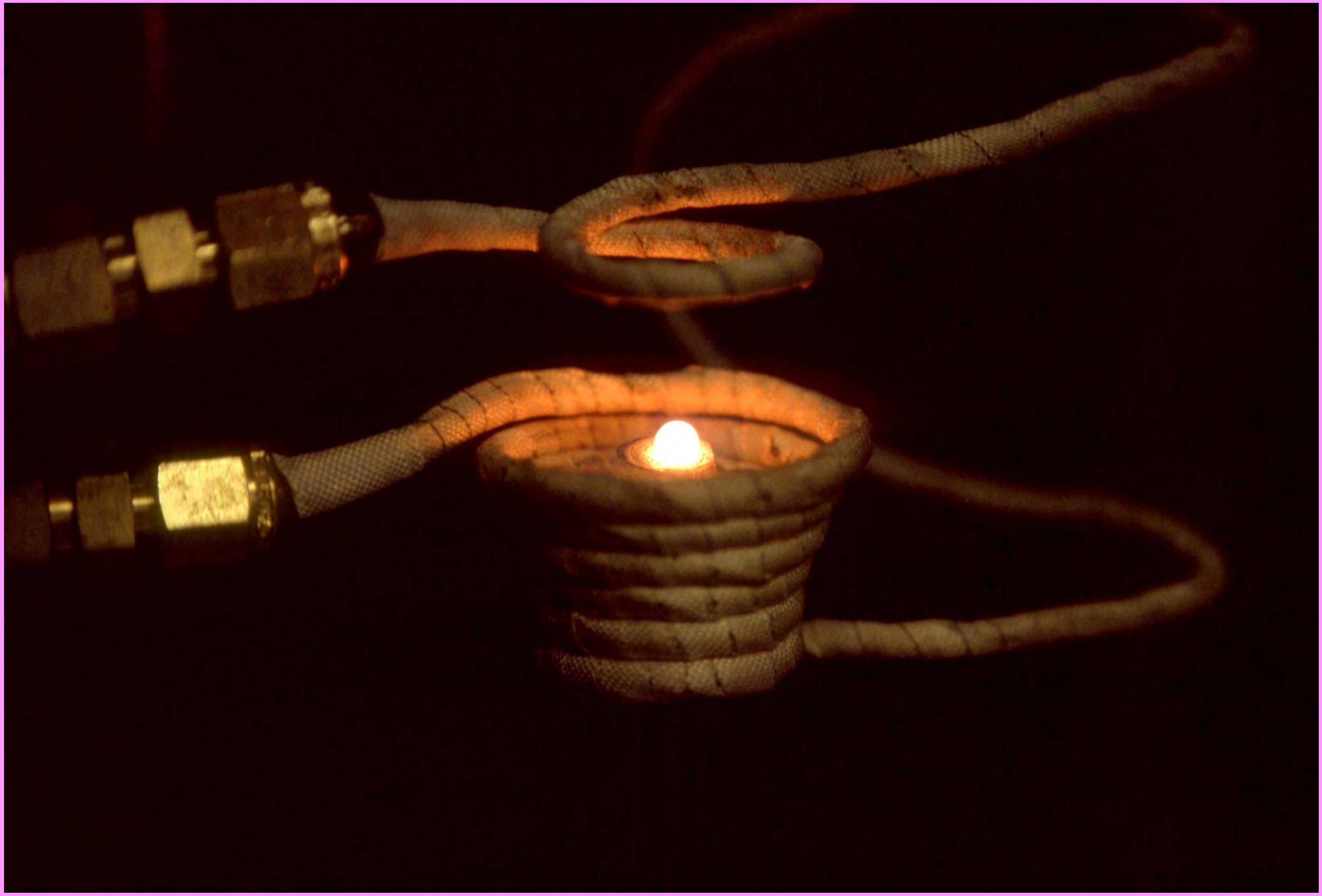
Motivation and Background

- Applied electromagnetic (EM) fields produce body forces in electrically conducting fluids.
- Electromagnetic body forces affect and modify the fluid flow.
- Electromagnetic fields can and are used to influence the fluid flow behavior of electrically conducting fluids.
- Some common industrial applications include EM braking in continuous casting, levitation melting, EM shaping and EM pumping.
- Reliable, easy to use, multi-physics analytical methods for the prediction of the effects of EM fields on fluid flow and heat transfer phenomena in electrically conducting fluids are needed.

Example: Induction Melting



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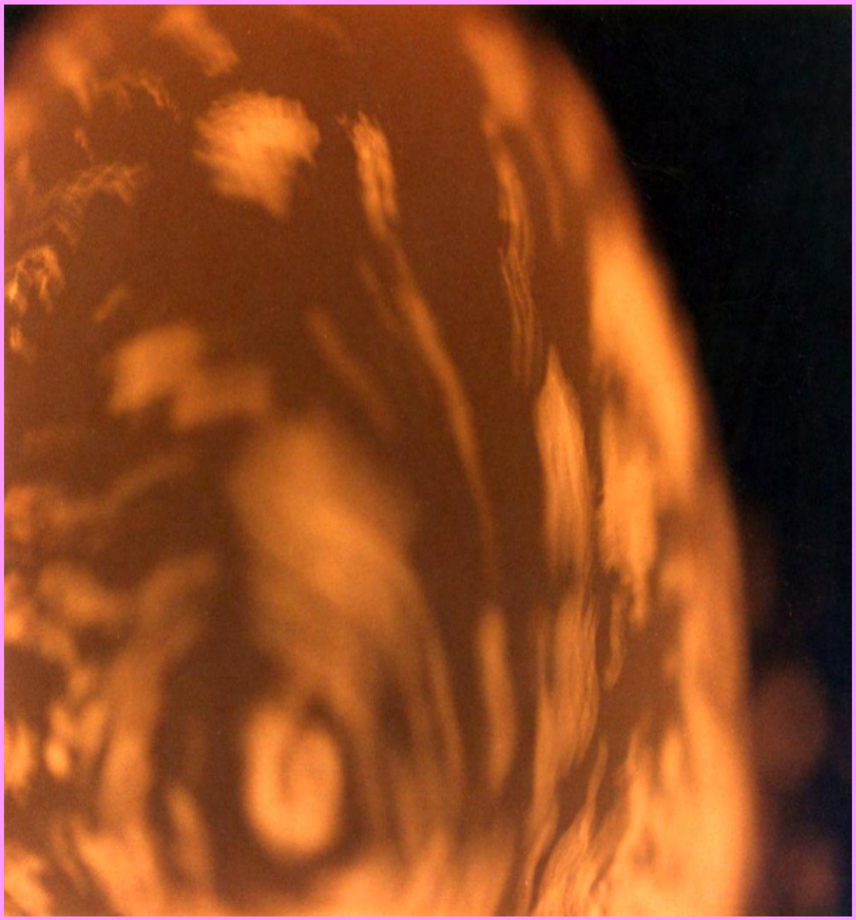


Governing Equations

$\nabla \times \mathbf{E} = - \partial \mathbf{B}/\partial t$ (Faraday's Law)

$\nabla \times \mathbf{B} = \mu \mathbf{J}$ (Ampere's Law)

$\nabla \cdot \mathbf{B} = 0$

$\nabla \cdot \mathbf{J} = 0$ (Kirchoff's First Law)

$\mathbf{J} = \sigma (\mathbf{E} + \mathbf{v} \times \mathbf{B})$ (Ohm's Law – No Hall effect)

$\nabla \cdot \mathbf{v} = 0$ (Continuity)

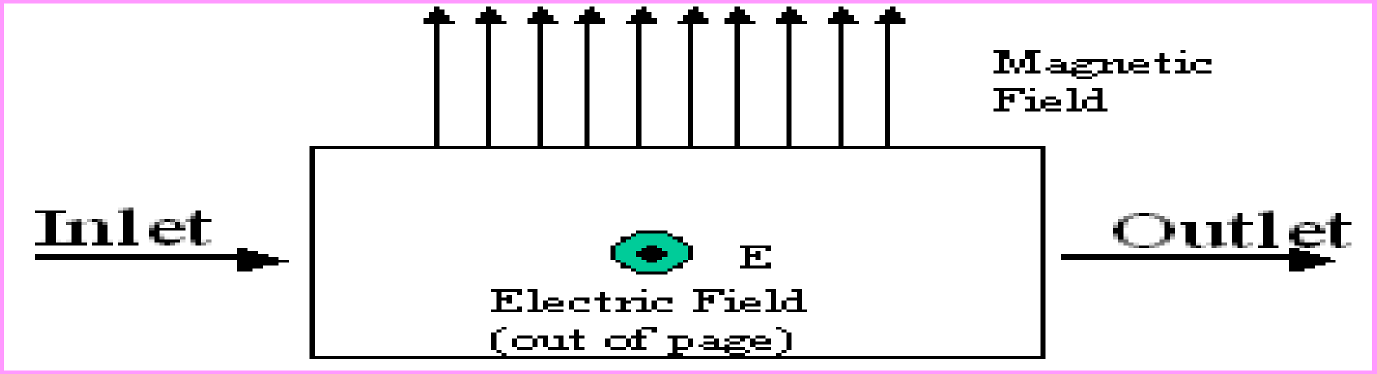
$\varrho\, \partial \mathbf{v}/ \partial t + (\mathbf{v} \cdot \nabla) \mathbf{v} = - \nabla p + \mathbf{J} \times \mathbf{B} + \eta \nabla^2 \mathbf{v}$ (Navier-Stokes)

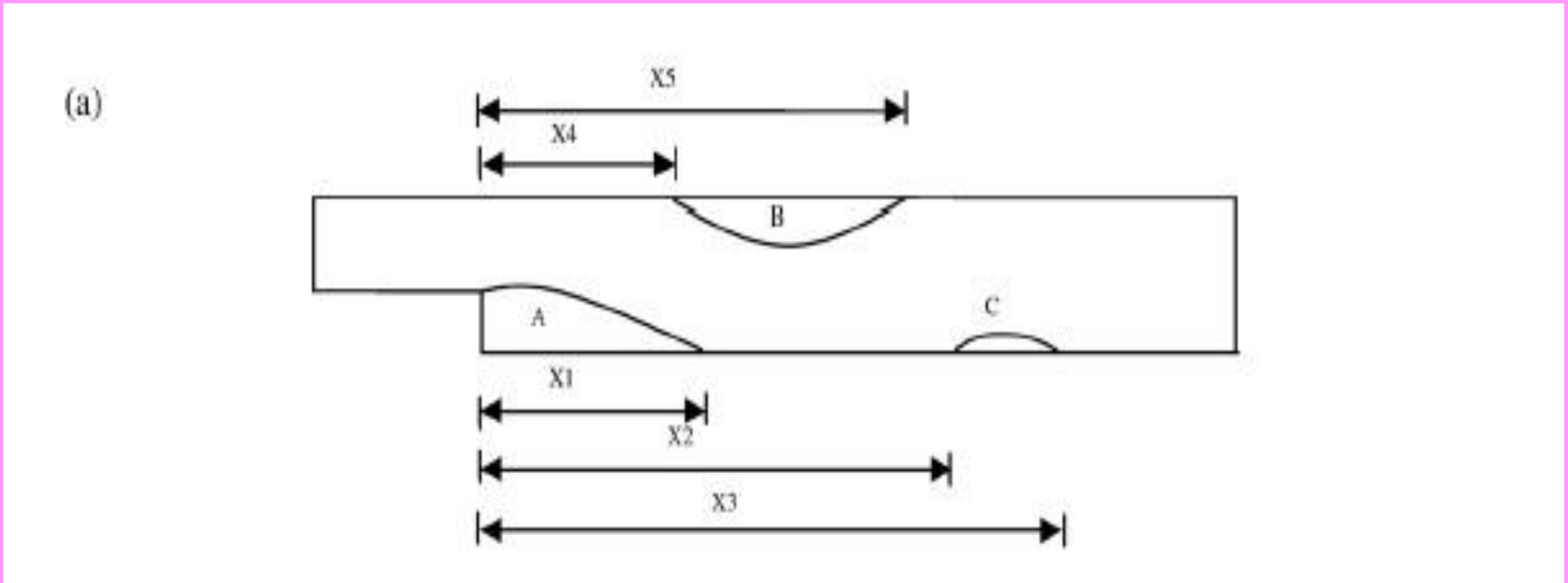
$\varrho\, C_p\, \partial T/ \partial t + \mathbf{v} \cdot \nabla \mathbf{T} = k \nabla^2 T$ (Energy Equation)

Model Description

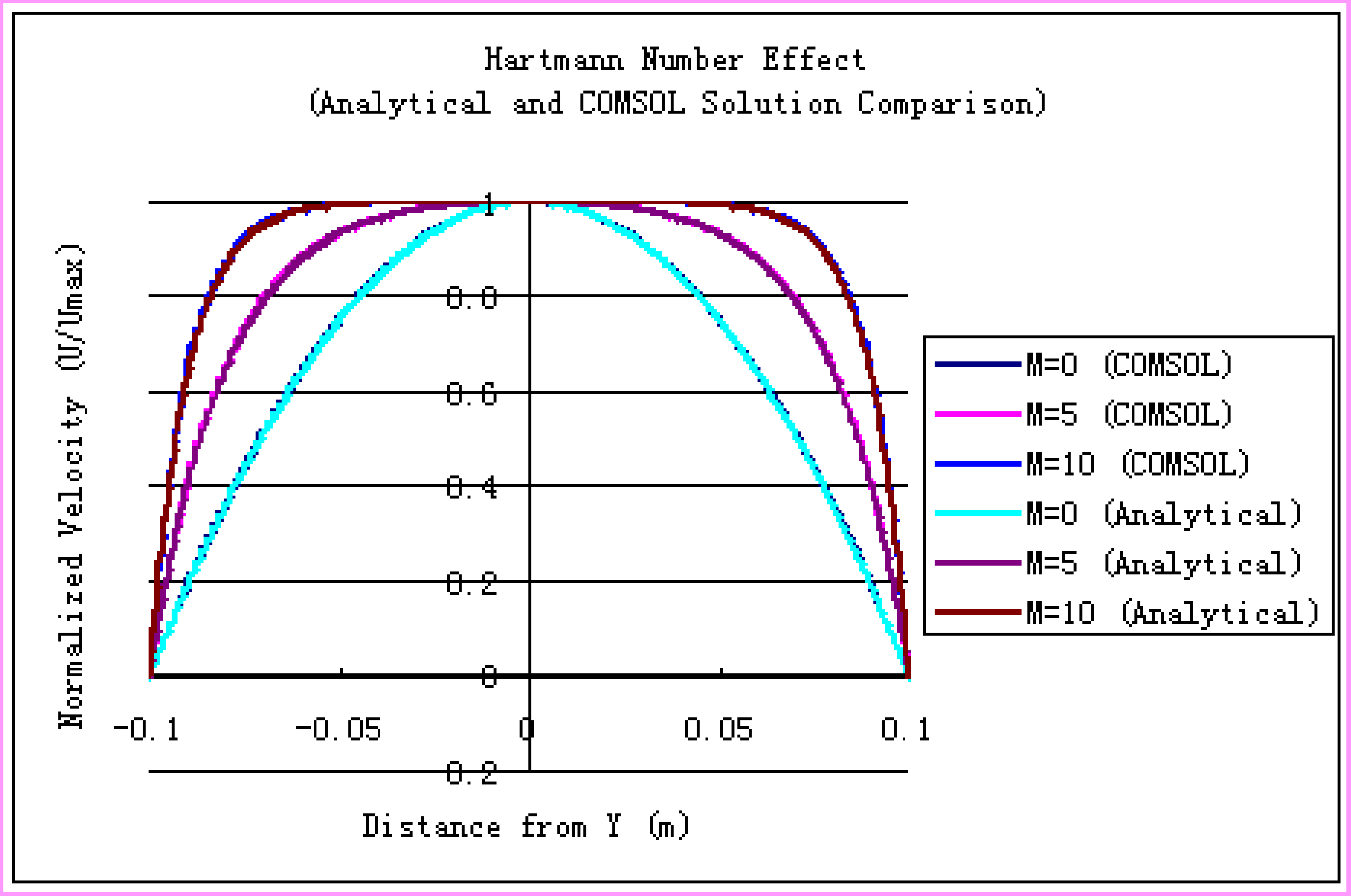
- To gain confidence in the approach and validate modeling work two simple configurations were selected for analysis.
- Steady Laminar Hartmann Flow. A conducting fluid flows between two large parallel plates. Magnetic field applied perpendicular to the plane of the plates. Electric field (if any) applied perpendicular to the plane formed by the fluid velocity and the magnetic field.
- Steady Laminar Flow around a Backward Facing Step. A conducting fluid flows between two large parallel plates and it comes into a backward facing step where a magnetic field is applied perpendicular to the plane of the plates. Electric field (if any) applied perpendicular to the plane formed by the fluid velocity and the magnetic field. The presence of the step, in general leads to flow separation and the formation of vortex structures.
- The working fluid was NaK.

Flow Geometries

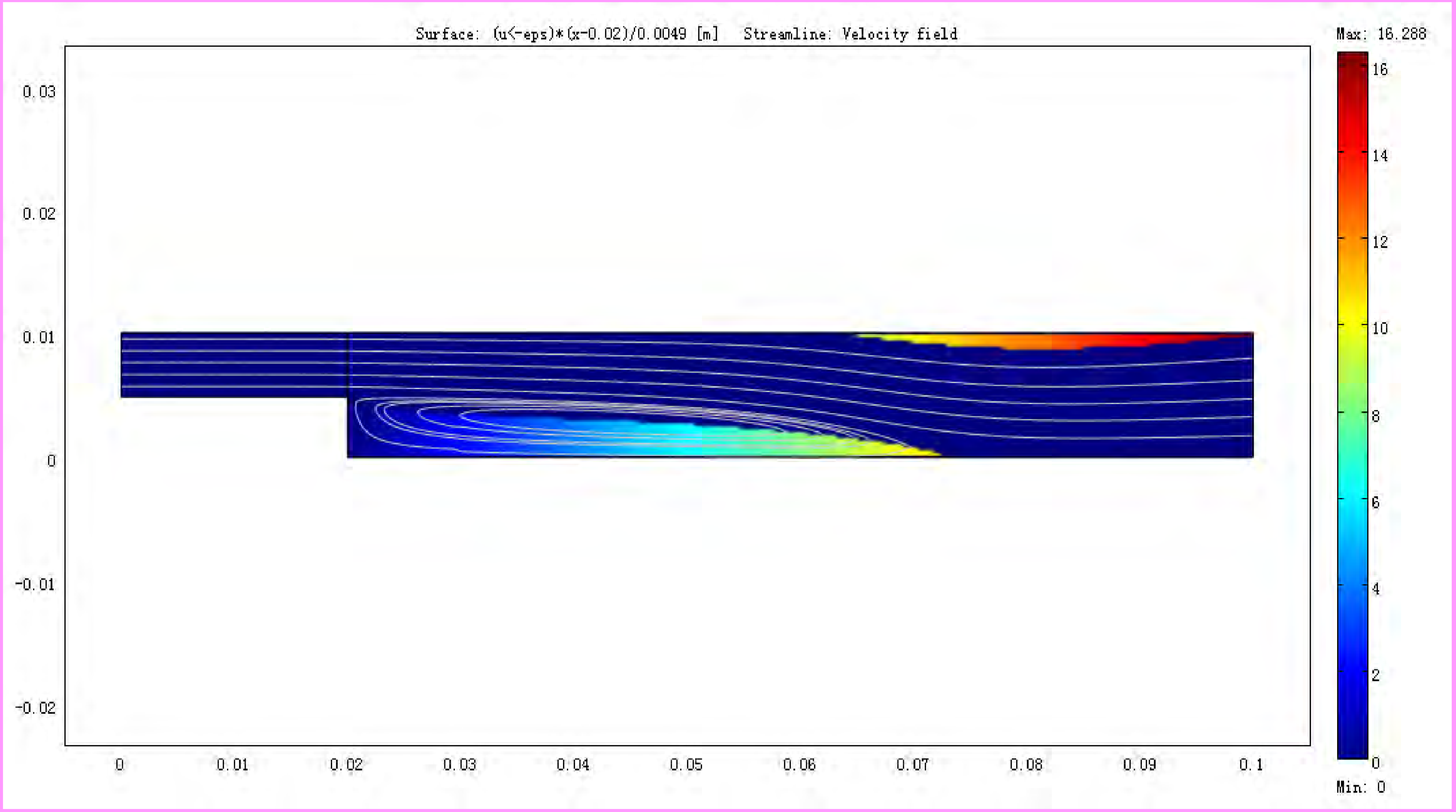




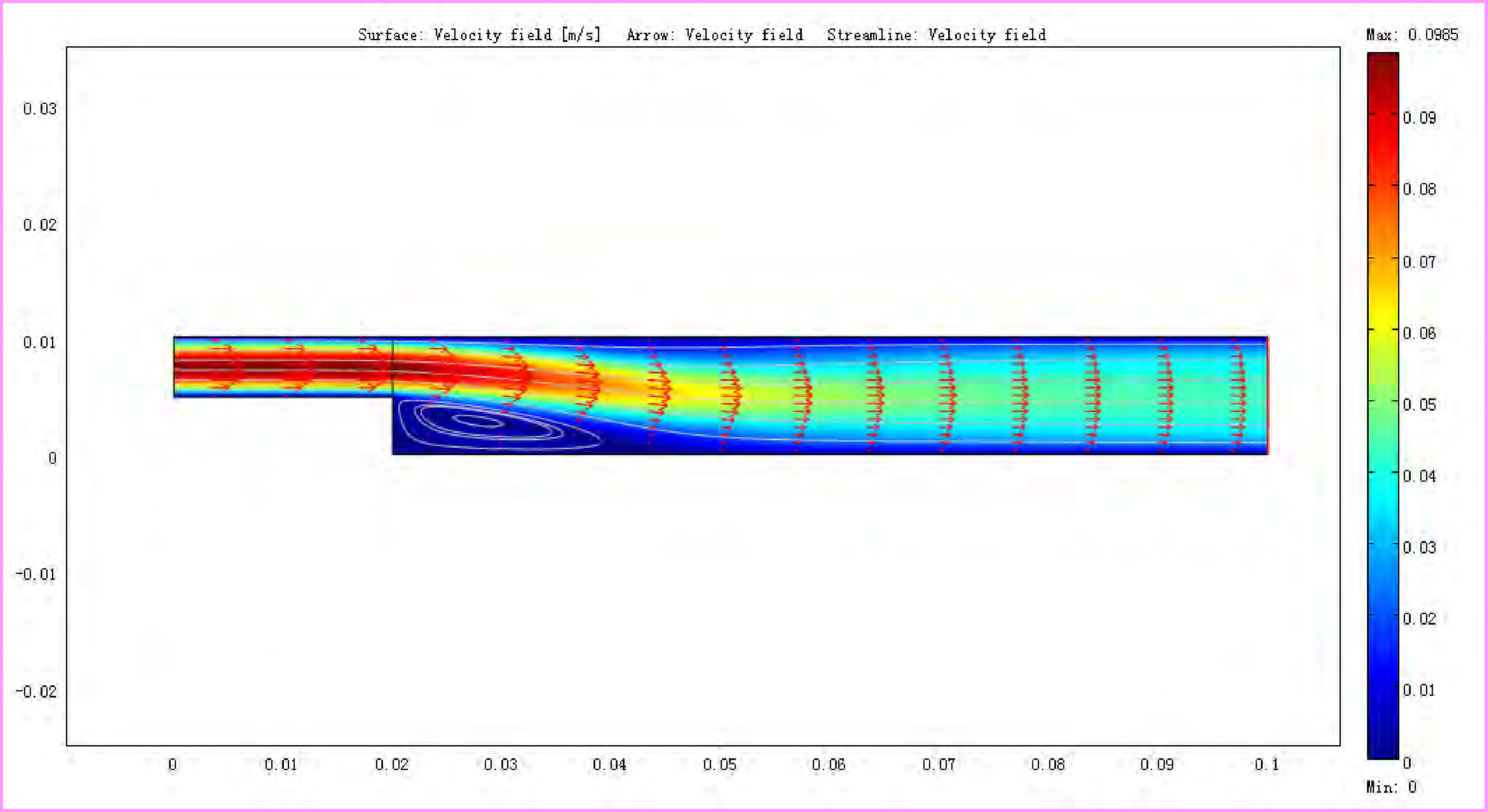
Hartmann Flow Results



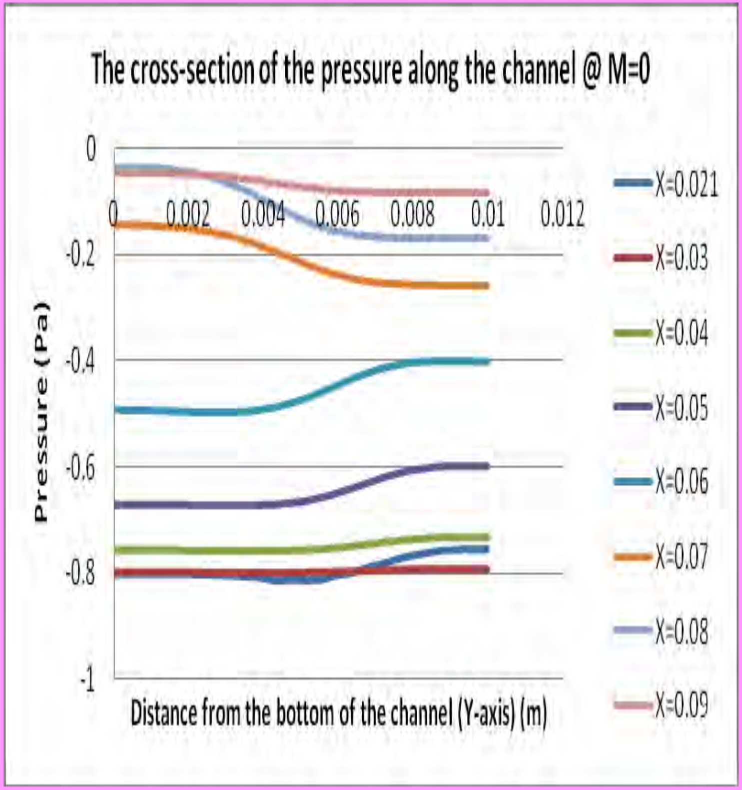
Step Flow Results (no EM field)

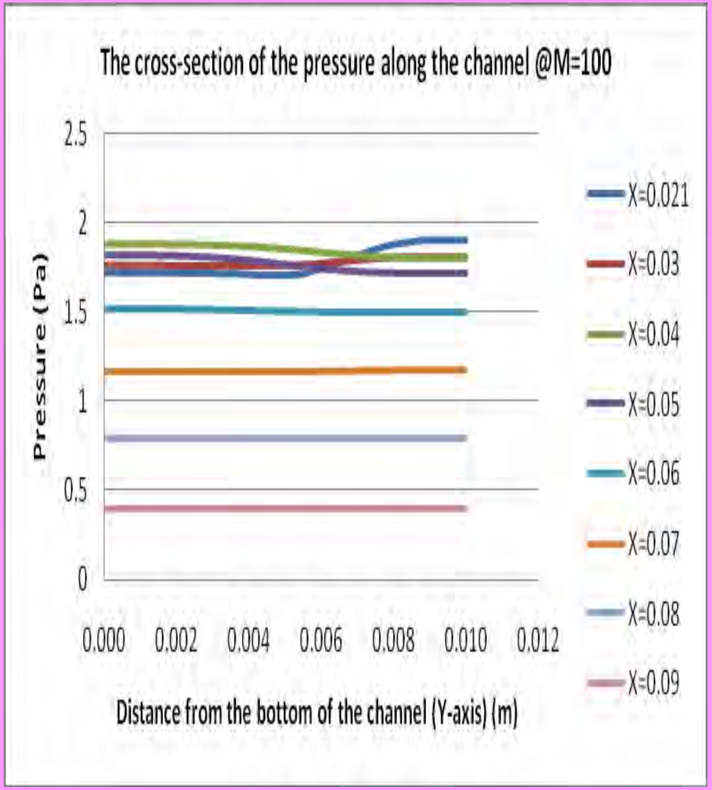


Step Flow Results (EM field applied)

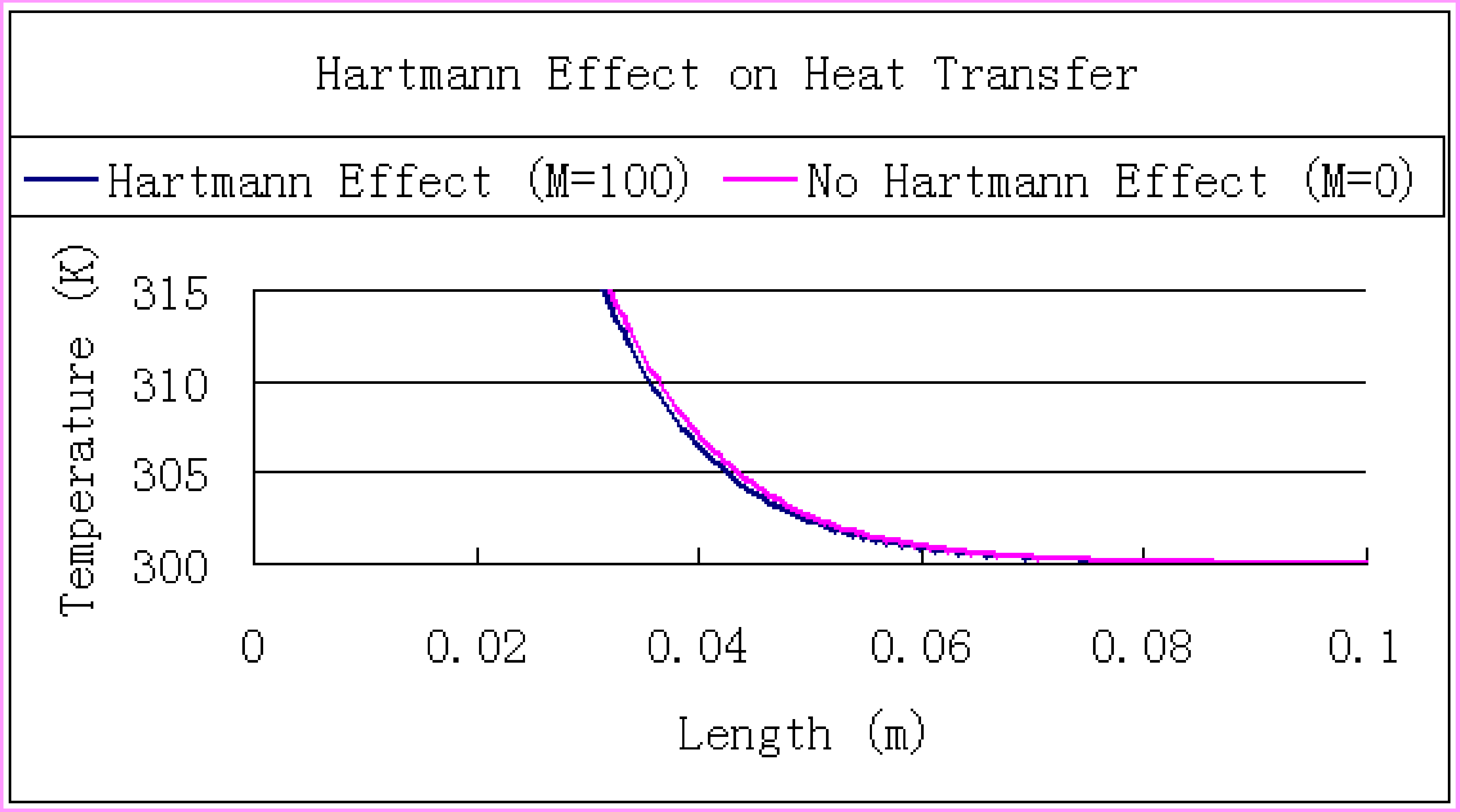


Step Flow Results (Pressure Profiles)





Step Flow Results (Temperature Profile)



Summary

- COMSOL Multi-physics has been used to model the steady laminar flow and convective heat transfer of an electrically conducting fluid subjected to an applied electromagnetic field in two simple flow configurations, namely, flow between parallel plates (Hartmann flow) and flow around a backward facing step.
- The COMSOL results are in excellent agreement with the available exact solution for the Hartmann problem.
- The COMSOL results predict the expected flattening of velocity profiles as well as the vortex elimination in the backward facing step flow.
- The obtained results are encouraging and suggest that COMSOL Multi-physics could be used to investigate more complex magnetohydrodynamic flows.