Thermomagnetic Siphoning on a Bundle of Current-Carrying Wires

Dr. Jeffrey C. Boulware
Dr. Scott Jensen

Space Dynamics Laboratory
Utah State University Research Foundation
Overview

• Introduction
• Theory
• Use of COMSOL Multiphysics
• Results
• Conclusions
• Acknowledgements
Introduction

- Thermomagnetic siphoning (TMS) uses differences in magnetic susceptibility to generate fluid motion.
- The current study analyzes the temperature of a bundle of wires surrounded by a magnetorheological fluid (MRF) jacket.
Problem Setup

Bundle of wires generates heat and induces a magnetic field.

Jacket wall is assumed isothermal.

Fluid jacket transports heat by conduction and/or convection if MRF.
• Curie’s Law dictates that magnetic susceptibility increases as temperature decreases.

\[ \chi = \frac{C}{T} \cdot \frac{\rho}{MW} \cdot 4\pi \]

\[ f_m = \mu_0 (M \cdot \nabla)H \]

\[ \chi = \frac{M}{H} \]

\[ B = \mu_0 (H + M) \]

\[ B = \nabla \times A \]

\[ f_m = \frac{\chi}{\mu_0 (1 + \chi)^2} \begin{bmatrix} A_{zy} A_{zxy} + A_{zx} A_{zx} \\ A_{zy} A_{zyy} + A_{zx} A_{zxy} \\ 0 \end{bmatrix} \]
Use of COMSOL Multiphysics

$T_{\text{jacket}} = 300 \text{ K}$

$I = 1-10 \text{ A}$

MRF with fluid properties of water

$q = \frac{I^2 \rho}{(\pi r^2)^2} \frac{W}{m^3}$

$J = \frac{I}{\pi r^2} \frac{A}{m^2}$

**Mesh Type:** Advancing Triangle

- # of DOF's: 81593
- # Elements: 10294
- Min Element Qual.: 0.8326
- Max Element Size: 1.47e-4
- Min Element Size: 1.8e-5

**Application Modes:**
- Magnetostatics
- Weakly Compressible
- Navier Stokes
- Convection and Conduction

**Relative Tolerance:** 0.001

**Linear Solver:** PARDISO
Results

1 A  
Conduction only

5 A  
TMS
Results

![Graph showing temperature over time for different currents. The graph has a color-coded scale from 300 K to 370 K. The current values are represented by different colors: 10 A (red), 7 A (cyan), 9 A (yellow), 6 A (dark blue), 8 A (green), and 5 A (purple). The graph shows how the bundle temperature changes with time for each current level.](image-url)
Results

- As high currents induce greater temperatures and magnetic fields, TMS becomes increasingly effective.

- Disclaimer! The study did not factor:
  - Operability
  - Manufacturing
  - Affordability
  - Boiling
  - Electrostatic discharge
Conclusions

• TMS was studied for its cooling performance on a bundle of current-carrying wires using COMSOL Multiphysics 3.5a.
• The magnetic, thermal, and fluid equations were solved and compared a MRF versus a non-magnetic fluid.
• The benefits of TMS were shown through a significant reduction of the steady-state temperature.
• Actual fabrication of a magnetic fluid jacket may negate any benefits due to additional cost and complexity.
Acknowledgments

• Air Force Office of Scientific Research
• Space Dynamics Laboratory
  – Dr. Clair Batty
  – Mr. Bob Anderson