Numerical Analysis of Different Magnet Shapes on Heat Transfer Application using Ferrofluid

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COMSOL CONFERENCE
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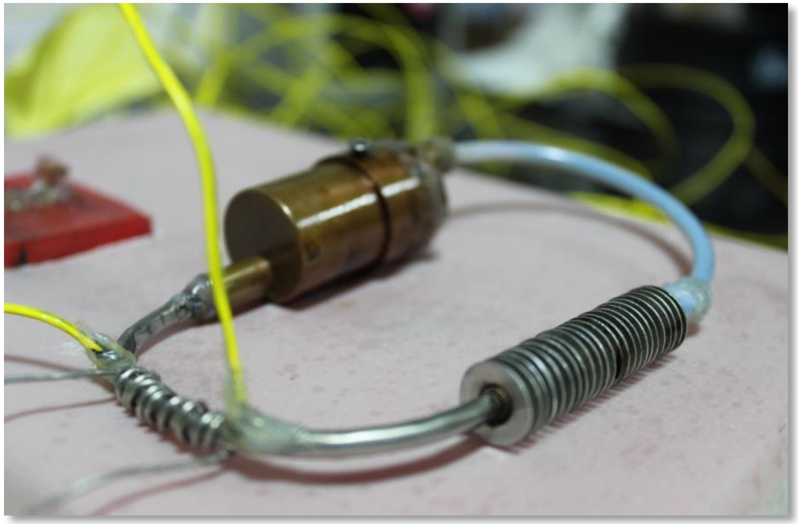
INTRODUCTION

- Magnetic fluid, which also known as a ferrofluid, is a colloidal suspension of single domain magnetic particles with dimension of particle about 8-10*nm,* dispersed in a liquid carrier.
- In order to avoid agglomeration, the magnetic particles have to be coated with a shell of an appropriate material like oleic acid.
- A ferrofluid is a temperature sensitive magnetic fluid which means that its magnetization is function of temperature. An external magnetic field imposed on a ferrofluid, with varying susceptibility results in a non-uniform magnetic body force, which leads to a form of heat transfer called thermo-magnetic convection and can be controlled by varying ferrofluid properties, the magnetic field strength and also the temperature distribution.

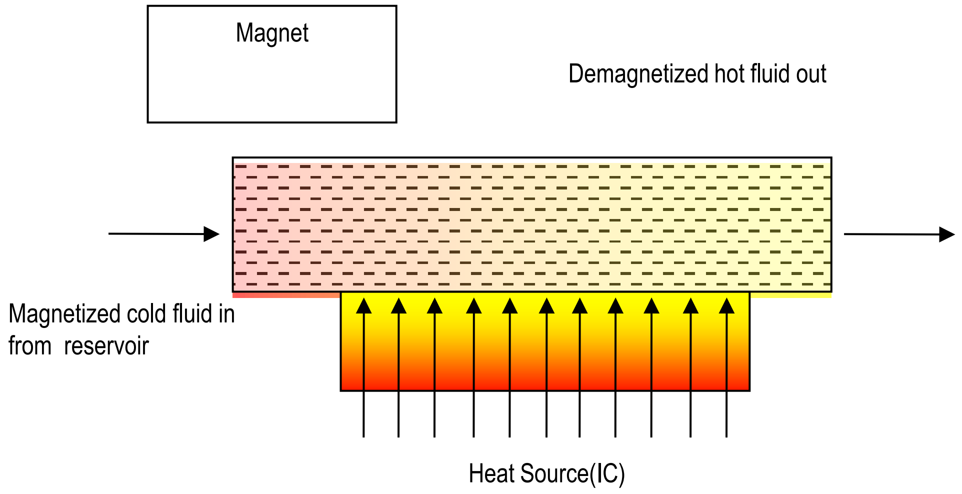
Ferrofluid as cooling system

- Ferrofluid based cooling system is a cooling device which utilizes heat and magnetic field to dissipate heat from the circuit or heat source.
- The ferrofluid based cooling device is a truly 100% passive without conventional cooling components and thereby enhancing the reliability.
- The invention makes use of high heat transfer coefficient and natural circulation caused by the magnetic pump of ferrofluid.
- It is noiseless and without mechanical moving elements thus having high reliability.



Working Principle

- A ferrofluid based smart miniature cooling system utilizes Kelvin body force for pumping the ferrofluid in the vicinity of magnetic field generated by permanent magnet and temperature field created by heat source.



Application Area

- Electronic circuit cooling
- Computer Processor chip cooling
- Customized miniature cooling

Simulated Model

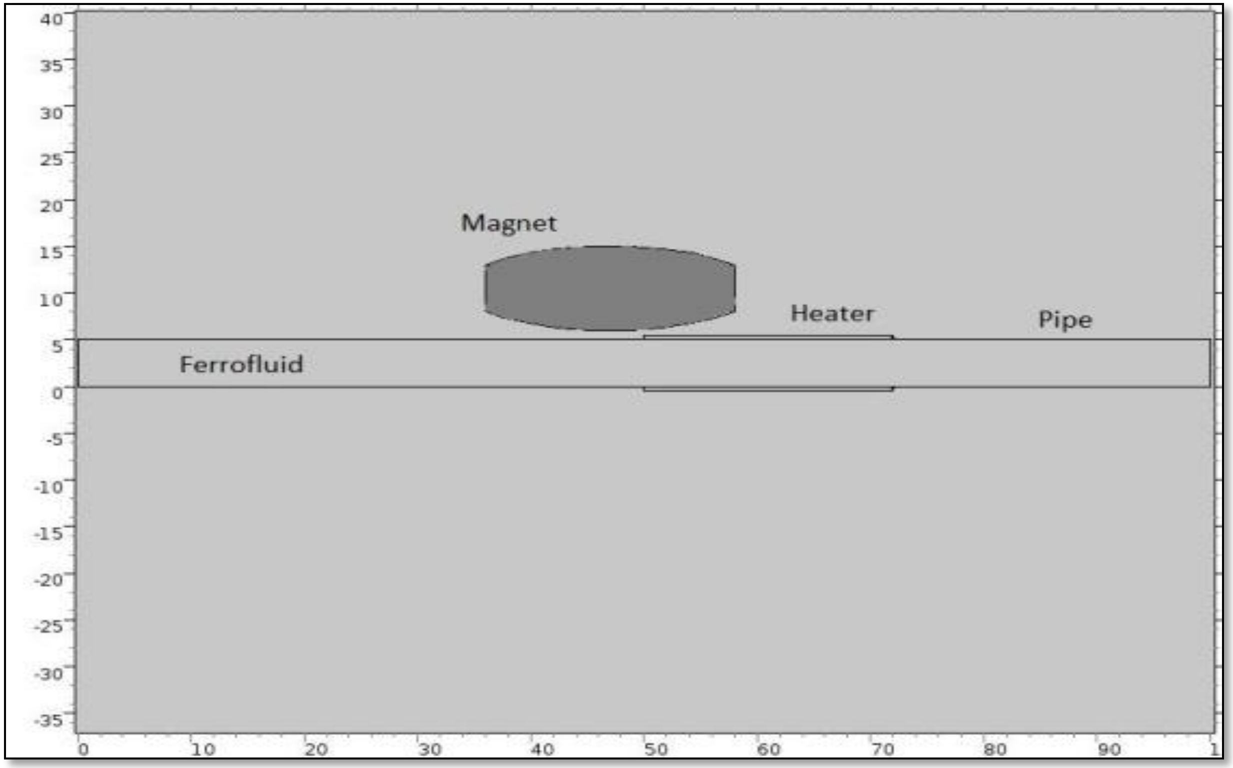


Diagram of simulated model in Comsol

Initial and boundary condition

- Initial conditions:
  - Temperature of fluid is 298.3K
  - Total heat applied by heaters 350W
  - Surrounding temperature 298.3K

- Boundary conditions:
  - Length of pipe 100mm
  - Width of pipe 5mm
  - Max. length of magnet 25mm
  - Max. width of magnet 10mm

Properties

- Properties of fluid:

Property	Value
Density (Kg/m^3)	1050.0
Viscosity (Pa-s)	0.0030
Susceptibility	0.3860
Thermal conductivity ($Wm^{-1}K^{-1}$)	0.1500
Specific heat ($JKg^{-1}K^{-1}$)	1715.0
Thermal expansion coefficient (K^{-1})	0.0009
Curie temperature (K)	353.00

- Properties of magnet:
  - Permanent magnet
  - Remnant flux density 1.3Tesla

Numerical Analysis

- The numerical analysis was done using the multiphysics in Comsol:

- ➢ Laminar Flow (spf)
- ➢ Heat Transfer in Solid (ht)
- ➢ Magnetic Field No Current (mfnc)

Laminar

- Momentum equation:

$$\rho \frac{\partial u}{\partial t} + \rho(u.\nabla)u = \nabla.[-pI + \mu(\nabla u + (\nabla u)^T) + (M.\nabla)B$$

  - Body Force:

$$F = (M.\nabla)B$$

  - Magnetization of fluid:

$$M = \chi_m H$$

- Continuity equation:

$$\rho\nabla.u = 0$$

Heat Transfer

- Heat transfer in Fluid:

$$\rho C_p \mathbf{u}.\nabla T = \nabla\ .(k\nabla T) + Q + Q_{vd} + Q_p$$

- Heat transfer in solid:

$$\rho C_p \mathbf{u}.\nabla T = \nabla\ .(k\nabla T) + Q$$

- Energy equation:

$$\rho c_p \left(\frac{\partial T}{\partial t} + \ u.\nabla\ T\right) = k\nabla - \mu_0 T \frac{\partial M}{\partial T}\Big((v.\nabla)H\Big)^2 T + \mu\Phi$$

Magnetic Field No Current

- Magnetic field

$$H = -\nabla V_m$$

$$\nabla . B = 0$$

- Magnetic flux density due to Permanent Magnet

$$B = \mu H + B_r$$

Results

- For Concave Shape:

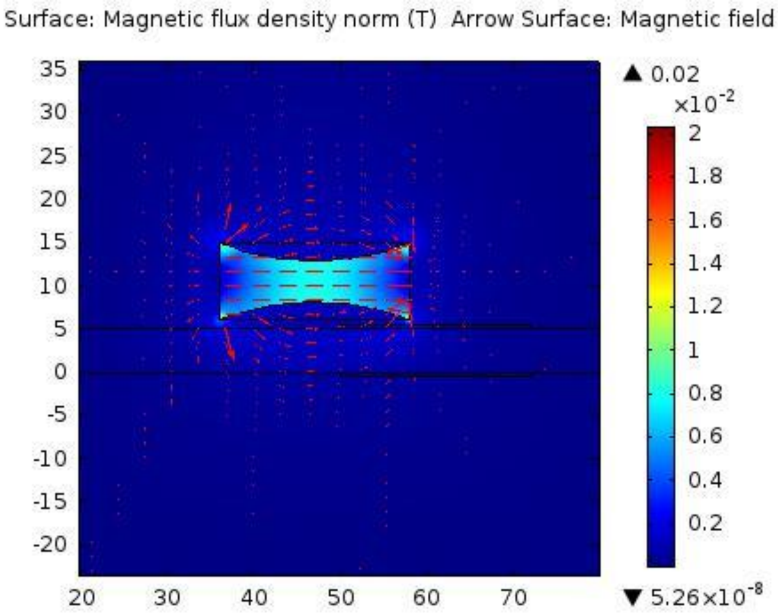


Figure 1

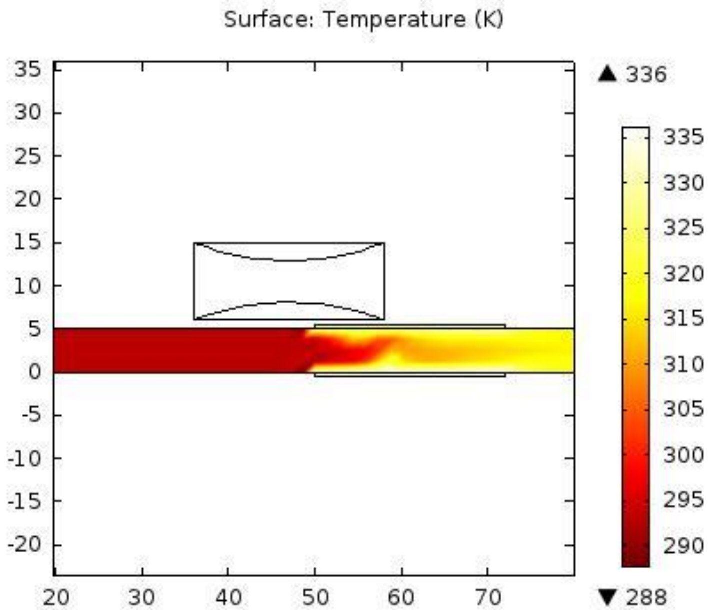


Figure 2

For Concave shape magnet , the field line are shown in figure 1 and temperature plot in figure2. The velocity calculated is 1.532mm/sec and temperature 319K.

Results

- For convex shape:

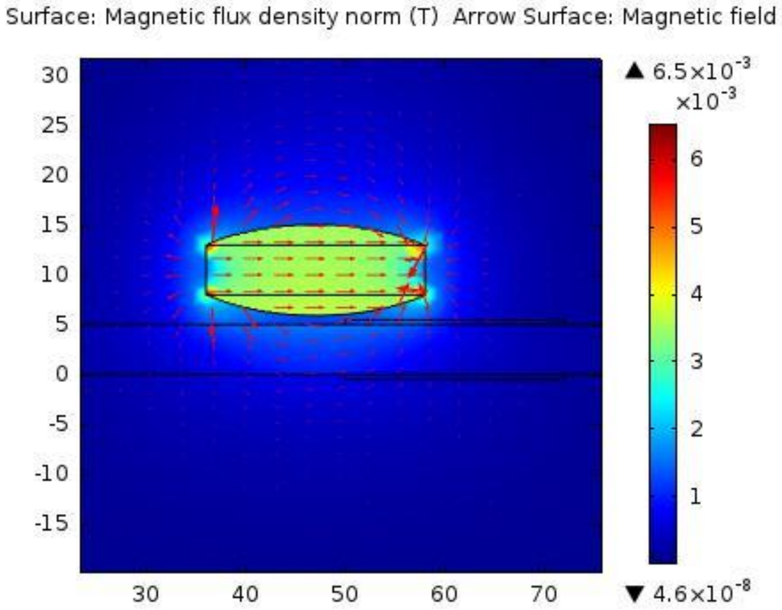


Figure 1

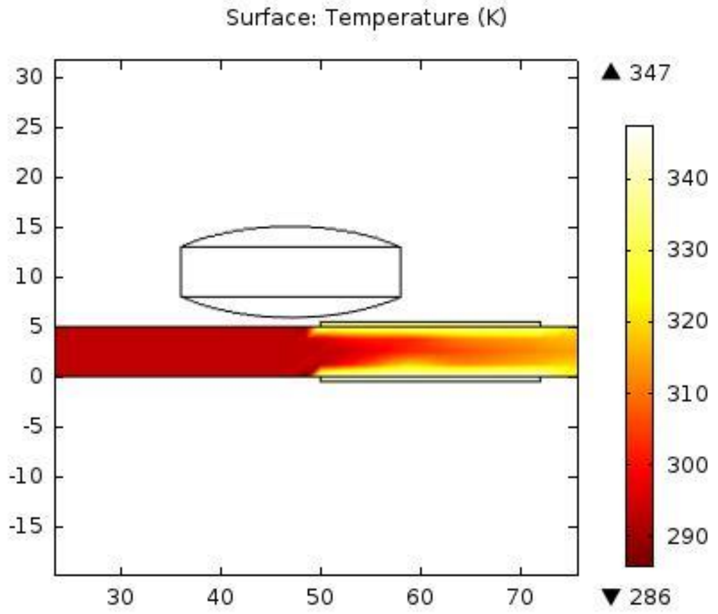


Figure 2

For Convex shape magnet , the field line are shown in figure 1 and temperature plot in figure2. The velocity calculated is 1.592mm/sec and temperature 321K.

Results

- For tapered shape:

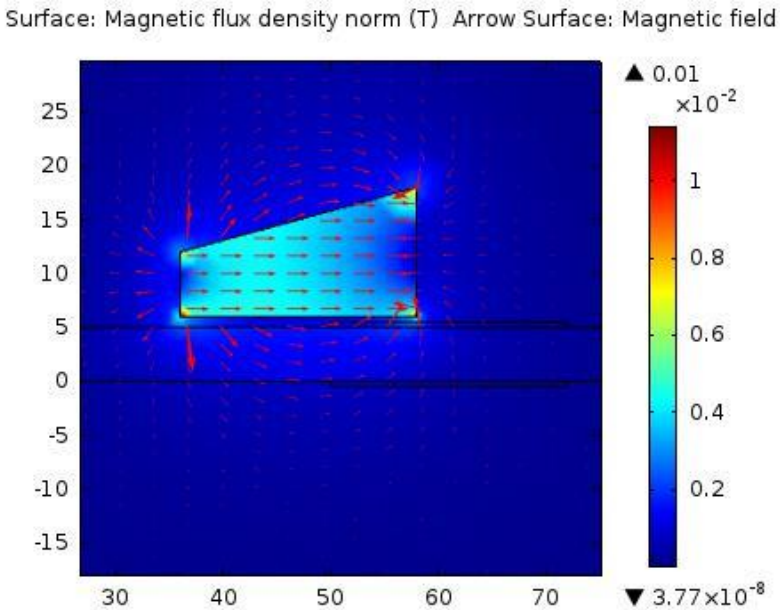


Figure 1

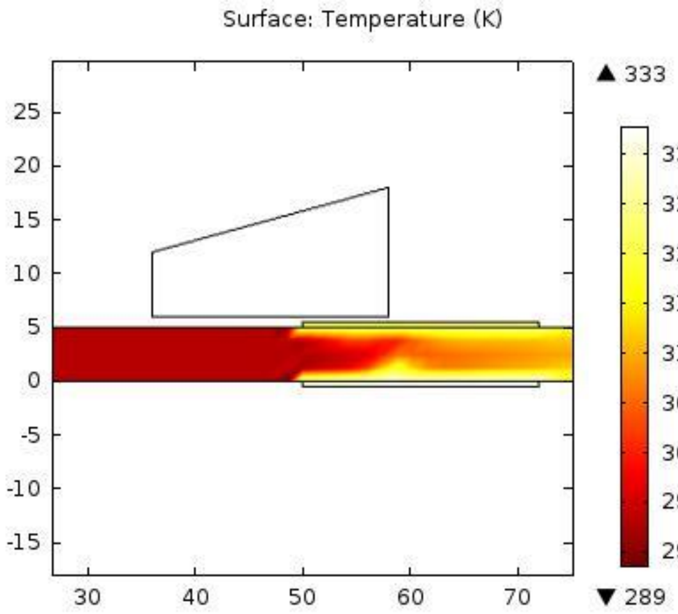
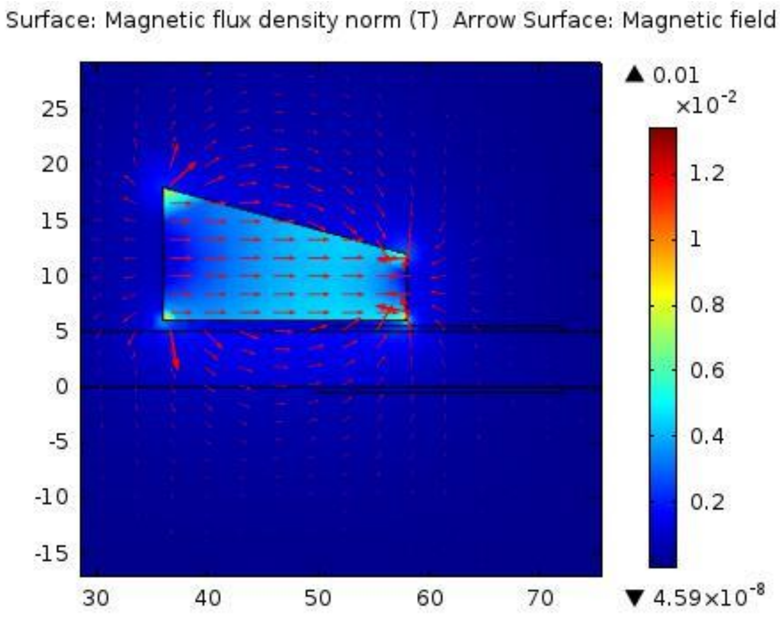


Figure 2

For Tapered shape magnet , the field line are shown in figure 1 and temperature plot in figure 2. The velocity calculated is 1.986mm/sec and temperature 314K.

Results

- For rev. tapered shape:



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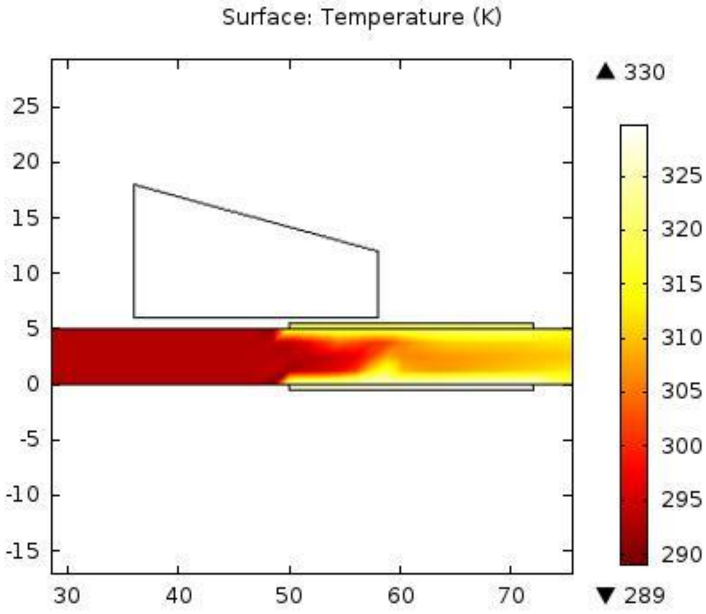
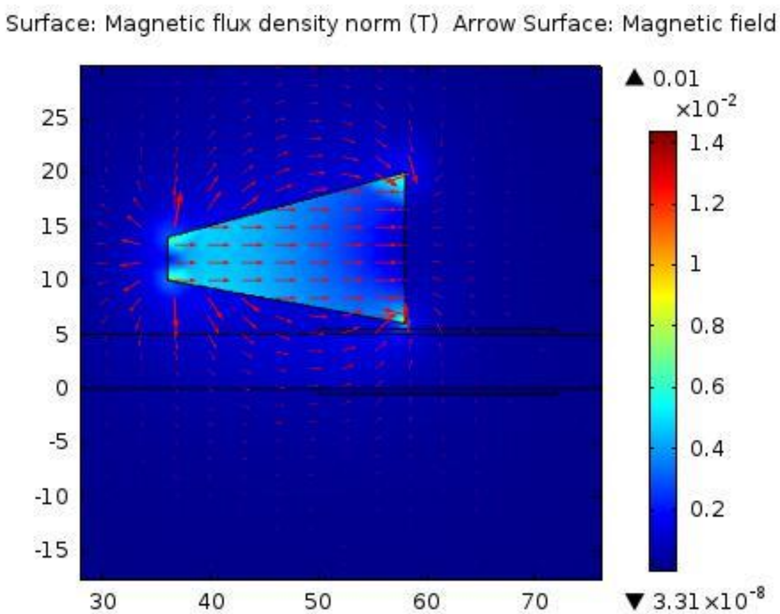


Figure 2

For Rev. tapered shape magnet , the field line are shown in figure 1 and temperature plot in figure2. The velocity calculated is 1.956mm/sec and temperature 314K.

Results

- For trapezoidal shape:



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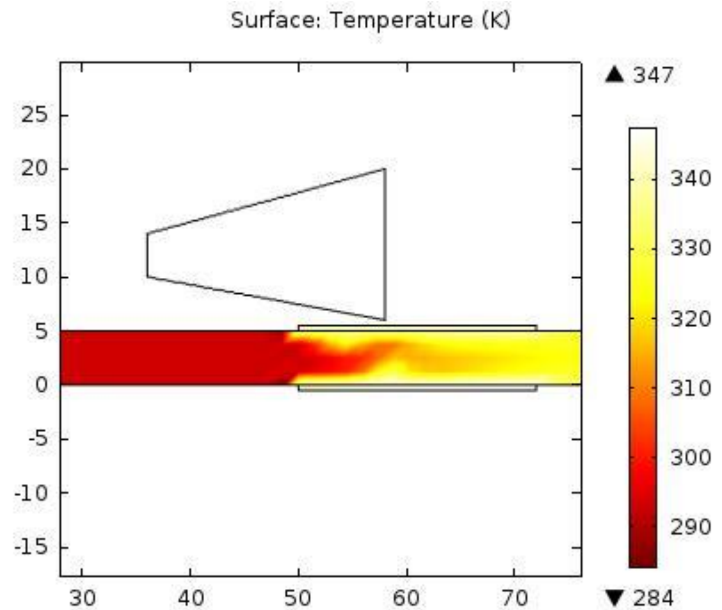


Figure 2

For trapezoidal shape magnet , the field line are shown in figure 1 and temperature plot in figure2. The velocity calculated is 1.137mm/sec and temperature 328K.

Results

- For rev. trapezoidal shape:

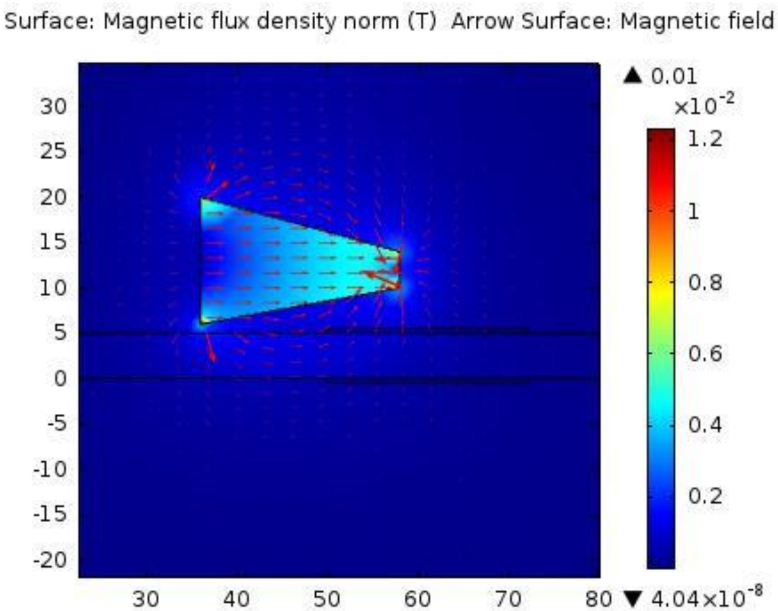


Figure 1

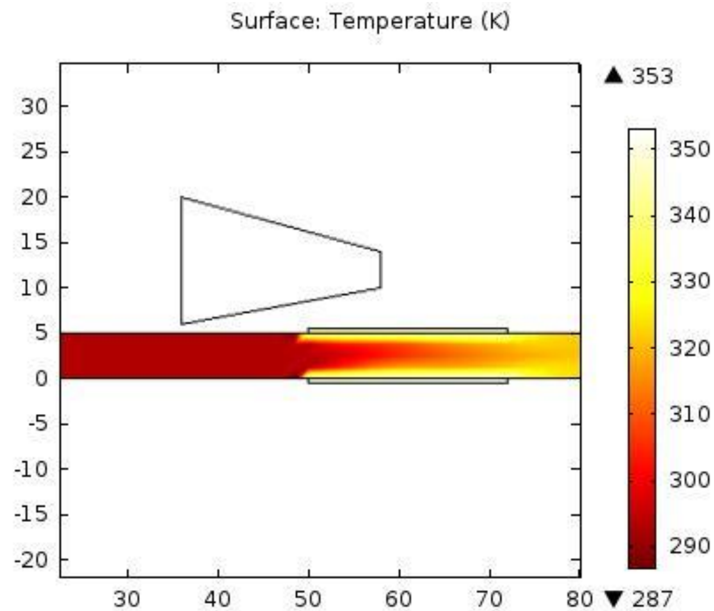
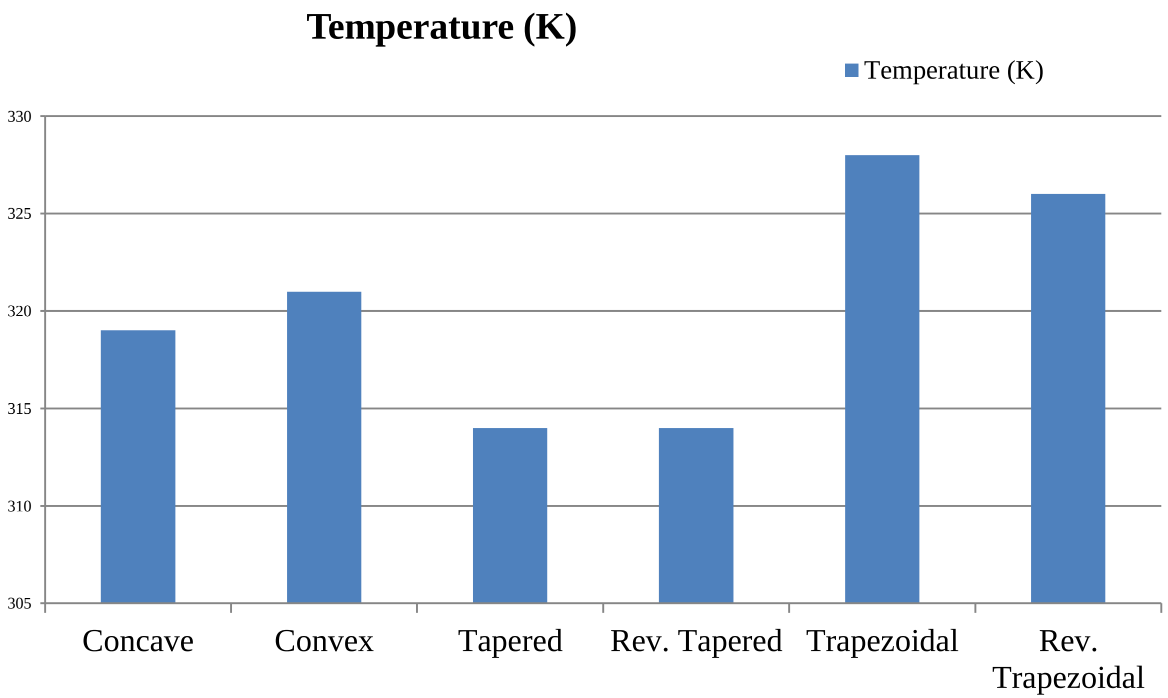


Figure 2

For Rev. trapezoidal shape magnet , the field line are shown in figure 1 and temperature plot in figure2. The velocity calculated is 1.267mm/sec and temperature 326K.

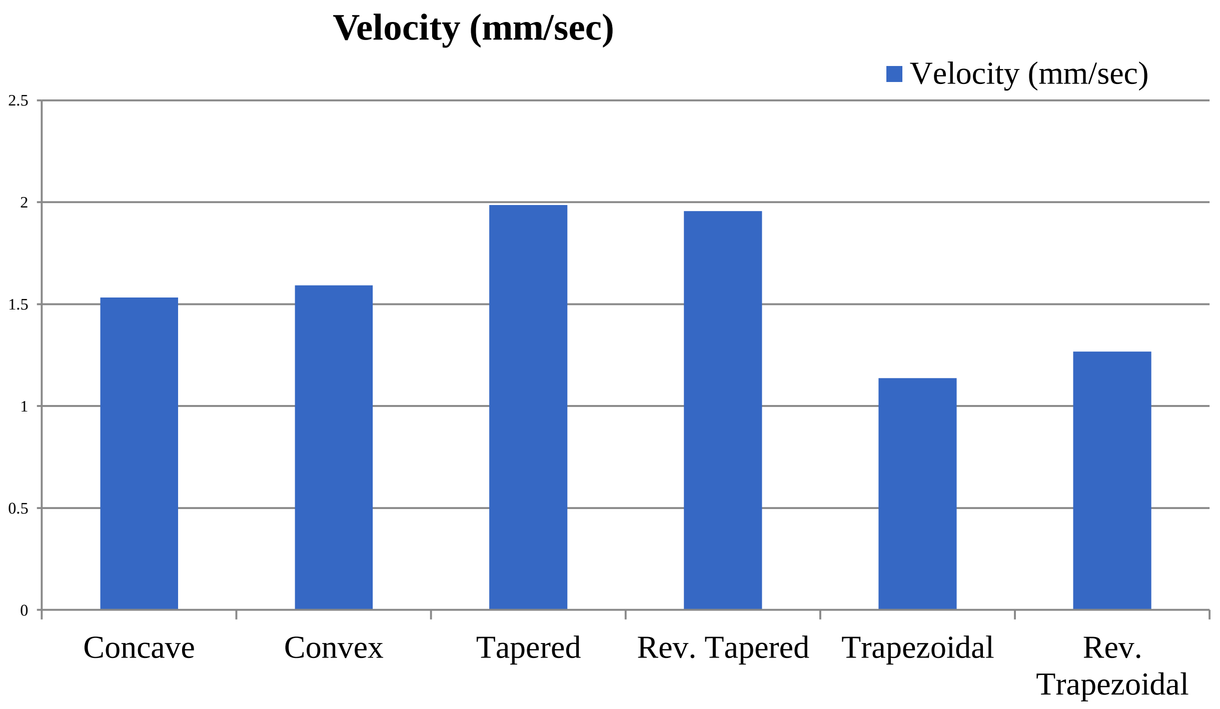
Comparison of Results

- Temperature



Comparison of Results

- Velocity



Conclusion

- Magnetic body force acting on the ferrofluid depends upon the shape and strength of the field line from the magnet.
- Magnetic body force induces the flow which reduces the temperature of the system for this study.
- The model is able to calculate reasonable magnitude of velocity and temperature. The avg. higher velocity found with convex shape 1.592 mm/sec for 5mm inner diameter was obtained.

References

- Peterson GP, Li CH. Advance Heat Transfer 2006; 39: 275.
- L J. Love, J.F. Jansen, T.E. Mcknight, Y. Roh, T.J. Phelps, “Ferrofluid induced flow for microfluidic applications,” IEEE Trans. Mechatronics, vol.10, pp. 68-76, 2005.
- Qiang Li, W. Liang, H. Sun, JF. Jansen, “Investigation on operational characteristics of a miniature automatic cooling device,” International Journal of Heat and Mass Transfer, vol. 51, pp.5033-5039, 2008.
- T.Strek, H.Jopek, “Computer simulation of heat transfer through ferrofluid,” Journal of Solid State Physics 244 1027-103, 2006.
- H Yamaguchi, I Kobori, Y Uehata, K. Shimada, “Natural convection of magnetic fluid in a rectangular box,” Journal of Magnetism and Magnetic materials, vol. 201, pp. 264-267, 1999.

THANK YOU