Enhancement of Dual Phase Pulsating Heat Pipes using Hybrid Ferritic Nanofluid under Active Magnetic Field

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Abstract

Heat transfer characteristics and cooling time of a Pulsating Heat Pipe with Ferrofluid (Magnetite+Engine Oil) under magnetic field has been investigated in this study using numerical simulations based on Finite Volume Method. The simulations were performed using AnSys FLUENT with MHD module.Heat transfer and cooling time under constant and fluctuating thermal loads were computed with and without magnetic field and the results were compared with that of water .Increased heat transfer was found with ferrofluid and the performance was much more improved under magnetic field for both single and double phase modes of operation.Cooling time was found to be significantly reduced compared to regular heat pipes.

Keywords

Nanofluid— PHP — Ferrofluid —Magnetized Flow — Fluctuating Thermal Load

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Introduction

Pulsating Heat pipes are passive devices that cool objects, mostly hot electronic components that require fast cooling under fluctuating load,by transferring the heat to a working fluid by convective process , which can be both single or multiphase, in a pulsating manner.These devices are essential to get the maximum effectiveness of electronic devices as the performance of electronic components decline exponentially with increment of heat flux.Development of a high performance heat pipe will enhance usability of electronic devices.But unfortunately there is a limit to this performance enhancement due to low thermal conductivity of available working fluids.This limit however can be transcended if nanofluids are utilized.

Nanofluids are colloidal suspension of nanoscale particulates or structures(nanotubes,nanosheets or nanofibers) in a base fluid.Due to the presence of condensed nanomaterials,thermophysical properties of the base fluid such as convective heat transfer coefficient,diffusivity, specific heat and thermal conductivity etc. increase significantly.This enhanced characteristics makes them an ideal choice as working fluid for many heat transfer equipment including heat pipe.

Using nanofluids as working fluid in heat pipes ,independent of the operation type, increment in the performance beyond the capability of ordinary fluid can be achieved.Although there are still problems.Most prominent problem is that the fluid flow faces high drag due to enhanced vortex creation by the moving nanoparticles.To push the limits furthermore magnetic effects could be used. If the nanoparticles suspended in the nanofluid are magnetically active, their motion can be controlled via application of active magnetic field.It was shown in a study that such a setup can achieve negative viscosity [1].This increased mobility adds up to the overall heat transfer coefficient and the thermal performance is improved much more.

Multiphase application of nanofluids creates some problematic issues regarding stability of the nanofluid.For example deposition of nanoparticles occur at corners and wicked structure can't be used as it interferes with the flow.Also because of the magnetic field assembly the setup needs to be shielded from other components for which magnetic field could be hazardous.

In recent years the idea of using nanofluids for heat pipe performance enhancement has cau.

This paper represents comparison of this performance limits and investigates optimum values of control parameters (fill ratio , nanoparticle density and magnetic field magnitude) to achieve the best performance.

1. Model and Mesh

The model is created in SOLIDWORKS.Dimensions of the pipe are taken from GAMMAXX GT model by DeepCool technology [2] because it's one of the best selling and highly efficient type of heat pipe currently available. Division of fluid gas regions based on fill ratio and selection of different sections (evaporator , adiabatic and condenser) were done in AnSys Design Modeller.

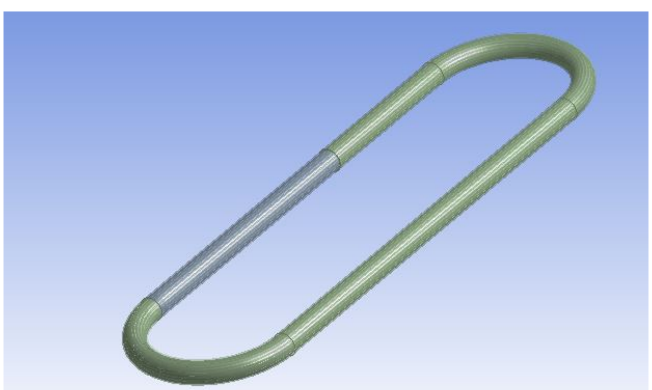

Figure 1. 3D Model of the Heat Pipe in SOLIDWORKS

The meshing wad done in AnSys Mesh Modeller.Fine mesh with high resolution and hybrid shapes were chosen.The evaporator region mesh was further refined manually for reliable results.

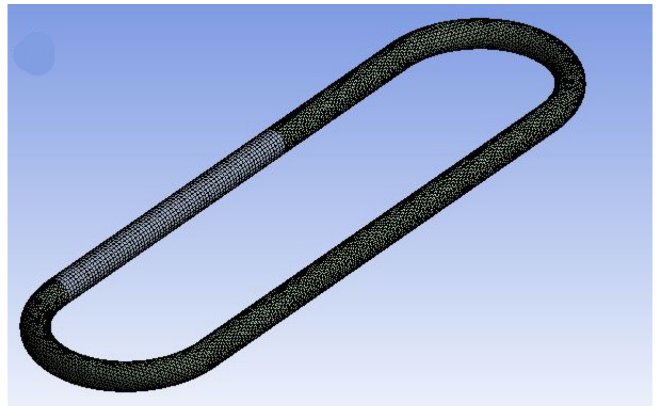

Figure 2. Meshing of The Model in Meshmodeller

Mesh Report

Table Mesh Information for Water

Domain	Nodes	Elements	Tetrahedra	Wedges	Pyramids	Hexahedra	Polyhedra
gas	9072	6137	0	0	0	6137	0
liquid	2378	1620	0	0	0	1620	0
All Domains	11450	7757	0	0	0	7757	0

Table Mesh Statistics for Water

Domain	Minimum Face Angle	Maximum Face Angle	Maximum Edge Length Ratio	Maximum Element Volume Ratio
gas	61.1332 [degree]	121.364 [degree]	1.91948	1.90238
liquid	55.3885 [degree]	123.209 [degree]	2.15944	2.09507
All Domains	55.3885 [degree]	123.209 [degree]	2.15944	2.09507

Figure 3. Meshing Profile

2. Thermophysical Properties

The Nanofluid chosen for the simulation was APG E-32 . This is a ferofluid with low viscosity and the magnetic response is very good.The properties of the fluid were calculated using two models provided by the manufacturer FerroTec [3].The chart below summarises the properties.

Quantity		Value	Error	Unit
Density	ρ	1168	± 1	$\mathrm{kg\,m^{-3}}$
Surface tension	σ	30.9	± 5	$\mathrm{mN\,m^{-1}}$
Viscosity at 10 °C	η	4.48	± 0.1	$\mathrm{Pa\,s}$
Saturation magnetization	M_S	26.6	± 0.8	$\mathrm{kA\,m^{-1}}$
Initial susceptibility at 10 °C	χ_0	3.74	± 0.005	
Fit of $M(H)$ with the model by Ivanov and Kuznetsova (2001):				
Exponent of the Γ-distribution	α	3.8	± 1	
Typical diameter	d_0	1.7	± 0.2	nm
Volume fraction	ϕ	5.96	± 0.2	%
Critical induction from $M(H)$	B_c	10.5	± 0.1	mT

Figure 4. Material Thermophysical Properties

The heat transfer coefficient is computed using empirical correlations.These were obtained from the paper by Xue et al. [4]

Laminar flow $$h_{nf} = \begin{cases} \frac{k_{nf}}{D}\left[1.953\left(\frac{\rho_{nf}c_{p.nf}VD^2}{xk_{nf}}\right)-1\right] & \textit{Entrance region} \\ 4.36\left(\frac{k_{nf}}{D}\right) & \textit{Fully developed} \end{cases}$$

Turbulent flow $$h_{nf} = 0.023\frac{c_{p.nf}^{0.4}k_{nf}^{0.6}\rho_{nf}^{0.8}V^{0.8}}{\mu_{nf}^{0.4}D^{0.2}}$$

Figure 5. Heat Transfer Coefficient for Nanofluid

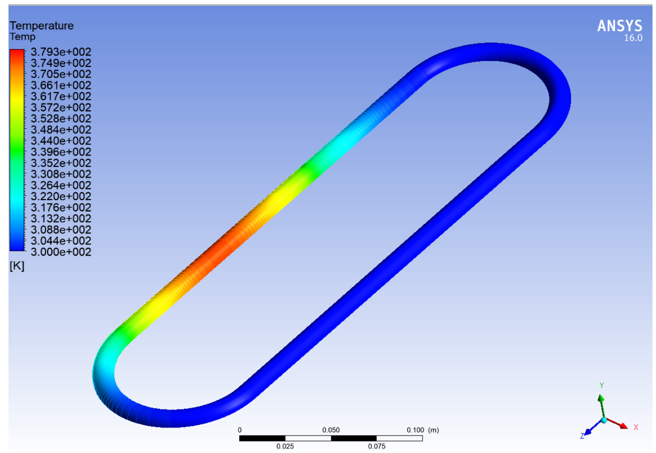

Figure 7. Magnetic Field Applied Temperature Distribution

3. Simulation Conditions

Peak Temperature:110°C
Time Interval: 250 s
Solution Method:SIMPLEC
Simulation Type: Transient
Viscosity:$k-\varepsilon$
Model: Mixture(VOF)
Patching: Zonewise

It can be clearly seen that the performance under magnetic field is significantly better.The peak temperature is reduced and the cooling effect is much more rapid spreading.

The nucleation site formation was observed in postprocessing via volume of fraction criterion.It can be seen that more nucleation sites occur under magnetic field.

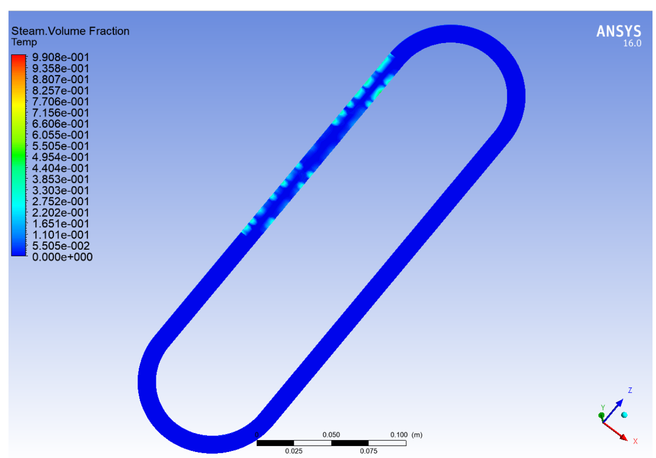

Figure 8. Beginning of Nucleation Sites

4. Simulation Results

For both the magnetic field present or absent cases temperature distribution was obtained along the evaporator arm.The plot shows temperature distribution after 1 minute.

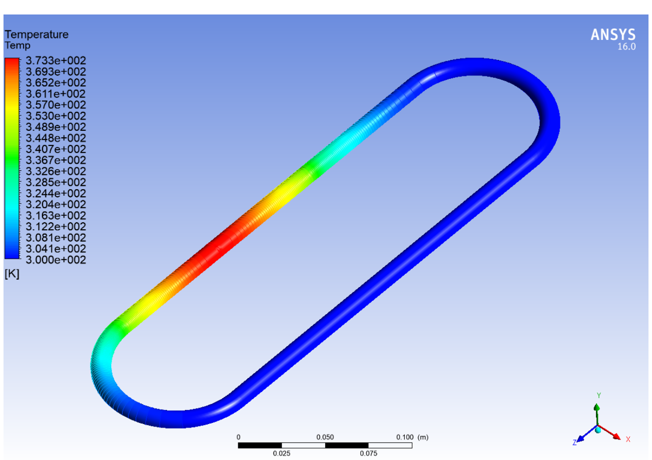

Figure 6. Nanofluid Temperature Distribution

5. Comparison

The visualization and post processing was done in AnSys CFDpost.The values of temperature were obtained at the midpoint of evaporator section and a plot of Temperature vs Time was generated fr conoarison.

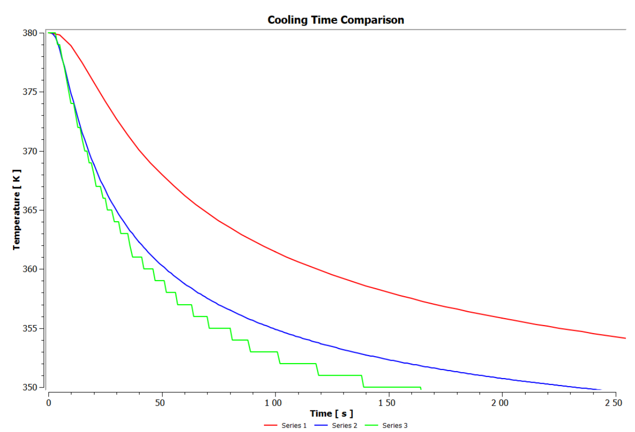

Figure 9. Comparison of Cooling Curve for Different Cases

The performance for Nanofluid is far superior compared to water.The response is much better under magnetic field. The curve for magneyic field case is stepped to avoid sharp transition in magnetic field as a smooth function for magnetisation was unavailable.

6. Discussion

The residual plot shows marginal stability.The Lyapunov Criteria shows that further improvement is possible for increased no of iteration.

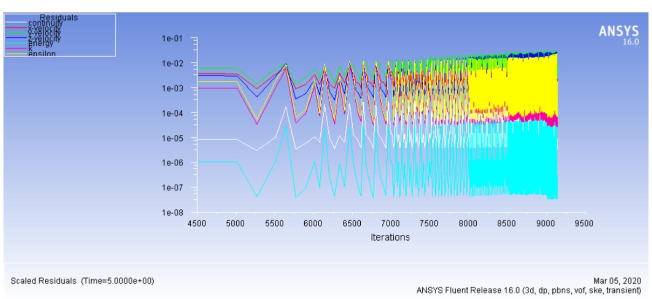

Figure 10. Residual Behaviour of Solution

The main point to notice about the results is that the performance under magnetic field is very much increased for the viscosity decrement effect.Also using plasma theory model of Hans Alfven it can be showed that there is an overall increase in the fluid pressure gradient which boosts the flow.

APG E-32 has a thermal conductivity of 150% higher than water.So the overall thermal resistance is low.Furthermore the rapid formation of nucleation sites helps the boiling process and spreads the heat faster.

The performance is better in case of magnetic field although it wouldn't be the case for all pipe materials as demonstrated by Gandomkar et al. [5]

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