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

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Research Motivation

The logical pathway of arriving at the current research topic is as follows-

- Electronics cooling is essential for better performance
- PHPs provide efficient cooling
- PHP cooling capacity is limited by fluid properties
- Use of Nanofluid improves heat transfer
- Use of ferritic nanofluid takes advantage of MHD effects
- Nanofluid & MHD effects together enhance PHP performance
- MHD improvements expected due to works of [Fakour, 2015],[Hussain, 2016],[Mousavi, 2016]

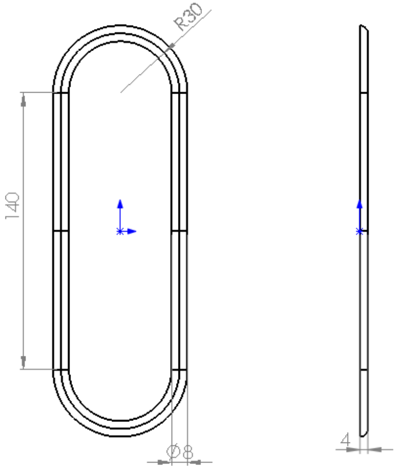
Research Problem Definition

Main Objective

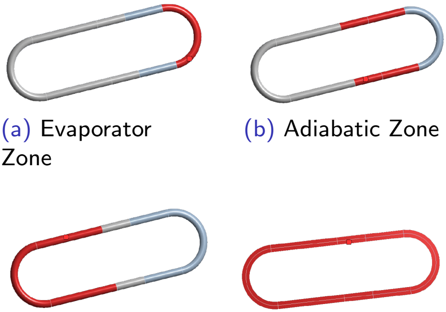
Investigating whether PHP performance improvement is possible when it's charged with ferrofluid while working under a magnetic field and if so the degree of improvement.

- Constant magnetic field considered
- Cooling capacity is the parameter of interest
- Subjected to isoflux load
- Transient Step input considered
- Designing an ideal ferrofluid is auxiliary objective

Computational Domain Specification



Orthographic projection sketch of model



(a) Evaporator Zone

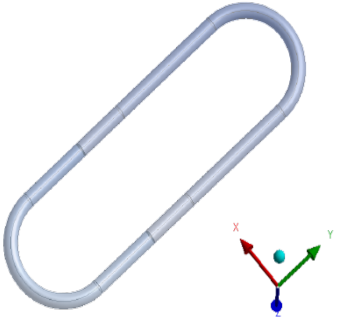
(b) Adiabatic Zone

(c) Condenser Zone

(d) Symmetry Zone

Zone Markup of the Model

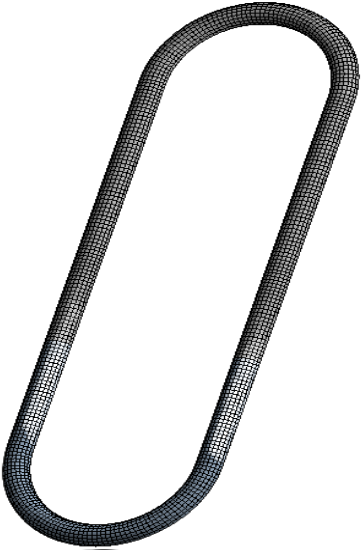
Model & Working Fluid



PARAMETER	ASSIGNMENT
Bulk Fluid	Acetone and Buckwheat Oil Blend
Nanoparticle	LiTi Ferrite(α and γ variants)
Volume Fraction(%)	5.96
$\rho(kgm^{-3})$	1168
$\mu(Pa.s)$	0.00025
$C_p(kJkg^{-1}K^{-1})$	1.524
$k(Wm^{-1}K^{-1})$	0.1548
$\sigma(Nm^{-1})$	0.0212
$L_v(Jkg^{-1})$	501033.1
$T_{bp}(K)$	329.3
$h_0(Jkg^{-1})$	-2.49×10^8
$s_0(Jkg^{-1}K^{-1})$	295350
$\Lambda(Sm^{-1})$	2.5
κ	0.999465

3D model with WCS orientation (Gravity along -ve y-axis)

Mesh Specification



Parameter	Value
Nodes	9065
Elements	6176
Min. Cell Size	1.5976×10^{-5}

Mesh Profile

Essential Equations

Property Determination

$$\rho_{nf} = \phi\rho_{np} + (1-\phi)\rho_{bf}$$

$$\rho_{nf}(C_p)_{nf} = \phi\rho_{np}(C_p)_{np} + (1-\phi)\rho_{bf}(C_p)_{bf} \text{[Eastman, 2004]}$$

$$\mu_{nf} = \mu_{bf}(1 - 0.19\phi + 3.6\phi^2) \text{[Sidi, 2005]}$$

$$k_{nf} = k_{bf}\frac{k_{np} + (n-1)k_{bf} - (n-1)(k_{bf} + k_{np})\phi}{k_{np} + (n-1)k_{bf} + (k_{bf} + k_{np})\phi} \text{[Hamilton, 1962]}$$

Governing Equation

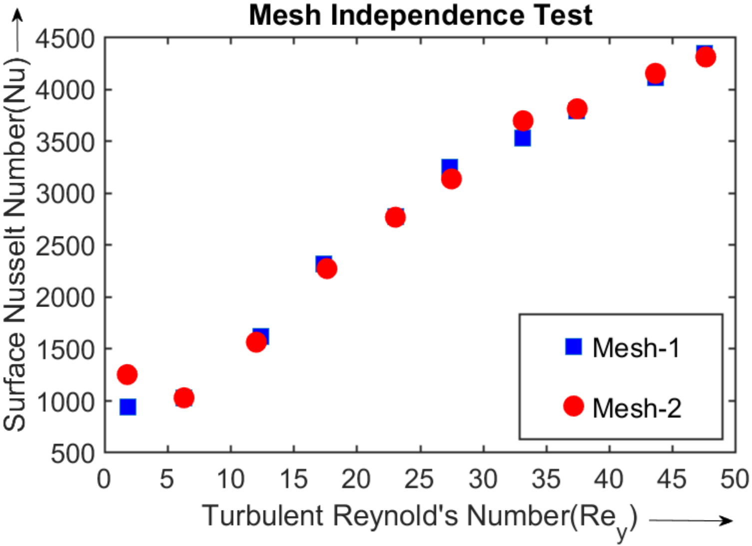
$$\vec{\nabla}(\rho\vec{V}) + \frac{\partial\rho}{\partial t} = 0\ ;\ \rho\left(\frac{\partial\vec{V}}{\partial t} + (\vec{V}\cdot\vec{\nabla})\vec{V}\right) = -\vec{\nabla}P + \mu\nabla^2\vec{V} + \vec{f}$$

$$P(x) = P_0 + \frac{1}{\widetilde{\mu}}\int_{x_i}^{x_f} B\frac{\partial B}{\partial x}dx \quad \text{[Alfven, 1990]}$$

Computational Process Profile

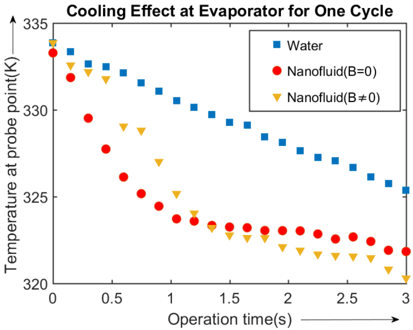
Numerical Scheme	:	SIMPLEC*(Semi Implicit Method for Pressure Linked Equation-Consistent)*
Solution Process	:	FVM*(Finite Volume Method)*
Mixture Model	:	VOF*(Volume of Fraction)*
Viscosity Model	:	$k - \epsilon$
Transient Nature	:	Unsteady
Model Type	:	3D
Time Steps	:	100000
Time Step Size	:	0.00003 s
Iterations per Time Step	:	10
Boundary Condition	:	Isoflux*(Step function)*
Total Number of Elements	:	6176
Average Element Size	:	1.5976×10^{-5} m
Element Type	:	Tetrahedral
Computational Platform	:	AnSys Fluent® & Matlab®

Mesh Validation

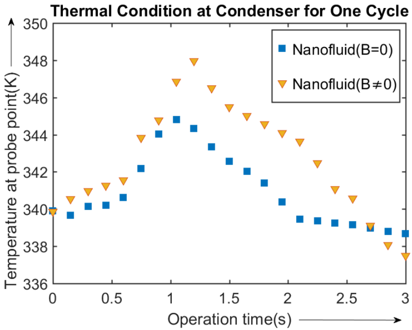


Nu vs. Re plot in evaporator section for two distinct mesh constructs

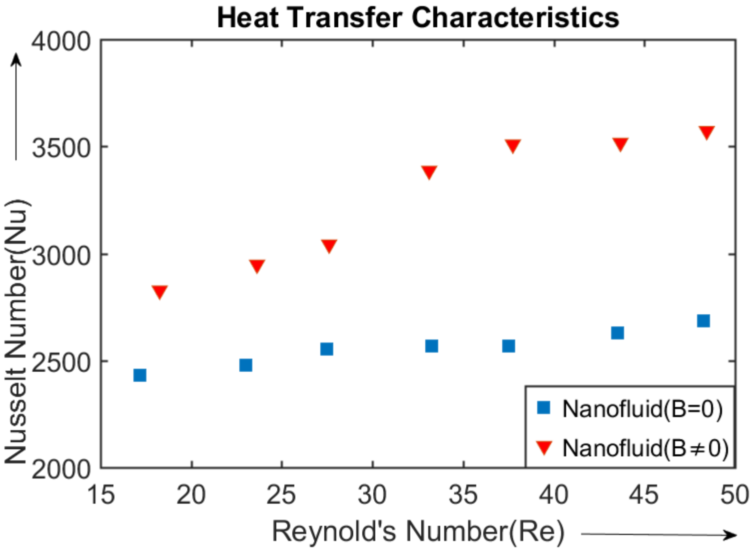
Cooling Effect



Evaporator cooling behavior comparison

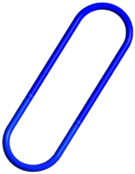


Condenser temperature variation comparison

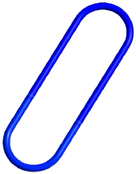


Heat transfer comparison

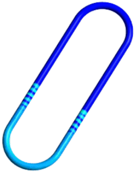
Vapor Evolution



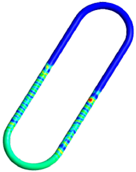
(i) timestep=0



(i) timestep=0



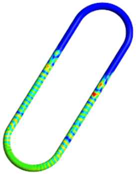
(ii) timestep=10



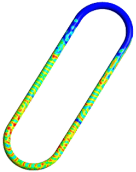
(ii) timestep=10

[a] Nanofluid(B=0)

[b] Nanofluid(B≠0)

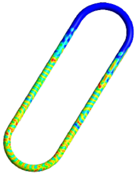


(iii) timestep=20

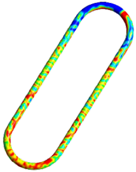


(iv) timestep=30

[a] Nanofluid(B=0)



(iii) timestep=20



(iv) timestep=30

[b] Nanofluid(B≠0)

Concluding Remarks

In presence of magnetic field-

- heat removal rate found to be higher
- quicker vapor onset observed
- convective current velocity noted to be higher
- shorter system response time found

Focus of future studies could be-

- experimental validation of proposed data
- effects of particle agglomeration
- study under non-constant magnetic field
- consideration of ferrofluid self inductance

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Thank You for Your Attention

Questions about the subject matter

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