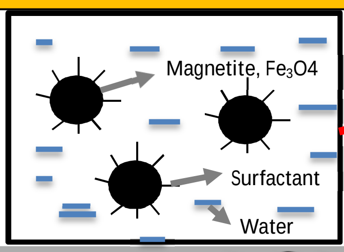
NUMERICAL SOLUTION ON MIXED CONVECTION HEAT TRANSFER OF FERROFLUID OVER A HORIZONTAL CIRCULAR CYLINDER

INVENTOR: SITI HANANI MAT YASIN
FACULTY: CENTRE FOR MATHEMATICAL SCIENCES
UNIVERSITY: UNIVERSITI MALAYSIA PAHANG
EMAIL: hananimatyasin@gmail.com
CO-INVENTORS: MUHAMMAD KHAIRUL ANUAR MOHAMED, ZULKHIBRI ISMAIL, MOHD ZUKI SALLEH

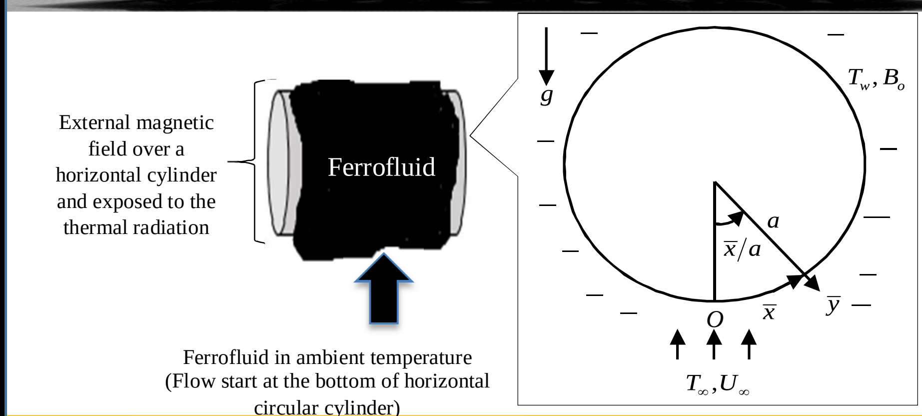
MOTIVATION

Characteristics of ferrofluid

- Becomes highly magnetized in the presence of a magnetic field.
- Classified into two groups which are surfacted ferrofluid (SFF) and ionic ferrofluid (IFF).
- Composed of 5% volume of small particles (~ 3-15 nm) solid, magnetic, single domain particles coated namely magnetite (Fe_3O_4), maghemite (γ -Fe_2O_3), cobalt ferrite ($CoFe_2O_4$) and other compounds having iron with a molecular layer of dispersant which suspended in 85% volume of base fluid (water, oil, ethylene glycol, etc.) as well as 10% volume of surfactants (lauric acid, oleic acid, etc.)
- Exhibits superparamagnetism of magnetic behavior.
- The understanding of ferrofluid characteristics has greatly helped the researchers in analyzing the ferrofluid flow problems in different geometries when many researchers have experimentally proven the water based magnetite nanofluid can enhance the thermal conductivity.
- To fully understand the heat transfer capabilities of water based magnetite nanofluid, it is necessary to understand the thermophysical properties at different volume concentrations and temperatures.
- Main focus: The viscosity of the water based magnetite nanofluid is examined theoretically for magnetite volume fraction when ferrofluid flows over a horizontal circular cylinder by using boundary layer equations.

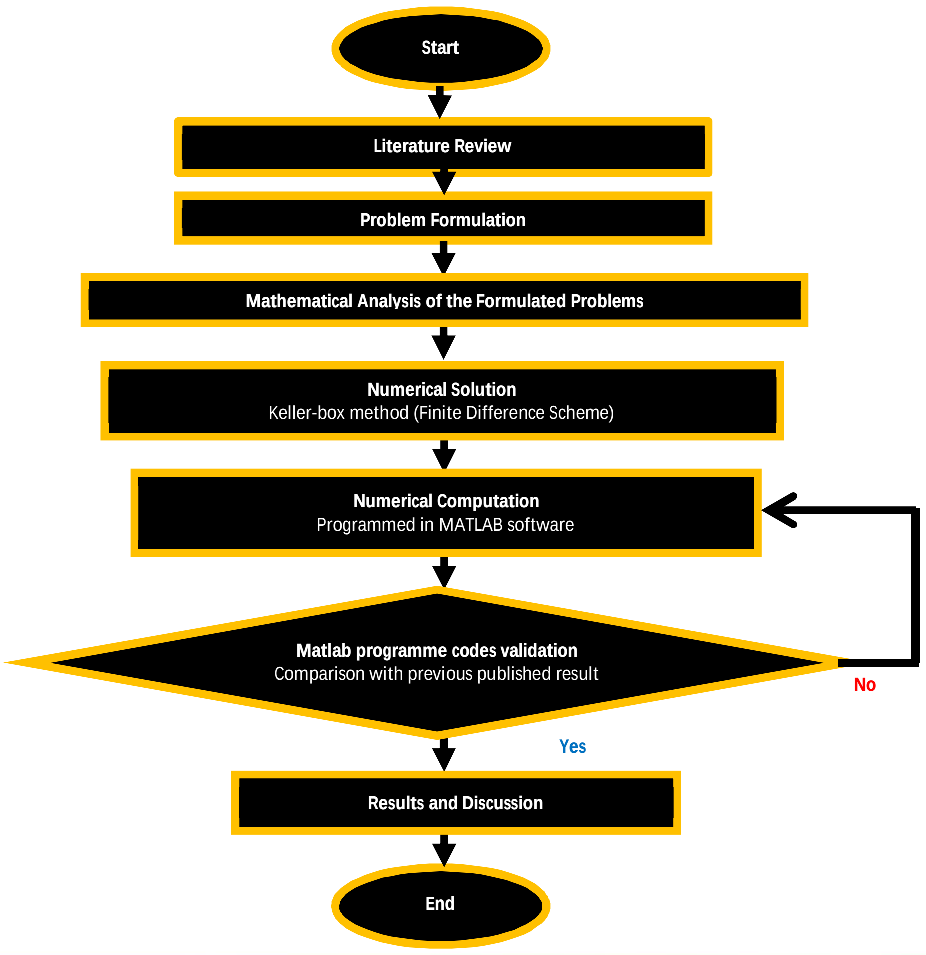


PHYSICAL MODEL



- Considered a steady, two-dimensional laminar mixed convection boundary layer flows of incompressible ferrofluid.
- A horizontal circular cylinder of radius a embedded in a ferrofluid which is heated cylinder occur when $T_w > T_\infty$ for assisting flow and cooled cylinder occurs when $T_w < T_\infty$ for opposing flow where T_w is constant surface temperature and T_∞ is ambient temperature with free stream velocity, U_∞ far flow from the cylinder.
- The orthogonal coordinates of $\bar{x}$ and $\bar{y}$ are measured along the cylinder surface, starting with the lower stagnation point $\bar{x} = 0$ and normal to it, respectively.
- A uniform magnetic field of strength, B_o is assumed applied normal on the cylinder surface.
- The magnetic Reynolds number is assumed to be small, and thus the induced of magnetic field is negligible.
- Both the base fluid and ferroparticles are assumed to be in thermal equilibrium.
- The cylinder surface is subjected to a constant wall temperature and no slip velocity condition.

OPERATIONAL FRAMEWORK



MATHEMATICAL MODEL

Governing Equations

Continuity, Momentum & Energy Equations

$$\frac{\partial \bar{u}}{\partial \bar{x}} + \frac{\partial \bar{v}}{\partial \bar{y}} = 0, \quad (1)$$

$$\bar{u}\frac{\partial \bar{u}}{\partial \bar{x}} + \bar{v}\frac{\partial \bar{u}}{\partial \bar{y}} = \bar{u}_e \frac{\partial \bar{u}_e}{\partial \bar{x}} + \nu_{ff}\frac{\partial^2 \bar{u}}{\partial \bar{y}^2} + \frac{(\rho\beta)_{ff}}{\rho_{ff}} g\left(T - T_\infty\right)\sin\frac{\bar{x}}{a} - \frac{\sigma_{ff} B_o^2}{\rho_{ff}}\left(\bar{u} - \bar{u}_e\right), \quad (2)$$

$$\bar{u}\frac{\partial T}{\partial \bar{x}} + \bar{v}\frac{\partial T}{\partial \bar{y}} = \alpha_{ff}\frac{\partial^2 T}{\partial \bar{y}^2} - \frac{1}{\left(\rho C_p\right)_{ff}}\frac{\partial q_r}{\partial \bar{y}}, \quad (3)$$

subjected to the boundary conditions

$$\bar{u}(\bar{x},0) = \bar{v}(\bar{x},0) = 0,\ T(\bar{x},0) = T_w \ \text{at}\ \bar{y} = 0,$$
$$\bar{u}(\bar{x},\infty) \to \bar{u}_e(x),\ T(\bar{x},\infty) \to T_\infty \ \text{as}\ \bar{y} \to \infty, \quad (4)$$

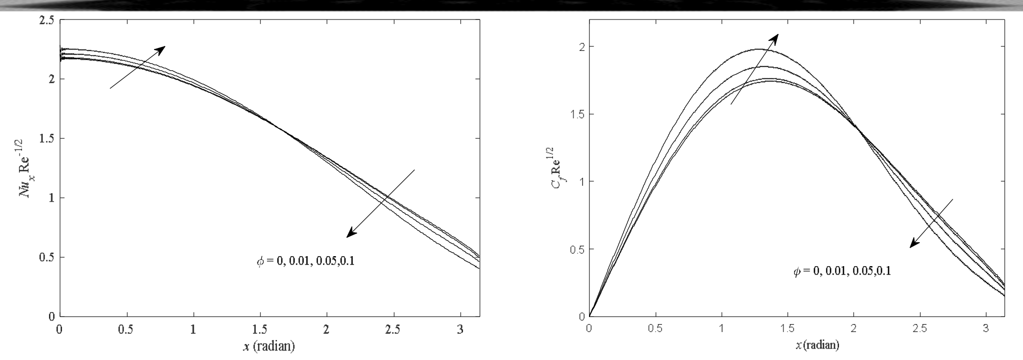
SOLVER VALIDATION

- The accuracy of the numerical method and Matlab programme codes used are verified by comparison with previously reported results. In particular, the best comparative results selected from the other studies have the same momentum and energy equation as well as the same boundary conditions when that equations simplify to the suitable conditions but using the different method of solving.
- The results from Zahar et al. (2020) are chosen to make a comparison where they use the hybrid linearization-Chebyshev spectral method (HLCSM).

Comparison values of $Nu_x \mathrm{Re}^{-1/2}$ at the lower stagnation point, $x \approx 0$ with previously published results

λ	Zahar et al. 2020	Present
-1.75	0.4198	0.4198
-1.00	0.5067	0.5067
-0.50	0.5421	0.5421
0.00	0.5705	0.5705
0.50	0.5945	0.5945
1.00	0.6154	0.6156
5.00	0.7315	0.7315

RESULTS



- The high viscosity of Fe_3O_4-water based will effects the velocity and temperature of the fluid flow when increment in magnetite volume fraction, thus the $C_f \mathrm{Re}^{1/2}$ and $Nu_x \mathrm{Re}^{-1/2}$ are also increased but decline after certain region.

BENEFITS & IMPACTS

- Regarding the innovations and future expectations of ferrofluid applications, there are few formulations for forward looking devices that have yet to be imagined in implemented ferrofluid as a heat transfer fluid.
- The behavior of ferrofluid flow contributes low viscosity, density and energy in the presence of a magnetic field which gives imperative benefits to the research and development in heat transfer fluid.
- The results from this study give the theoretical predictions to explain and verify experiment when ferrofluid flow over a horizontal circular cylinder.

ACHIEVEMENTS / AWARDS

- The 2nd International Symposium on Fluid Mechanics and Thermal Sciences (2nd IS-FMTS 2018). Malaysian-Japan International Institute of Technology (MJIIT), Universiti Teknologi Malaysia, Kuala Lumpur. 1st December 2018. Numerical Solution on MHD Stagnation Point Flow in **Ferrofluid** with Newtonian Heating and Thermal Radiation Effect. (Presenter) (Award: Best Presenter).
- 11th Malaysian Technical Universities Conference on Engineering and Technology (MUCET2019). Bukit Gambang Resort City, Pahang. 19th – 22nd November 2019. MHD Free Convection Boundary Layer Flow near the Lower Stagnation Point Flow of Horizontal Circular in **Ferrofluid**. (Award: The Best of the Best (Mechanical, Manufacturing Engineering (MME)).
- AIMS Postgraduate Poster Symposium. Universiti Malaysia Pahang. Mathematics Support Centre (MSC), UMP Gambang. 12th December 2018. Numerical Investigation on Boundary Layer Flow of **Ferrofluid**: Keller-Box Method. (Awards: Best Poster).
- 2nd Postgraduate Symposium in Mathematical Sciences. Universiti Malaysia Pahang. Mathematics Support Centre (MSC), UMP Gambang. 11th December 2019. Numerical Solution on Boundary Layer Flow of **Ferrofluid** over a Horizontal Circular Cylinder. (Awards: Best Poster).

PUBLICATIONS

- Yasin, S. H. M., Mohamed, M. K. A., Ismail, Z, Widodo, B., Salleh, M. Z. (2019). Numerical Solution on MHD Stagnation Point Flow in **Ferrofluid** with Newtonian Heating and Thermal Radiation Effect. CFD Letters 11(2), 21-31. (Scopus indexed) (Published)
- Yasin, S. H. M., Mohamed, M. K. A., Ismail, Z., Widodo, B., Salleh, M. Z. (2019). MHD Flow and Heat Transfer of **Ferrofluid** on Stagnation Point along Flat Plate with Convective Boundary Condition and Thermal Radiation Effect. Journal of Physics: Conference Series, 1366(1). (Scopus indexed) (Published)
- Yasin, S. H. M., Mohamed, M. K. A., Ismail, Z., Salleh, M. Z. (2020). Mathematical Solution on MHD Stagnation Point Flow of **Ferrofluid**. Defect and Diffusion Forum 399, 38-54. (Scopus indexed) (Published)
- Yasin, S. H. M., Mohamed, M. K. A., Ismail, Z., Salleh, M. Z. (2020). MHD Free Convection Boundary Layer Flow near the Lower Stagnation Point Flow of a Horizontal Circular Cylinder in **Ferrofluid**. IOP Conference Series: Materials Science and Engineering, 736(2), 022117. (Scopus indexed) (Published)
- Impact of buoyancy force and Lorentz force in Magnetohydrodynamic Blasius Flow of Fe3O4-Water Based **Ferrofluid**. (Under review).
- Magnetohydrodynamic Effects in Mixed Convection of **Ferrofluid** at Lower Stagnation Point on Horizontal Circular Cylinder. (Under review)

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