Abstract—In the present work, effects of magnetic field and fins on convective heat transfer of a nano-ferrofluid in a cylindrical geometry have been investigated using computational fluid dynamics (CFD) technique. Mixture model have been chosen for prediction of the nanofluids behavior, and \( \text{Fe}_3\text{O}_4 \) nanoparticles in a kerosene liquid was used as the nanofluid. An external uniform magnetic field parallel to temperature gradient between top and bottom of the geometry was applied and results have been compared with cylinders in the presence of fins. Numerical results illustrate that the magnetic field compare to fins has more influence on heat transfer enhancement.

Keywords—CFD, Fin, Heat Transfer, Magnetic Field, Nano-Ferrofluid.

I. INTRODUCTION

In the industry, heat transfer is one of the most important processes, and there are different techniques that can increase it. Based on Bergles [1] enhanced heat transfer mechanisms are divided into active and passive methods. In active methods an external power such as a magnetic field needs to enhance heat transfer. The other method does not require an external power, but it uses fins or nanofluids like nano-ferrofluids. In the existence of fins in equipments because of extension of the surface area, convective heat transfer increases [2]. Till now very investigations have been carried out experimentally and numerically on the effect of fins [3]-[6], but there is not any published data about comparison of magnetic field and fin on heat transfer enhancement of nano-ferrofluids.

Nano-ferrofluids are one type of nanofluids which are the mixture of paramagnetic nanoparticles suspended in a carrier fluid [7]. Due to high capability to control the thermophysical properties with an external field, the nano-ferrofluids have been used for heat transfer enhancement purposes [8]. External magnetic field has significant influence on thermal conductivity and viscosity of magnetic fluids [9]. In addition, the direction of magnetic field has effect on the heat transfer enhancement; and it has been found that the magnetic field parallel to temperature gradient compare to perpendicular one has more effect [10].

CFD is a branch of fluid mechanics that uses numerical methods to solve problems. CFD is a fast growing technology than can be useful to simulate complex flows. There are some CFD simulations of nano-ferrofluids that uses different methods, single phase and multi-phase models. Comparison between these methods demonstrates that the mixture method is more effective than others [11]. As CFD is a powerful technique and comparison of magnetic fields and fins on the heat transfer enhancement of nano-ferrofluids is not reported yet, the main objective of this work is numerical investigation of these two methods using CFD.

II. GOVERNING EQUATIONS

Since mixture model compare to other methods can better predict the nanofluids’ treatment [12] it was used in this study. The continuity, momentum and energy equations and volume fraction equation for the secondary phase (nanoparticles) are as follow:

\[
\frac{\partial}{\partial t} \rho^m + \nabla \cdot (\rho^m \mathbf{v}^m) = 0 \tag{1}
\]

\[
\frac{\partial}{\partial t} \left( \rho^m \mathbf{v}^m \right) + \nabla \cdot \left( \rho^m \rho_p \mathbf{v}^m \mathbf{v}_p \right) = -\nabla P^m + \nabla \left( \mu^m \nabla \mathbf{v}^m \right)
+ \rho^m g + \nabla \left( \alpha_p \rho_p \rho^m \mathbf{v}_p \mathbf{v}_m \mathbf{v}_p \right)
+ \alpha_p \rho_p \mathbf{v}_p L(\xi) \nabla H \tag{2}
\]

\[
\frac{\partial}{\partial t} \left( \rho^m c_{m} \rho^m T \right) + \nabla \cdot \left( \alpha_p \rho_p \rho^m \mathbf{v}_p \mathbf{v}_m \mathbf{v}_p + \alpha_p \rho_p \mathbf{v}_p \mathbf{v}_p T \right)
= \nabla \left( k_m \nabla T \right) \tag{3}
\]

\[
\frac{\partial}{\partial t} \left( \rho^m \rho_p \right) + \nabla \cdot \left( \alpha_p \rho_p \rho^m \mathbf{v}_p \right) = \nabla \left( \alpha_p \rho_p \mathbf{v}_p \mathbf{v}_m \mathbf{v}_m \right) \tag{4}
\]
Where $\rho$, $\vec{v}$, $P$, $\mu$, $\alpha$, $\vec{g}$, $m$, $\xi$, $\vec{H}$, $T$, $c$ and $K$ are density, velocity, pressure, viscosity, volume fraction, acceleration gravity, magnetic moment, Langevin parameter, magnetic field, temperature, heat capacity and conductivity, respectively. $\vec{v}_{dr,p}$ is drift velocity, $\vec{v}_{Mi}$ is diffusion velocity and the subscripts $m$, $c$ and $p$ sequentially refer to the mixture, primary phase (kerosene) and secondary phase (magnetic nanoparticles).

III. NUMERICAL METHODS

Commercial software, Gambit was used to create geometries illustrated in Fig. 1. Both height and diameter of all cylinders is 10 mm. Fig. 1 (a) shows the cylinder without fins and two others, Fig. 1 (b) and (c), have three fins that two of them are near the colder and warmer surface, respectively.

To ensure results are not grid dependent, a grid independency check has been performed. It was assumed that cylinders contain water and temperature difference 40 K was applied over the top and bottom of geometries. Nu numbers after 150 s was considered to compare grids. As table I demonstrates, in each cylinder, the difference between calculated Nusselt number for grid 2 and 3 is lower than 7%. Therefore, the grid 2 has been used for simulations.

IV. RESULTS AND DISCUSSION

Mixture of Fe$_3$O$_4$ magnetic particles with diameter 5.5 nm and kerosene with 98% volume fraction as the base fluid was used in this study. Temperature difference 40 K was applied in all simulations. It should be mentioned that top and bottom temperatures respectively are 290 and 330 K. Physical properties of magnetic particles and the based fluid are presented in table II.

Numerical results illustrate that nano-ferrofluids are approximately different from other types of nanofluids and the effect of magnetic field on the heat transfer is significant. As Fig. 2 shows in the absence of magnetic field and fins, magnetic nanoparticles does not have a considerable improvement on the heat flux. The same results also were reported by Lajvardi et al. [4].

In order to study the effect of fins, the heat flux in different geometries (cylinder 1, 2 and 3) were compared to each other and results have been presented in Fig. 3. It can be seen that in the existence of fins because of an improvement in the surface area the heat transfer increases. In addition, in the case that most of fins are near the bottom (warmer surface) heat transfer increases. In addition, in the case that most of fins are near the colder and warmer surface, respectively.
Effects of the uniform magnetic field (H=160 kA/m) parallel to temperature gradient and fins on heat transfer of the nano-ferrofluid have been presented in Fig. 4. In this section, cylinder 3 which has more effect on the heat transfer has been chosen. It is obvious that the effect of magnetic field is more significant. It is because that the magnetic field increases the fluid motion and presence of more vortices in the cylinder has been observed by researchers in this study.

![Fig. 4 Comparison of magnetic field’s and fin’s effect on heat transfer of the nano-ferrofluid](image)

V. CONCLUSION

In the present study, the heat transfer enhancement of a nano-ferrofluid in the existence of a uniform magnetic field has been compared with fin’s effect using a CFD technique, and the following results were obtained.

- Presence of fins near the surface with higher temperature has more effect on the heat transfer compare to put them near the surface with the lower temperature.
- The effect of magnetic field on the heat transfer is more significant than fins’ effect.

REFERENCES