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# The influence of non-uniform magnetic field on heat transfer intensification of ferrofluid inside a T-junction

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A R T I C L E I N F O

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A B S T R A C T

In this research, the effects of non-uniform magnetic field on the heat transfer of ferrofluid inside a T-junction are investigated. The finite volume method with the SIMPLEC algorithm is applied to simulate the effects of non-uniform magnetic field on the thermal and friction factor of ferrofluid. The ferrofluid inside T-junction is assumed single phase and laminar and constant heat flux is applied on the wall while three wires are chosen as a source of non-uniform magnetic field. This study focused on main effects of magnetic field on the flow feature and temperature distribution in the vicinity of magnetic source. Comprehensive parametric studies are performed to investigate the influence of various factors such as intensity of magnetic field and Reynolds number on the heat transfer. Obtained results show that average heat transfer of ferrofluid rises more than 64% when magnetic field is applied. In addition, the local heat transfer increases more than 200% in vicinity of the first magnetic field.

## 1. Introduction

Recently, advance of microprocessors and other electronic components is an essential task for the increasing the power of these devices and decreasing the computational cost. One of the main problems in increasing the power of the microprocessors is heat generation due to energy dissipation. This challenge motivates researchers to find efficient heat dissipating system to overcome this issue [1,2]. lately, developments in nanofabrication have allowed researchers to produce solid particles in nanometer scale. Adding these particles into the base fluid has led to new type of fluids, known as 'nanofluids' [3]. These fluids could significantly be used for electronic cooling applications [4]. The presence of these nanoparticles induces a special character which enabled the fluid to be influenced by various sources such as a magnetic field [5].

According to these significant and special characteristics in heat transfer, various researches have been applied this type of fluid in various applications. Salimpour et al. [6] presented an experimental study on deposited surfaces due to nanofluid pool boiling: comparison between rough and smooth surfaces. Abdollahi et al. [7,8] experimentally investigated the boiling heat transfer of nanofluids on a flat plate in the presence of a magnetic field. Kakaç and Pramuanjaroenkij [9] comprehensively reviewed convective heat transfer enhancement with nanofluids. Khan et al. [10] presented bionic study of variable viscosity on MHD peristaltic flow of Pseudoplastic fluid in an asymmetric channel. Bhatti [11,12] studied heat transfer with nonlinear thermal radiation on sinusoidal motion of magnetic solid particles in a dusty fluid. Sheikholeslami et al. [13–26] performed several studies on the effect of magnetic file on heat transfer of nanofluid. Beg et al. [27] also Compared single-phase and two-phase models for bio-nanofluid transport phenomena.

The influence of the magnetic field on the heat transfer has been examined by several researchers. Recently, scientist and researcher used CFD device for simulation and evaluation of the non-uniform magnetic field on the heat transmission of ferrofluid [28–32]. Mousavi et al. [28,29] studied the effect of magnetic field on heat transfer of ferrofluid in heat exchanger with a sinusoidal double pipe. Hariri et al. [30] investigated heat transfer of a ferrofluid inside a tube in the presence of a non-uniform magnetic field. Mokhtari et al. [31] applied CFD method to study non-uniform magnetic field on heat transfer of swirling ferrofluid flow inside tube with twisted tapes. Sheikholeslami et al. [32] investigated forced convective heat transfer of Fe-water nanofluid in the presence of external magnetic source.

The heat transfer of nanofluid inside T junction is also studied by

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**Nomenclature**

| | |
|---|---|
| (a,b,c) | The position of wire (m) |
| $C_p$ | Specific heat (J/kg K) |
| D | Hydraulic diameter (m) |
| $D_p$ | Magnetic particle diameter (m) |
| $H_r$ | Characteristic magnetic field strength (A/m) |
| $H_x$ | The intensity of magnetic field in x direction (A/m) |
| $H_y$ | The intensity of magnetic field in y direction (A/m) |
| $H_z$ | The intensity of magnetic field in z direction (A/m) |
| I | Electric intensity (A) |
| k | Thermal conductivity (W/m °C) |
| $K_B$ | Boltzmann constant ($1.3806503 \times 10^{-23}$J/K) |
| M | Magnetization (A/m) |
| T | Temperature, °C |
| x | Direction |
| y | Direction |
| Y | Length of pitch |
| z | Direction |

various researchers. Murshed et al. [33,34] performed experimental researches on the droplet formation and size manipulation of nanofluids in a microfluidic T-junction at diverse temperatures. Wehking et al. [35] performed experimental examinations in a T-junction microfluidic system. Although several works were conducted in heat transfer of the nanofluid, there are limited works devoted to study the flow feature and temperature distribution inside the micro T-junction. In addition, the influence of magnetic source on the nanofluid inside T junction was not investigated in previous studies. Since T junction is a dominant section in cooling of the microelectronic devices and refrigerators, finding a new technique for improving the heat transfer could enable the researchers to improve the performance of the future processors. In fact, T junction heat transfer is a common model in various micro devices and using magnetic field for enhancement of the heat transfer could be a useful in the cooling of different instruments such as microprocessors.

The goal of this research is to study the influence of magnetic field on the laminar convective heat transfer of ferrofluid inside the T junction. The finite volume approach is used to simulate the flow feature and obtain heat transfer inside the T junction when the wire as the source of the non-uniform magnetic field is presented. Comprehensive parametric studies are performed to investigate the effect of the magnetic intensity and Reynolds number on main characteristics of base fluid. In addition, the streamline and temperature distribution of different conditions are compared. The overall average heat transfer inside the micro T junction is comprehensively studied(Table 1).

## 2. Numerical approach

### 2.1. Geometry and grid

Fig. 1 demonstrates the schematic of the T junction in the presence of three wires in normal direction of surface as source of magnetic field. In this study, the radius of the inlet flow is 0.05 m. The applied boundary condition is also presented in the figure. As an electric current

**Table 1**
The value of current equivalent to the chosen magnetic intensity.

| *Mn* | *I* |
|---|---|
| 0 | 0 |
| $3.26 \times 10^{-5}$ | 3 |
| $9.06 \times 10^{-5}$ | 5 |
| $17.76 \times 10^{-5}$ | 7 |
| $52.2 \times 10^{-5}$ | 12 |

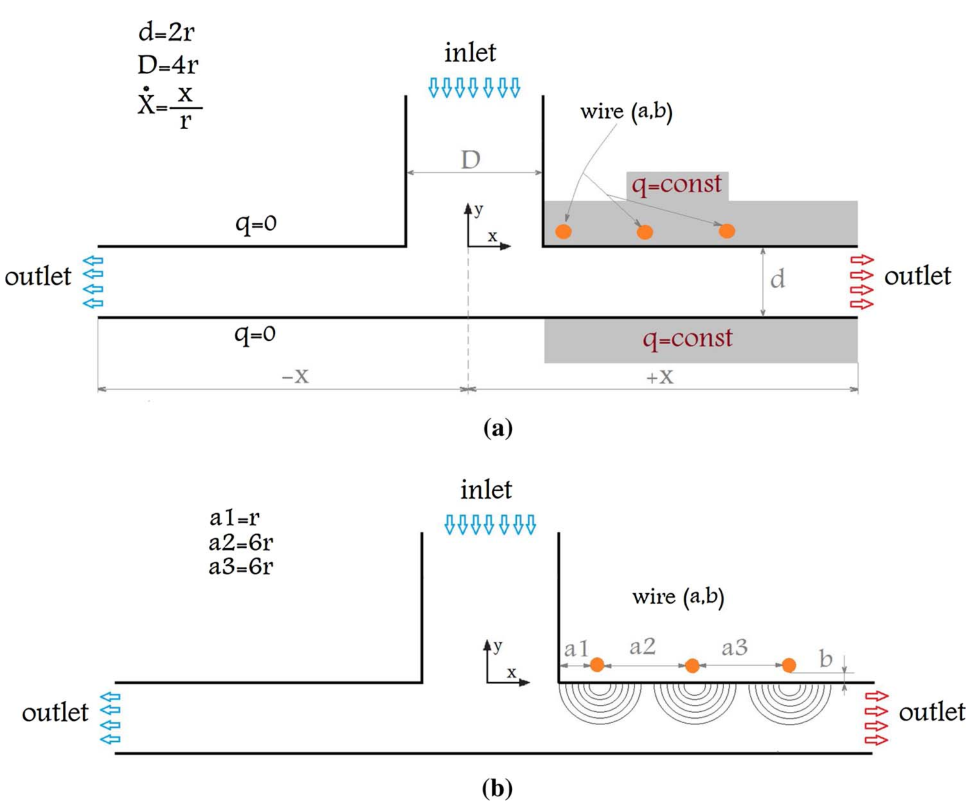


**Fig. 1.** (a) Schematic of T junction in presence of magnetic field (wire); (b)The schematic distribution of magnetic field in the domain.