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Discussion

# The effect of magnetic field on nanofluids heat transfer through a uniformly heated horizontal tube

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ABSTRACT

In this study, the effects of magnetic field on forced convection heat transfer of $Fe_3O_4$–water nanofluid with laminar flow regime in a horizontal pipe under constant heat flux conditions were studied, experimentally. The convective heat transfer of magnetic fluid flow inside the heated pipe with uniform magnetic field was measured. $Fe_3O_4$ nanoparticles with diameters less than 100 nm dispersed in water with various volume concentrations are used as the test fluid. The effect of the external magnetic field ($Ha = 33.4 \times 10^{-4}$ to $136.6 \times 10^{-4}$) and nanoparticle concentrations ($\varphi = 0$, 0.1, 0.5, 1%) on heat transfer characteristics were investigated. Results showed that by the presence of a magnetic field, increase in nanoparticle concentration caused reduction of convection heat transfer coefficient. In this condition, heat transfer decreased up to 25%. Where, in the absence of an external magnetic field, adding magnetic nanoparticles increased convection heat transfer more than 60%. It was observed that the Nusselt number decreased by increasing the Hartmann number at a specified concentration of magnetic nanofluids, that reduction about 25% in heat transfer rate could be found.



## 1. Introduction

Magnetic fluid, which is also called ferrofluid, is a magnetic colloidal suspension that is composed of magnetic nanoparticles such as iron, nickel, cobalt and their oxides and etc. with a base fluid. Due to the unique features of ferrofluid, this magnetic fluid acts as an intelligent and functional fluid. Thus, it finds a place in various fields such as electronic package, mechanical engineering, aerospace, bio-engineering and so on [1,2]. Jafari et al. [3] simulated the heat transfer of a ferrofluid based on kerosene into a cylinder and under the influence of a magnetic field. They reported that by presence of magnetic field, heat transfer increased and formation of nanoparticles aggregations resulted in a heat transfer reduction. Li and Xuan [1] experimentally investigated the convective heat transfer around a heated wire under the influence of uniform magnetic field. They observed that in the most of Reynolds numbers, Nusselt number of magnetic field in presence of magnetic field is smaller than Reynolds number of magnetic fluid in absence of magnetic fields, and by increasing Hartmann number, Nusselt number decreased. Lajavardi et al. [4] conducted an experiment on heat transfer of laminar flows of ferrofluid including $Fe_3O_4$ nanoparticles in presence of magnetic field. They reported that firstly, water–$Fe_3O_4$ nanofluids cannot increase heat transfer of laminar flow regime in absence of magnetic field. Secondly, by an increase of magnetic field strength, heat transfer coefficient increases. Aminossadati et al. [5] numerically studied laminar forced convective heat transfer of $Al_2O_3$–water nanofluid in a horizontal microchannel. Their researches indicated that Nusselt number increases by Hartmann number. They reported that the reason is high flow rate near microchannel which is created by high heat transfer of walls to the flow. Malekzadeh et al. [6] numerically investigated the effect of magnetic field on laminar flow of heat transfer in a tube. They applied the effects of magnetic field in the governing equation and believed that applying magnetic field improves heat transfer. Magnetic field effects on natural convection heat transfer of nanofluids of copper–water and copper oxide–water were studied numerically by Sheikholeslami et al. [7] and Mahmoudi and Abu-Nada [8], respectively. The effect magnetic field on the onset of nanofluid convection was examined by Yadav et al. [9,10]. In some works, the effect of Hall current was investigated, too [11,12]. The reason of applying and control of energy and flow transfer processes by means of applying an external magnetic field, penetration of magnetic fluids in heat engineering

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**Nomenclature**

| | | |
|---|---|---|
| $C_p$ | Heat capacity | J/kg k |
| $D$ | Tube internal diameter | m |
| $h(x)$ | Local heat transfer coefficient | W/m$^2$ k |
| $I$ | Current | A |
| $K$ | Thermal conductivity | W/m k |
| $L$ | Tube length | m |
| $M$ | Mass | kg |
| $Nu_x$ | Local Nusselt number | dimensionless |
| $Pe$ | Peclet number | dimensionless |
| $Pr$ | Prandt number | dimensionless |
| $Q$ | Volume flow rate | m$^3$/s |
| $q''$ | Wall heat flux | W/m$^2$ |
| $Re$ | Reynolds number | dimensionless |
| $T$ | Temperature | °C |
| $V$ | Voltage | volts |
| $V$ | Volume | m$^3$ |
| $X$ | Axial distance | m |

*Greek symbols*

| | | |
|---|---|---|
| $\Phi$ | Volume fraction | |
| $P$ | Density | kg/m$^3$ |

*Subscript*

| | |
|---|---|
| $b$ | Bulk |
| $bf$ | Base fluid |
| $in$ | Inner |
| $np$ | Nanoparticle |
| $out$ | Outside |
| $w$ | Wall |

have been remarkable in recent decades, but most of the studies conducted in numerical aspects.

In this article, convection heat transfer of water–$Fe_3O_4$ nanofluids in a horizontal tube has been studied experimentally with and without an external magnetic field. Volume fraction of nanoparticles, magnetic field strength and flow rate were investigated in these experiments.

## 2. Experiment procedure

### 2.1. Particle characterization

The required nanofluids are prepared by dispersing $Fe_3O_4$ nanoparticles in distilled water as a base fluid. $Fe_3O_4$ nanoparticles were made by US Research Nanomaterials, Inc. Company with true density of 5180 kg/m$^3$ and bulk density of 840 kg/m$^3$. These particles are spherical in shape and their size is less than 100 nm.

### 2.2. Preparation of nanofluid

Magnetic $Fe_3O_4$ nanoparticles were dispersed in distilled water in order to achieve a ferrofluid. Volumetric concentration was estimated from Eq. (1):

$$\varphi = \frac{V_{np}}{V_{bf}} \times 100 = \frac{m_{np}/\rho_{np}}{V_{bf}} \times 100 \tag{1}$$

At first, nanoparticles were mixed by an ordinary agitator (MJ-176NR, Japan) with 11500 rpm for 30 minutes and then pH was adjusted. In the category of stability of nanofluids, pH is an important parameter which is related to electrostatic charge on particle surface. In the present work, nanofluid samples with 0.1 vol% $Fe_3O_4$ were prepared in 2 to 13 pH volume. The pH samples were adjusted by HCl and NaOH solutions and were measured by a pH meter (pH7110, WTW). The sample with pH = 13 was more stable than the other samples.

### 2.3. Experimental setup

The schematic diagram of the experimental apparatus is presented in Fig. 1. Nanofluids into circulator (RE308, LAUDA) are set at a certain temperature and pumped from here to the test section. The fluid into circulator tank is constantly stirring during experiment time so that all points of the tank become equal in temperature. Moreover, the used mixer ensures nanofluid stability during the test. Magnetic field is applied perpendicular to the flow direction (parallel to the temperature gradient) before testing part. The testing section consists of a copper tube with 1 m length, 6 mm internal diameter and 14 mm external diameter, and a heat tape with a maximum power of 500 watts. Eleven thermocouples within a distance of 10 cm into holes with a depth of 3 mm have been installed on a copper pipe. The thermocouples are k-type and their accuracy is 0.1 °C. Temperature is measured by these thermocouples which are displayed by two temperature indicators (N113-D6, JNM). Totally three insulations wrapped on the copper tube to minimize heat transfer between test section and outside environment. The 12th thermocouple is inserted into silicon hose next to outlet of copper pipe to measure the outlet fluid bulk temperature. Constant heat flux is provided by a power supply (TDGC2-1, EMERSUN). Output current of power supply is AC as the same as the input current. So, output AC current of the power supply is converted to DC by a rectifier. A multimeter was used to read the output current and voltage of the rectifier, exactly.

### 2.4. Data analysis

Heat flux can be given to the system by means of a heat tape that is obtained from the following equation:

$$q'' = \frac{IV}{\pi DL} \tag{2}$$

where $I$ and $V$ are current and voltage, respectively and both of them are gotten from multimeter. In the present work, $V = 120$ volt, $I = 1.05$ A and $q = 126$ W. Also, heat flux of the fluid can be obtained from the following equation:

$$q'' = \frac{Q\rho C_p}{\pi DL}(T_{out} - T_{in}) \tag{3}$$

Relative heat loss can be obtained from the following equation and it can be used to evaluate the apparatus accuracy:

$$q_{loss}(\%) = \frac{IV - Q\rho C_p(T_{out} - T_{in})}{IV} \times 100 \tag{4}$$

The bulk temperature of an arbitrary cross section in the tube is estimated from the following equation [6]:

$$\Rightarrow T_b(x) = T_{in} + (T_{out} - T_{in})\frac{x}{L} \tag{5}$$

where $T_b(x)$ is fluid bulk temperature and $T_{in}$ and $T_{out}$ are input and output temperatures of test section, respectively. $L$ is the length of copper pipe which is heated and $x$ is the distance which started from applying heat tape point. Heat transfer coefficient and



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