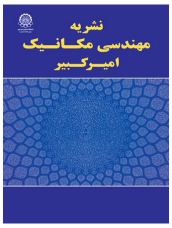

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Convection Heat transfer Fe_3O_4/Water in a Square microchannel Under Uniform Heat Flux and Magnetic Field

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ABSTRACT: This study aimed to investigate the heat transfer of water/Fe_3O_4 nanofluid in a square cross-sectional channel with dimensions of 80 cm ×1 cm ×1 cm under the influence of a uniform heat flux perpendicular to the laminar flow of ferrofluid in the presence of a magnetic field. Firstly, the production of ferrofluid with concentrations of 0.5 vol.% and 1vol.%, their quality, and the quality of the production method was investigated. The results of zeta potential and vibrating-sample magnetometer tests show the good quality and stability of the produced ferrofluid. The thermophysical properties of the made ferrofluid are compared and evaluated with existing experimental correlations. The heat transfer of the produced ferrofluids under the influence of heat fluxes of 134-546 Watts is investigated in the absence of an external magnetic field. Then, the effect of the external magnetic field on the heat transfer at 0.5 vol.%, under the influence of a total heat flux of 1258.2 Watts is investigated. The magnitude of increase of heat transfer coefficient compared to pure water, without external field, for ferrofluid with 1 vol.%, under total heat fluxes of 134, 545, and 321.3 Watts, are 30%, 48%, and 38% respectively. At a heat flux of 1258.2 Watts, the heat transfer coefficient in the presence of an external magnetic field increases by 3.16% at 0.5 vol.% compared to the absence of a magnetic field.

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1- Introduction

A kind of nanofluids so-called ferrofluids exists that includes ferromagnetic nanoparticles in the base fluid. Ferrofluids have notable heat transfer applications because of their controllable thermo-magnetic heat transfer by an external magnetic field. Kikura et al. [1] and Sawada et al. [2] directed experimental research in a concentric horizontal cubic and annular chamber under the influence of a magnetic field. The permanent magnet was placed in different parts of the chamber, and the consequence of the magnetic gradient on the ferrofluid heat transfer was investigated. The heat transfer of combined natural and magnetic convection through a ferrofluid in a cubic chamber was numerically simulated by Snyder et al. [3], and the outcomes indicated good agreement with the experiment. Zablockis et al. [4] numerically studied the thermal-magnetic convection produced by a non-uniform constant magnetic field of a coil in a hot cylinder. Despite a noteworthy number of researches in this domain, researchers believe that a lack of broad investigations exists on square cross-sectional channels, and the accurate behavioral pattern of this type of fluid is not yet available.

In the present study as an innovation, the experimental investigation of convection coefficient and the Nu number of ferrofluid Fe_3O_4/water under a constant heat flux was done with/without applying an external magnetic field in a channel with a square cross-section in the laminar flow regime. The impact of various vol.% and the location of field application were other cases of study. It should be noted that the geometry of the present problem, which is one of the innovations of this research, is used in heat exchangers. The results showed an increment in heat transfer via employing a magnetic field. This approach may pave the way for the next generation of high-efficiency heat transfer engineering.

2- Methodology

2- 1- Apparatus and materials

Set-up includes ferrofluids, pump, a channel which has a square cross-section, flow meter, radiator, 6 temperature sensors, refractory mica sheets, magnets, 2 pressure sensors, autotransformer, and the tape heater which was wrapped around the channel Adam cards were used to collect data, reservoir tank.

At a distance of 0.7 meters from the channel inlet, the fully-developed happens. Though, the distance of both origin of the heater and the location of the first thermal sensor (x=0 cm) from the outset of the channel is 1 meter. Fig. 1 shows the set-up circuit and the distance between the sensors and their position relative to the channel.

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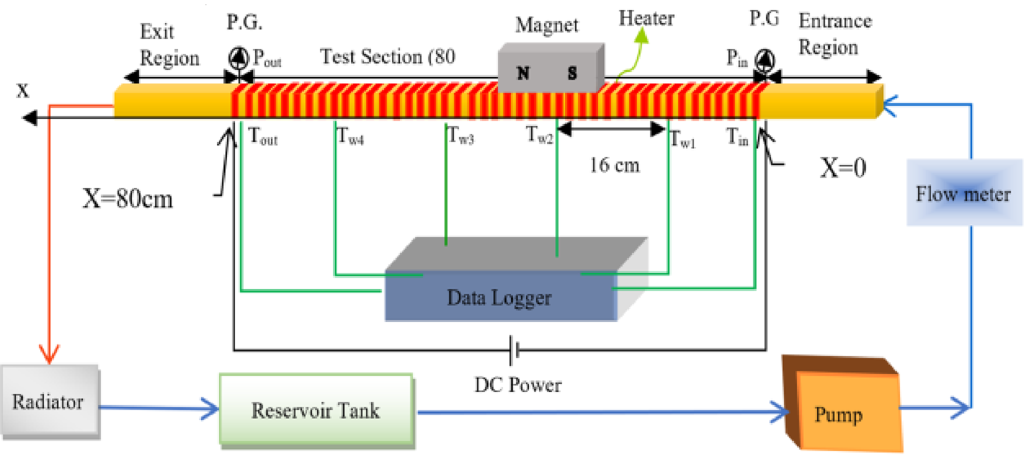

Fig. 1. Schematic diagram of the experimental setup

The result of the zeta potential test is 62.1 mV, which is much higher than 30 mV and, has good stability [5]. Thus, it is observed that the method proposed by Berger et al. [6] is a very suitable method for the production of water/Fe3O4 ferrofluid.

In the Vibrating-Sample Magnetometer (VSM) test, the amount of magnetic saturation of water/Fe3O4 with 1 vol.% was 2 emu/g and for ferrofluid with 0.5 vol.%, 0.6 emu/g was obtained. The hydrodynamic diameter of the Channel is 0.007. Despite the equality in volumetric flow rate and constant velocity of the working fluids, slight differences occur in Reynolds numbers due to differences in their density and viscosity. Therefore, instead of the Reynolds value, a volume flow is reported that is constant in all tests.

2- 2- Validation

In order to confirm the validity of the tests, water was used as a working fluid when the external field was zero. Bejan et al. [7] showed that according to these conditions the Nu number is 3.6 and it depends only on the geometry and dimensions of the channel. This value was found to be 3.56 for the first five points of the channel and 3.52 for the endpoint of the channel, which is very close to 3.6 (Fig. 3).

3- Results and Discussion

3- 1- Convection heat transfer coefficient

In the case of B=0 and according to , when the values of hydrodynamic diameter and Nusselt number are constant the ratio of should be constant [7]. So, the h will increase as long as the k increases, , (Fig. 2). Fig. 2 shows that the local convection coefficient for pure water and ferrofluid 0.5 vol.% are approximately constant versus its slight changes in ferrofluid of 1 vol.%. Under the heat flux of 1258.2 Watts and When the permanent magnet place at x = 80, 32, and 0 cm, the convection coefficient of ferrofluid with 0.5 vol.% show in Table 1. In all cases, the magnet place in the developed area. Where the magnets place, the value of the convection coefficient has increased. When the magnet place at the beginning of the test section, it increases by +2.8%. At this heat flux, when the magnet place at the end of the test section, the convection coefficient increases by 3.16%. When the magnet place at x=32 cm, the convection coefficient rises by 2.67%.

In the heat flux of 545 Watts, the maximum increase in convection coefficient relative to pure water is for the ferrofluid 1 vol.% is 48%. This value for ferrofluid of 0.5 vol.% in the flux of 134.4 Watts is 15.8%.

3- 2- Nu Number

As can be seen in Fig. 3, the test results show accepted the agreement with 3.6, [7] that indicates the good accuracy of the experiments performed .

4- Uncertainty

Without the presence of an external field, the maximum uncertainty of the convection coefficient related to both ferrofluids is 0.017, and for the Nusselt number is related to the ferrofluid with 0.5 vol% is 0.011. In the presence of an external magnetic field, the maximum convection uncertainty is 0.0032. These values indicate the high accuracy of the tests performed.

5- Conclusion

- In the absence of an external magnetic field, the use of 0.5 vol.% and 1 vol.% ferrofluid in comparison with water causes 15.8% and 30% growth in convection heat transfer respectively. For ferrofluid 1 vol.%, under the heat flux of 545 Watts, an increase of 48%, and under the heat flux of 321.3 Watts, 38% growth was observed.

Table 1. Ferrofluid local convection coefficient with 0.5 vol.% under the constant magnetic field and heat flux of 1258.2 Watts in channel different positions

Magnet positions (cm)	Local convection coefficient at magnet position (W/m^2k)	
	Without magnetic field	With magnetic field
0	358.4 ± 0.0032	368.74 ± 0.0032
32	358.42 ±0.01737	368.00±0.01737
80	358.4 ± 0.0032	369.76 ± 0.0032

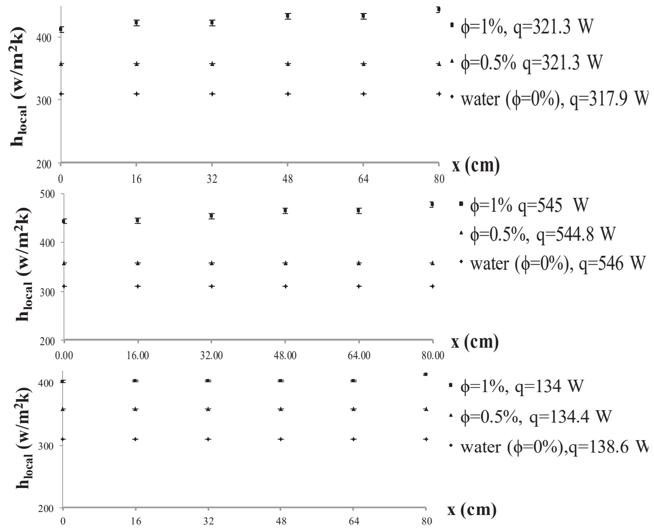

Fig. 2. Local convection coefficient in samples, 500 ml/min, without applying a magnetic field, at the thermal fully developed region at thermal fluxes: a) 317.9 and 321.3 Watts b) 545, 544.8 and 546 Watts c) 134, 134.4, and 138.6 Watts

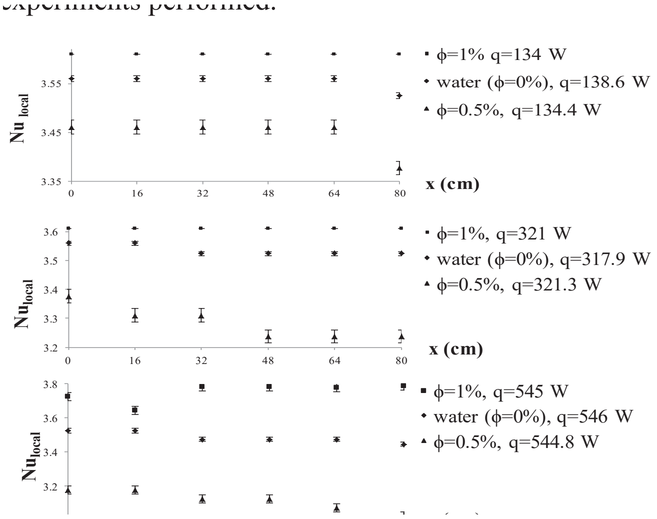

Fig. 3. Local Nusselt number in different fluids, flow rate 500 ml/min and heat fluxes a) 134, 134.4, and 138.6 Watts b) 317.9 and 321.3 Watts c) 544.8, 545 and 546 Watts, without External magnetic fieldM

- At a heat flux of 1258.2 Watts, when the magnet place at x = 0 cm, the convection coefficient increases by 2.8%. When the magnet place at x = 80 cm, the convection coefficient increases by 3.16%, and when the magnet place at x = 32 cm, the convection coefficient increases by 2.67%. When the fluid moves away from the location of the magnet along the channel, the convection coefficient decreases to 358.42 . These results confirm the positive effect of the magnetic field on local heat transfer within the test conditions.

- The zeta potential test result is 62.1 mV, which is much higher than 30 mV (the proper ferrofluid stability limit). For this reason, ferrofluid produced by the Berger method [6] possesses pretty good stability.

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