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Experimental investigation of the effect of magnetic field on the thermal properties of water-ethylene glycol based iron oxide nano fluids for vehicle radiator cooling applications

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ABSTRACT

This study investigates the effect of a magnetic field on the thermal properties of ethylene glycol and water-based Fe_3O_4 magnetic nanofluids. To make a magnetic nanofluid an option, the magnetic field strength and concentration of the magnetic nanoparticles should be optimized. This was achieved in a small-scale laboratory system designed to simulate the cooling cycle of an internal combustion engine, which was exposed to a constant magnetic field. The concentrations of the magnetic nanoparticle in the Fe_3O_4 nanofluid ranged between 0.025% and 0.2% by volume. The mean sizes of nanoparticles were 20–30 nm. The research used a consistent magnetic field of 0.05, 0.10, and 0.15 Tesla. The thermal properties that have been studied are the heat transfer coefficient, thermal conductivity, heat transfer rate, and Nusselt number. Experimental results indicate that the thermal properties of the Fe_3O_4 magnetic nano fluids were enhanced under an applied external magnetic field. The effect of the magnetic field is strongly dependent on the concentration of magnetic nanoparticles in a mixture of ethylene glycol/water. The thermal properties significantly improved at a magnetic field strength of 0.15 Tesla when using a concentration of 0.2 vol.% nanoparticles. This led to a maximum increase of 18.4% in the heat transfer coefficient. At this volume fraction and with the 0.15 Tesla magnetic field, the thermal conductivity increased by 8.22%. Additionally, the most significant increase in the Nusselt number was observed at a Reynolds number of 7500 under the same magnetic field conditions.

Keywords: nanofluid, magnetic field, thermal conductivity, vehicle radiator, coolant fluid.

INTRODUCTION

The effectiveness of heat exchange between the engine and the surrounding medium is important in the performance and efficiency of a water-cooled internal combustion engine. A mixture of ethylene glycol and water is most often the radiator coolant in most cars. This mixture, however, has very little heat capacity and hence, its capability of effectively dissipating heat throughout its operation is limited. To address this constraint, the solution that has been proposed is the use of magnetic nanofluids, which are colloidal suspensions of magnetic nanoparticles dispersed evenly in a base fluid. Such magnetic nanofluids are found to be very useful in improving thermal characteristics of liquid coolant and therefore can be applied in many of the applications since such nanofluids have high thermal conductivity. They comprise heat exchangers in the automobile industry, solar heat exchangers, microelectronics, round heat pipes, as well as air conditioning systems [1]. The concentration of nanoparticles and the strength of the magnetic field are paramount to the optimization of the nano fluids as coolants in the automotive cooling systems [2]. Several studies have investigated the thermal properties of magnetic Nano fluids under the influence of a magnetic field. A contemporary application of magnetic fields is their effect on the properties of water. [3] This review provides an elaborate analysis of how magnetic fields influence the distribution of molecules and electrons without influencing the atomic or molecular structure of magnetically responsive nanofluids in regard to heat transfer [4]. The work summarizes the findings of experimental, theoretical, and numerical studies, with the mechanisms of formation of magnetic particle chains, anisotropic conduction. The findings described that magnetic fields enhance convective heat transfer through the alignment of magnetic nanoparticles along thermal gradients, forming thermally conductive chains. The improvements will be based on the power of a magnetic field, loading particles and geometries of flow [5]. Assess the heat removal of engine-like thermal loads and apply artificial neural network (ANN) modeling to predict behaviour under different operating conditions. Even though TiO_2 nanofluids are not magnetic, the study is required as a reference point for the study of nanofluid cooling in the engine conditions. A magnetic field may alter the density of water, viscosity, thermal and electrical conductivity of water and surface tension of water [6]. The studies have demonstrated that the thermal and electrical conductivity of water under the influence of a magnetic field is also improved; the thermal conduction improved by 10 percent over the base fluid, and the viscosity and surface tension at the same time decreased [7]. Research has been conducted to determine how a magnetic field affects the physical characteristics of water, with particular emphasis on four kinds of magnetized water (MW). The results show that the magnetic field treatment modifies the specific heat, increases boiling point, changes the evaporation rates and optimizes the cooling performance [8]. The experiment explored the magnetic field of the thermal conductivity of magnetic nanocolloid additives, which contained additives like iron oxide nanoparticles (Fe_2O_3 and Fe_3O_4) and nickel oxide (NiO) of different base fluids, namely kerosene and ethylene glycol. Under the influence of an externally applied magnetic field, it was found that the highest thermal enhancement was experienced with the Fe_3O_4/ethylene glycol-based nano fluid using water and ethylene glycol (EG) [9]. The research paper explored the forced convoluted heat transfer properties of the water-ethylene glycol-based Fe_3O_4 nano fluid under the influence of an externally applied magnetic field. They obtained a growth in the heat transfer coefficient of about 2.78 percent and an enhancement of about 3.23 percent. Thus, convective heat transfer can be improved by increasing the dispersion stability of nanoparticles and optimizing the strength of the magnetic field [10]. A study was conducted to experimentally investigate the effect of an oscillating magnetic field on Nano fluids, specifically water mixed with Fe_3O_4 and water mixed with Fe_3O_4/CNT. The researchers assessed thermal conductivity while analyzing magnetic field strength and frequency. They discovered that the highest increase in thermal conductivity occurred when exposed to an oscillating magnetic field of 700 Gauss. [2] A study was conducted to investigate the thermo-physical properties of water-ethylene experimentally glycol-based Fe_3O_4 nanofluids at low concentrations and temperatures. The researchers measured the dynamic viscosity, thermal conductivity, and surface tension of these Fe_3O_4 nanofluids. The findings indicate that the thermo-physical properties of nanofluids are highly dependent on the concentration of the nanoparticles.

Based on the studies mentioned above, the thermal properties of the water-ethylene mixture have captured the attention of several researchers, and the nano fluids in automobile radiators compared to conventional fluids (water–ethylene glycol) have been studied by some researchers few studies have focused on the effect of a magnetic field on the thermal properties of nano fluids. Therefore, it is necessary to develop the next-generation cooling system for the internal combustion engine. The research identifies that utilizing magnetic nano fluids and controlling the strength of the magnetic field are paramount factors in improving the efficiency and performance of cooling applications. This research is important due to the combined effect of the two main factors, including the effects of the magnetic field and the properties of the nano fluid. The phenomenon of the magnetic field-nanoparticle interactions is important to the temperature regulation of the cooling loops in recent engine systems.

This paper aims to maximize the strength of magnetic fields and the concentration of nanoparticles in order to develop nano fluids that can be used as coolants in many industries, such as in car radiators of the automotive industry. The current research paper examines the results of the impact of a magnetic field on the thermal characteristics of the magnetic Fe_3O_4 nano fluids that are prepared using water and ethylene glycol.

To enhance the thermal properties, metal oxides are mixed with water-ethylene glycol to create nanofluids. The Fe_3O_4 nano fluids were prepared with nanoparticle concentrations ranging from 0.025% to 0.2% by volume, referring to [11].The study employed a consistent magnetic field ranging from 0.05,0.10, and 0.15 Tesla. The thermal properties examined include thermal conductivity, heat transfer coefficient, heat transfer rate, and Nusselt number. The results are compared with those of conventional fluids.

MATERIALS AND EXPERIMENTAL PROCEDURE

Nano fluids preparation and properties

The study employs a base fluid composition of water and an ethylene glycol ratio of 50:50, along with Fe_3O_4 magnetic nanoparticles. The mixture of water and ethylene glycol is commonly used in systems to prevent freezing, reduce viscosity, and enhance thermal conductivity, making it a popular choice as a working fluid in heat transfer systems. On the other hand, the Fe_3O_4 magnetic nanoparticles have magnetic properties. These Fe_3O_4 nanofluids exhibit unique properties due to their enhanced thermal conductivity and inherent magnetic characteristics. The combination of these properties provides higher thermal efficiency in the case of the application of an external magnetic field. Table 1 below shows the properties of a 50/50 blend of water and ethylene glycol. In addition to that, Table 2 shows the characteristics of Fe_3O_4 used in the experiments. The preparation of the nanofluid involved a series of processes such as the calculation of the target nanoparticle in terms of volume, the introduction of nanoparticles into the base fluid, preliminary mixing of the nanoparticles using a stirrer, and then subjecting the Fe_3O_4 nanoparticles to sonication to mix them with the water-ethylene glycol mixture, 3 hours with an ultrasonic disperser, and 1 hour with a stirrer respectively as shown in Figure 1. This was done to make sure that the Fe_3O_4 nanofluid was stable so that dispersion stability is maintained. The concentrations of the nanofluids are 0.025% to 0.2 vol.. Average nanoparticle sizes ranging from 20 to 30 nm were prepared and calculated using specific formulas. The required mass was determined based on the concentration. The thermal physical properties of Fe_3O_4 nanoparticles mixed with a 50/50 ratio of water and ethylene glycol were measured experimentally and are summarized in Table 3. The values for density ($\rho_n f$), viscosity ($\mu_n f$), specific heat ($C_n f$), and thermal conductivity ($k_n f$) are presented [12].

Calculation of nano-fluid properties

The relationships have been utilized to calculate the physical properties of nanofluids, including density ($\rho_n f$), viscosity ($\mu_n f$), specific heat ($C_n f$), volume concentration of the nanofluid, and thermal conductivity ($k_n f$). A nanofluid is composed of two components – nanoparticles and a base fluid.

Nano fluid properties is compound of base fluid properties and nanoparticle properties:

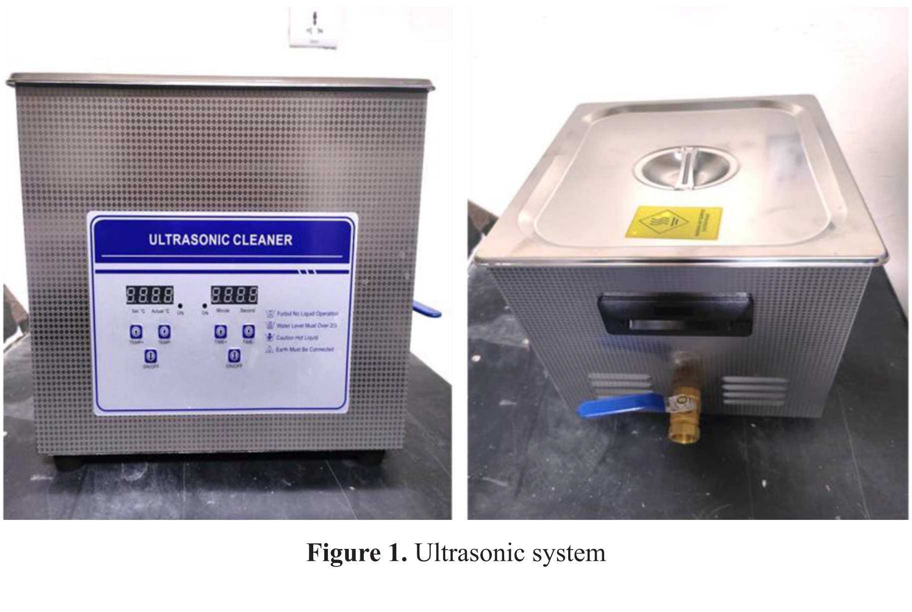

Figure 1. Ultrasonic system

Table 1. The specification of base fluid 50/50 water-ethylene glycol (base fluid)

Properties of a 50/50 water-ethylene glycol mixture			
Density	ρ	1050.440	kg/m³
Freezing point	T	-36.8	°C
Boiling point	T	107	°C
Heat capacity	C	3.499	KJ/kg.K
Viscosity (Dyn)	μ	1.538×10^{-3}	N S/M²
Viscosity (Kin)	ν	1.464×10^{-4}	M²/S
Thermal conductivity	K	4.108×10^{-4}	kW/m² K

Table 2. The specification of Fe_3O_4 nanoparticles

Item	Unit	Fe_3O_4
Purity	%	99.8
Thermal conductivity	w/m².k	80
True density	kg/m³	4950
Specific heat	J/kg.K	670

- Density (ρ_{nf}), viscosity (μ_{nf}), and specific heat capacity(CP_{nf})

The Nano fluid density was calculated using mixing theory

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_p \tag{1}$$

The viscosity of the nano fluid is as follows.

$$\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}} \tag{2}$$

The thermal equilibrium model calculated the nano fluid-specific heat capacity. [13]

$$Cp_{nf} = \frac{(1-\varphi)(\rho\, Cp)f + \varphi(\rho\, Cp)p}{\rho_{nf}} \tag{3}$$

- Thermal conductivity (k_{nf})

Thermal conductivity is calculated using the change in temperature along an infinitely long and thin line source as a periodic function [14]. The thermal conductivity equation can be expressed as follows [15]:

$$\frac{k_{nf}}{k_f} = \frac{k_p + 2k_f + 2\varphi(k_f - k_p)}{k_p + 2k_f + \varphi(k_f - k_p)} \tag{4}$$

- The calculation of the required quantity of nano fluid to be added to the base fluid by using the volume concentration (%) equation [16]:

$$\varphi = \frac{Volume\ of\ nanopartical}{Volume\ of\ nanopartical + + Volume\ of\ base\ fluid} \times 100\% \tag{5}$$

$$\%\ volume\ concentration = \frac{\left[\frac{W_p}{\rho_p}\right]}{\left[\frac{W_p}{\rho_p} + \frac{W_f}{\rho_f}\right]} \tag{6}$$

where: WP weight of nano fluid particles, W_f weight of base fluid, ρ_p density of nano fluid particles, ρ_p density of base fluid.

Magnetic field system

The effects of the magnetic field depend on the magnetizing conditions; specifically, the strength of the magnetic field and the velocity of the nanofluid were identified as two significant factors. The magnetizing equipment was utilized to establish a constant magnetic field. The equipment included

Table 3. The thermal physical characteristics of Fe_3O_4 nanoparticles and 50/50 water-ethylene glycol

Thermophysical properties	Unit	50/50 water-ethylene glycol mixture	0.025% Nanofluid	0.1% Nanofluid	0.15% Nanofluid	0.2% Nanofluid
Density (ρ_{nf}),	Kg/m³	1050.440	1050.41	1054.33	1056.28	1058.23
Specific heat (Cp)	kJ/kg.K	3.499	4.2874	6.62820	8.1840	9.7342
Thermal conductivity (K)	kW/m² .K	4.108×10^{-4}	4.117×10^{-4}	4.139×10^{-4}	4.167×10^{-4}	4.192×10^{-4}
Viscosity (μ_{nf})	m²/s	1.5380×10^{-4}	1.5382×10^{-4}	1.5421×10^{-4}	1.5437×10^{-4}	1.5464×10^{-4}

three magnets placed on the copper pipe to generate the necessary magnetic field intensity. The size of each magnet was circular (R1: 60 mm, R2: 80 mm). The magnetic field is applied across the copper tube as shown in Figure 2. The magnetic intensity was measured with a Gauss meter, which can measure over a range (0.05, 0.10, 0.15 Tesla). A Gauss meter is employed to measure the magnetic field intensity [17]. A neodymium permanent ring magnet (NdFeB) is selected due to its high magnetic energy density and stable magnetic field. The ring magnet is positioned coaxially around the tube to ensure a uniform axial magnetic field distribution within the tube's cross-section. The variation in magnetic field intensity is achieved by replacing the ring magnet with a magnetic of different grades. The magnetic field strength at the tube center is verified using a calibrated Hall-effect Gaussmeter probe inserted into the tube.

The experimental equipment consists of a cylindrical test tube with an outer diameter of 50 mm and a length of 120 mm, A permanent neodymium ring magnet (N_{42}) grade, a non -magnetic support structure to ensure concentric alignment, and a calibrated Gaussmeter for magnetic field measurement. The ring magnet is mounted concentrically around the tube, ensuring axial alignment, and the magnetic field is measured at the geometric center of the tube to ensure repeatability and accuracy. The magnetic specification, inner diameter 60 mm to fit over the 50 mm tube outer diameter, outer diameter 80 mm, thickness 20 mm, magnetization. The field direction relative to the flow perpendicular to the flow direction.

TESTING METHODS

Description of test rig

To assess the degree of correspondence that exists between theoretical work and the real flow, experimental tests were carried out on the cooling system of a small closed-loop circuit model. The experimental setup comprises a pipeline, a nano fluid tank, heating components, an electric control system, a control valve, a water circulation pump, flow meters, a magnetic field system, a vehicle radiator, and a direct current radiator fan. Figure 3 presents a schematic diagram of the experimental test setup. The work fluid occupies 80% of the 10-liter tank, which is heated by a 2500 W electric heater. A current control system is utilized to maintain the fluid at the desired temperature level. To measure the coolant mass flow rate, a rotameter is employed. Additionally, three type K thermocouples are installed along the flow line to measure the inlet and outlet temperatures of the nanofluid, and radiator wall temperature; these measurements are required for analysis. The examination of coolants, nano-fluid thermal properties in the presence of a magnetic field. The Fe_3O_4-water ethylene glycol nano fluid concentration rose from 0.025 to 0.2 vol%, the nano fluid in the tank was heated to a temperature of 80 °C, and the magnetic field strength grew from (0.05, 0.10, and 0.15 Tesla) [18]. Additionally, the velocity of the coolants' nanofluid was considered a significant factor in the study.

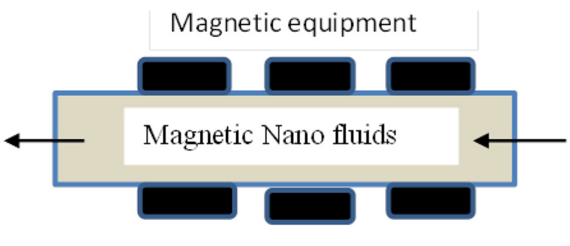

Figure 2. The schematic diagram of magnetization

Experimental procedure and measurements

A 2500 W heater heats the nano fluid in the tank to a temperature of 80 °C. The nano fluid is then drawn from the tank by a pump and directed to the flow meter to measure the flow rate. After passing through the flow meter, the fluid moves through a constant magnetic flux system before entering the radiator, where it exchanges heat with the surrounding air. When the liquid comes out of the bottom of the radiator, it is circulated back into the tank through a closed loop. The measurements involved the flow rate, the known magnetic field, and thermocouples (type K) to be able to measure the temperature of the inlet and outlet of the fluid, and the temperature of the radiator wall. One of the parameters of interest in evaluating the properties of heat transfer is the thermal conductivity, which was measured in this research. To measure the thermal conductivity of a nanofluid, the fluid was put in a fixed temperature condition, where a thermal conductivity meter was used to measure the thermal conductivity of the fluid. Measurements of the values were between 0.02 to 3.8 W/m K. The process starts by making the nanofluid, after which it is put in the heating tank. A control device is used

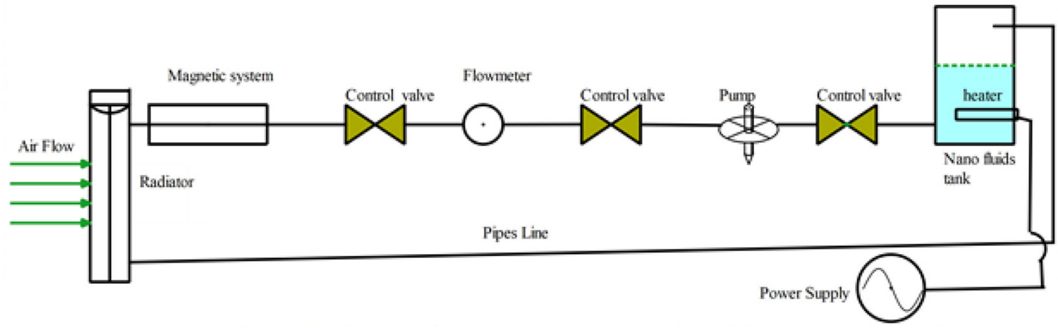

Figure 3. Shows the experimental setup for the magnetic field with Fe_3O_4 nano fluid

to switch on the electrical heater and adjust it to the required amount of heat. Next, the electrical pump is activated to circulate the nanofluid within the test rig. The flow rate is adjusted with a control valve to achieve the required level. After 30 minutes, steady state is reached. The inlet temperature of 80 °C remains constant for all fluids in our experiment. During this process, the thermocouple readings at the radiator's inlet and outlet, as well as the surface temperature of the radiator, are recorded. Once steady state is achieved, a constant magnetic intensity is maintained, and the following readings are taken: flow rate, temperatures, and power. This procedure is repeated for various nanoparticle concentrations and for each type of magnetic intensity.

Thermal conductivity measurements were conducted. Using a constant heat flux method.. The base fluid consisted of a 50:50 water-ethylene glycol mixture, and the nanofluid was prepared by dispersing Fe_3O_4 nanoparticles using ultrasonic agitation. Each test condition was repeated ten times (n = 10) to ensure reproducibility. The reported values represent the mean ± standard deviation. An uncertainty analysis was performed following the Kline-Clintock method , and the combined measurement uncertainty was found to be less than ±0.014.

Calculation of heat transfer

- Calculation of heat transfer coefficient [19],
- The relations have been used to calculate the nano fluid heat transfer coefficient (h_{nf}),
- The heat transfer rate in the test section of the tube follows Newton's law of cooling.

$$Q = h_{nf} A(T_w - T_b) \tag{7}$$

where: A – surface area of radiator tubes, T_w – tube wall temperature, T_b – bulk temperature.

- Tube wall temperature, T_b – bulk temperature.

$$(T_{in+}T_{out})/2 \tag{8}$$

- The heat transfer rate can be calculated as follows.

$$Q = mc_p(T_{in} - T_{out}) \tag{9}$$

where: T_{in} and T_{out} inlet and outlet temperature.

The local heat transfer coefficient was determined using the following equation.

$$h_{nf} = \frac{Q}{A(T_w - T_b)} = = \frac{m\, C_p(T_{in} - T_{out})}{A(T_w - T_b)} \tag{10}$$

- Calculation of nano fluid Nusselt number (Nu_{nf})

The relations have been used to calculate the nano fluid Nusselt number (Nu_{nf}). Nano fluid Reynolds number (Re_{nf})

$$Nu_{nf} = 0.023 Re_{nf}^{0.8} \times Pr_{nf}^{0.3} \tag{11}$$

where: Nu_{nf} – Nusselt number for the whole radiator.

Calculation of nano fluid Reynolds number

The Reynolds number (Re) was employed to characterize the flow region of the nanofluid flow inside the cooling system. The flow conditions were adjusted to achieve turbulent flow [20].

The Reynolds number was calculated using:

$$Re_{nf} = \frac{\rho_{nf} \times V_{nf} \times D_h}{\mu_{nf}} \tag{12}$$

where: ρ_{nf} is the density, μ_{nf} is the dynamic viscosity and D_h is the hydraulic diameter of the tube.

Calculation of thermal conductivity

The effective thermal conductivity of the nanofluid under forced convection in a circular tube was determined using a constant heat flux method. The nanofluid was circulated through a uniformly heated test section, with the wall and bulk fluid temperatures continuously monitored. The convective heat transfer coefficient was calculated from the energy balance equation.
The heat transfer rate:

$$Q = \dot{m}c_p(T_{out} - T_{in}) \tag{13}$$

Convection heat transfer coefficient from Equation 10.

From the Nusselt number equation

$$N_u = \frac{h\,D}{k_{eff}} \tag{14}$$

The thermal conductivity

$$k_{eff} = \frac{hD}{Nu} \tag{15}$$

RESULTS AND DISCUSSION

The thermal properties of nanofluids were compared to those of pure water-ethylene glycol mixtures. Additionally, the impact of a magnetic field on these properties was investigated. This was done by varying the concentration of magnetic nanoparticles from 0.025% to 0.2% by volume. The strength of the magnetic field was also adjusted, ranging from 0.05 to 0.15 Tesla. The results focused on comparing the heat transfer coefficient, thermal conductivity, Nusselt number, and heat transfer rate under these conditions. Furthermore, the nanofluid's velocity was considered an important factor.

Heat transfer coefficient

The heat transfer coefficient is a crucial parameter for cooling fluids, which can be enhanced by adding nanoparticles to the base fluid. When an applied magnetic field over a range of 0.05, 0.10, and 0.15 Tesla and Fe_3O_4 nano-fluid concentrations in the range of 0.025 to 0.2 vol.%. Figure 4 shows an increase in the overall heat transfer coefficient (h) with the concentration of Fe_3O_4 nano-fluid at a magnetic intensity of 0.05 Tesla. In Figures 5, 6, the overall heat transfer coefficient (h) is shown with the Fe_3O_4 nano-fluid concentration at magnetic intensities 0.10 and 0.15 Tesla. The heat transfer coefficient improved with an increase in both the concentration of Fe_3O_4 nanofluids and the strength of the magnetic field. Under the influence of the magnetic field, the Fe_3O_4 nanoparticles arranged themselves in a chain-like formation, creating fine turbulence in the flow. This, in its turn, increased the heat transfer. A much better heat transfer coefficient was realized. The largest coefficient was observed when the strength of the magnetic field was 0.15 Tesla and the concentration of the nanofluid was 0.2 vol.%. The improvements at this field strength were proportional to the magnetic field strength with 12.6, 15.2 and 18.4 increases at 0.05, 0.10,

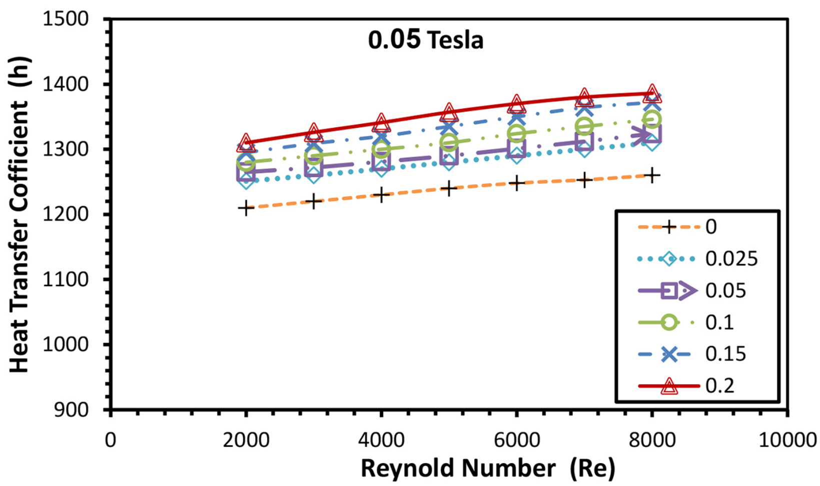

Figure 4. Demonstrates the value of heat transfer coefficient (h) against the concentration of Fe_3O_4 nanofluids and the intensity of a magnetic field which is 0.05 Tesla

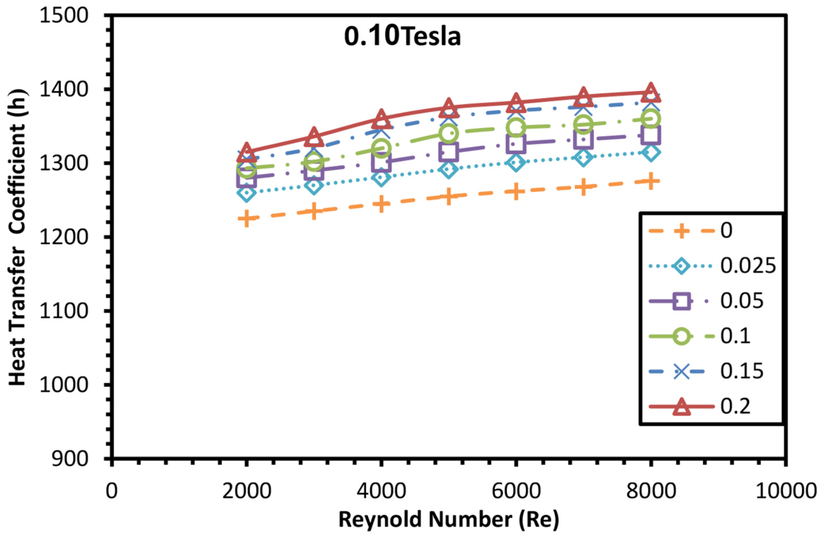

Figure 5. Indicates the coefficient of heat transfer (h) with respect to the concentration of Fe_3O_4 nanofluids at a magnetic field strength of 0.10 Tesla

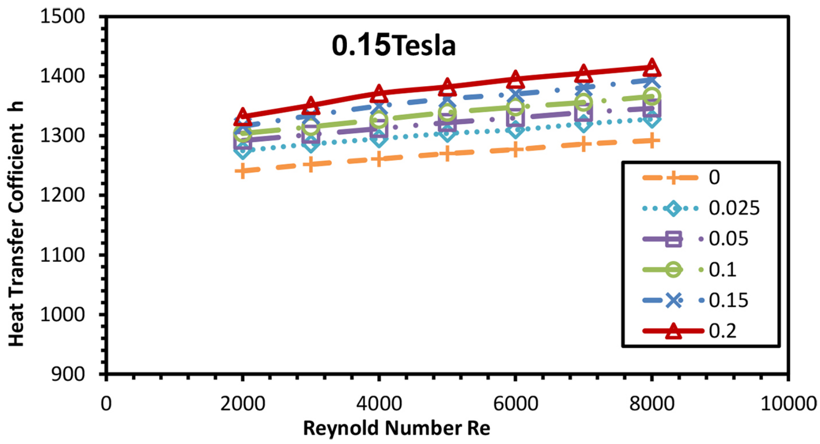

Figure 6. Shows the heat transfer coefficient (h) versus the concentration of Fe_3O_4 nanofluids at a magnetic intensity of 0.15 Tesla

and 0.15 Tesla of the magnetic field, respectively, as compared to the base fluid. With the increase in concentration, the coefficient of heat transfer also enhanced because more chains shaped nanoparticles were formed because of the influence of the magnetic field.

When nanofluids and other nanoparticles, especially magnetic nanoparticles, are applied to a magnetic field, their thermal characteristics are greatly influenced. We find that the heat transfer coefficient is the most significantly affected by the magnetic field. The Fe_3O_4 nanoparticles are more likely to form a chain-like structure, creating fine turbulence in the flow and increasing the total heat transfer. Moreover, the magnetic field is capable of affecting the Brownian motion of the nanoparticles, based on their strength and position. At low magnetic intensities, Brownian motion still plays a role in energy transport; however, as the field strength increases, this motion becomes more constrained along the direction of the magnetic field. Additionally, magneto-viscous effects result in changes to the fluid's viscosity, which affect the characteristics of convective heat transfer. The interaction between particle alignment, variations in viscosity, and reduced random motion ultimately determines the overall thermal performance of the nanofluid in the presence of a magnetic field.

Thermal conductivity

The thermal physical characteristics of Fe_3O_4 nanoparticles and 50/50 water-ethylene glycol used in the experiments were calculated using the formulas and are shown in Table 3. But the effect of a magnetic field can be illustrated through practical experiments. Figure 7 illustrates the thermal conductivity of Fe_3O_4 nano-fluids under a magnetic field of 0.15 Tesla. We observed that the thermal conductivity of Fe_3O_4 nano-fluids increases with higher concentrations of the nano-fluid. The maximum thermal conductivity was observed at a concentration of 0.2 vol.% and a magnetic field strength of 0.15 Tesla, increasing by 8.22%. It was found that thermal conductivity rises with both the increasing concentration of nanoparticles and the strength of the magnetic field. Under the influence of the magnetic field, Fe_3O_4 nanoparticles formed a chain-like structure, which created fine turbulence in the flow. The observed improvement is attributed to enhanced energy transport mechanisms, including Brownian motion, micro-convection, and reduced interfacial thermal resistance associated with the magnetic nanoparticles (Figure 8).

The magnetic field significantly influences the thermal conductivity of nanofluids, particularly when the suspended nanoparticles possess magnetic properties, such as Fe_3O_4. Under the influence of a magnetic field, these nanoparticles prefer to align themselves to the field lines to form chain-like structures that increase the rate of heat transfer in the fluid. This structural alignment reduces the thermal resistance between particles and improves effective thermal conductivity. Additionally, the intensity and orientation of the magnetic field are crucial factors in this process.

Nusselt number

The Nusselt number was obtained as a result of a number of experiments. Figure 9 shows that the Nusselt number increases with the increase in the Reynolds number for all nanoparticle concentrations. The maximum enhancement was 18.3% compared with the base fluid. Also, an enhancement in the Nusselt number with the magnetic intensity of 0.05 Tesla compared with the absence of a magnetic field effect. Figure 10. shows the Nusselt number at 0.10 Tesla. The Nusselt number was also increased, and the increase in the Nusselt number was due to the increase in the magnetic field strength and concentration of nanoparticles. The maximum enhancement was 21.4% compared with the base fluid. There was an improvement in the heat transfer coefficient, leading to an increase in the Nusselt number as well. Figure 11 After optimizing the effect of nano fluid concentration at 0.2 vol.% and magnetic field at 0.15 Tesla, the enhancement was 26.3% compared with the base fluid. The higher heat transfer rate when a magnetic field is applied to the ethylene glycol/water-based Fe_3O_4 Nanofluid is due to the effective effect of the magnetic field on the thermal properties of the nanofluid. When the magnetic field is perpendicular to the flow, it generates Lorentz forces which enhance microscale mixing motion, which improves mixing with in fluid. This reduces the thermal boundary layer thickness near the wall, thereby increasing the heat transfer coefficient. [21]

The use of a magnetic field has a strong impact on the convective heat transfer properties

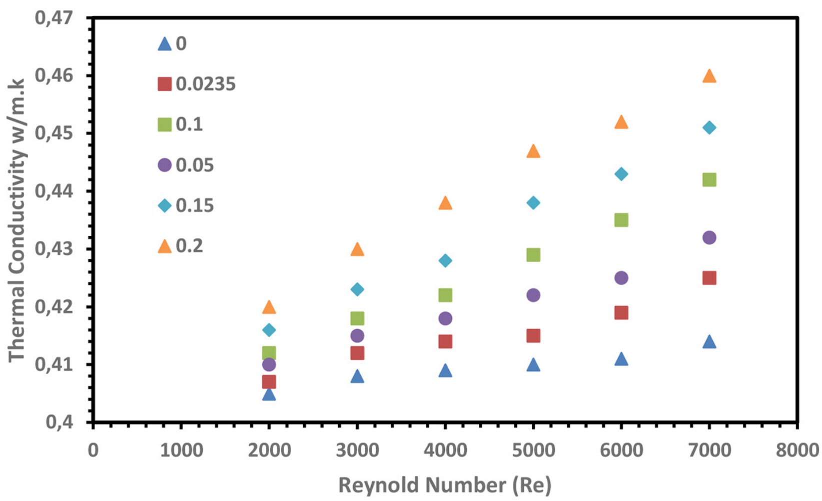

Figure 7. Shows the thermal conductivity of Fe_3O_4 nanofluids at various nanoparticle concentrations and under a magnetic field of 0.15 Tesla. At 85 °C, Error bars represent ±1 standard deviation (n=10)

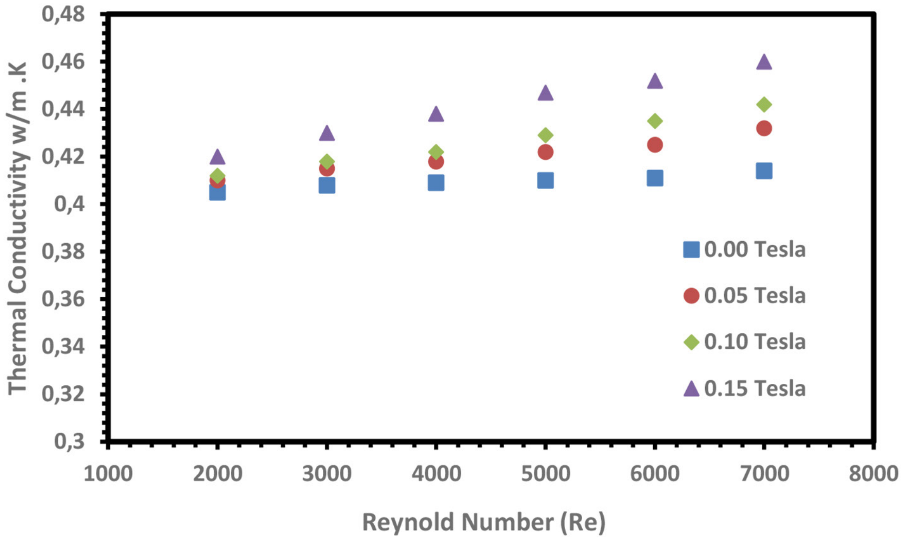

Figure 8. shows the comparison of the enhancement in thermal conductivity with the magnetic field at a 0.2 vol.% nanofluid concentration. At 85 °C, error bars represent ±1 standard deviation (n=10)

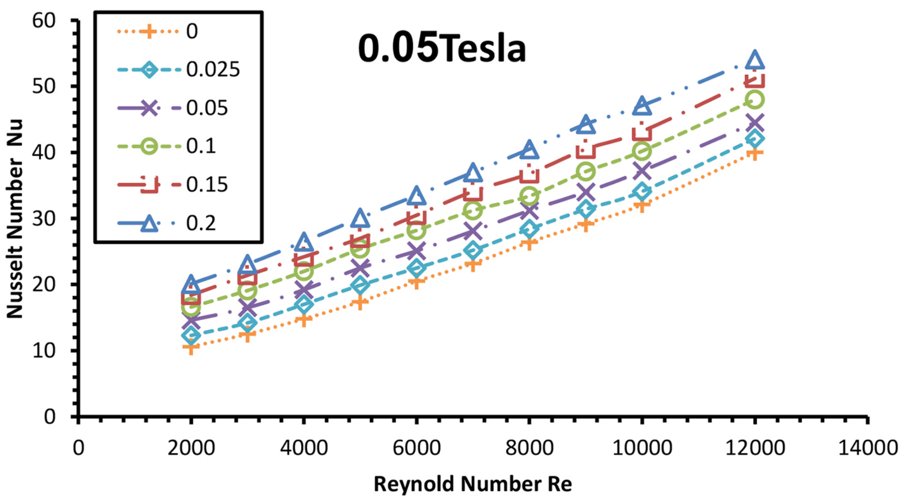

Figure 9. Shows the Nusselt number as a function of the Reynolds number (Re) influenced by a magnetic field of 0.05 Tesla and different nanofluid concentrations

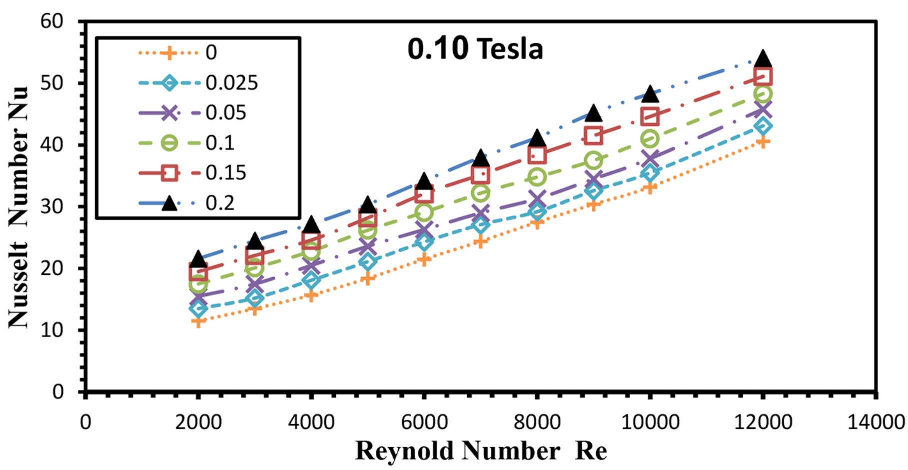

Figure 10. Shows the Nusselt number as a function of the Reynolds number (Re) influenced by a magnetic field of 0.10 Tesla and different nanofluid concentrations

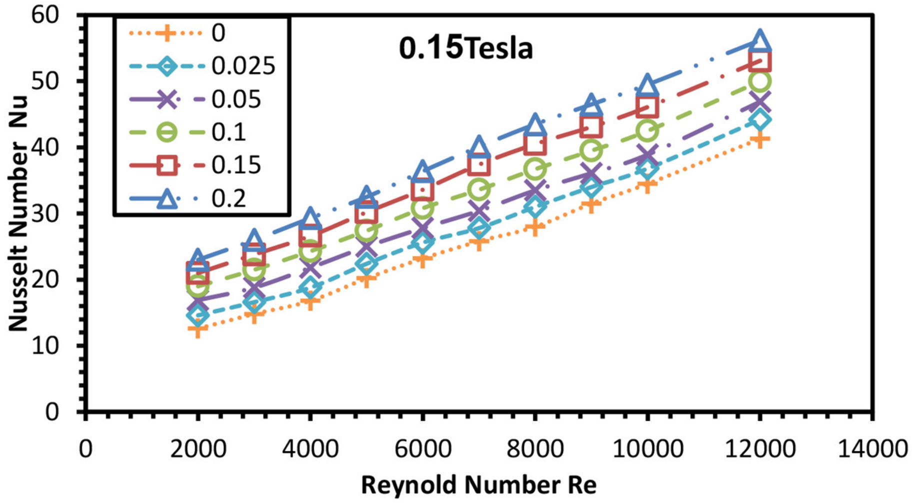

Figure 11. Shows the Nusselt number as a function of the Reynolds number (Re) influenced by a magnetic field of 0.15 Tesla and varying nanofluid concentrations

of magnetic nanofluids, as indicated by the variation of the Nusselt number. The major aspects that determine this improvement are the magnitude and orientation of the magnetic field, volume fraction of nanoparticles, and thermal physical characteristics of base fluid.

CONCULUSIONS

The experimental study examined the influence of a magnetic field on the thermal properties of an Fe_3O_4 nanofluid based on ethylene glycol and water. The findings can be summarized as follows.

1. It was observed that the heat transfer coefficient increases with the Reynolds number for all types of nanofluids and pure water-ethylene glycol mixtures. The thermal properties demonstrate an improvement as the concentration of the nano fluid increases.
2. The effect of the magnetic field depends significantly on the concentration of nanoparticles in the ethylene glycol/water base fluid, with an optimum concentration of 0.20 vol.% and a magnetic field strength of 0.15 Tesla.
3. The highest heat transfer coefficient was observed for the nanofluid containing 0.2 vol.% Fe_3O_4 nanofluid, with a magnetic field strength of 0.15 Tesla; the enhancement observed was 26.3% compared to the base fluid.
4. As the magnetic field effect of ethylene glycol and water increases, the thermal conductivity of the coolant also rises. It was observed that the thermal conductivity increased by 6.84% at a concentration of 0.2 vol.%, and a magnetic field strength is 0.15 Tesla.
5. Nusselt number was most pronounced at a magnetic field of 0.15 Tesla with an optimum concentration of nanoparticle of 0.20 vol.%. This rise is due to the magnetic force, which generated a turbulent flow vortex that, in turn, boosted the average Nusselt number.
6. An increase in the nanofluid concentration and the magnetic field intensity increases the rate of heat transfer in the engine cooling system.
7. The findings of this research can be used in the application of magnetic fields and nano-fluids in better cooling systems to increase the power generation efficiency in all types of industries. Engineers are able to streamline thermal systems, such as cooling and heat transfer systems.

Overall, the application of an optimized magnetic field can improve the heat transfer performance of nanofluids in cooling systems, leading to higher efficiency and better temperature control.

REFERENCES

1. Ertürk H, Koca T. Investigation of thermal performance of Fe_3O_4 nanofluid applied with magnetic field under constant heat flux. J Therm Anal Calorim 2025;150:11339–51. https://doi.org/10.1007/s10973-025-14454-8
2. Moslemi M, Mahmoodnezhad M, Edalatpanah SA, Zubair SAM, Khalifa HAEW. Magnetic field effect and heat transfer of nanofluids within waveform microchannel. CMES - Computer Modeling in Engineering and Sciences 2023;134:1957–73. https://doi.org/10.32604/cmes.2022.021481

3. Abbas F, Ali HM, Shah TR, Babar H, Janjua MM, Sajjad U, et al. Nanofluid: Potential evaluation in automotive radiator. J Mol Liq 2020;297. https://doi.org/10.1016/j.molliq.2019.112014
4. Shrikhande NS, Kriplani VM. Heat transfer enhancement in automobile radiator using nanofluids: A Review Student, IV Semester M. Tech (Heat power engineering). International Journal of Engineering Research & Technology, 2014.
5. Rambhapurwala PH, Desai J V, Patel TM, PRathod G, Scholar M, Professor A. Improving the cooling performance of automobile radiator with CuO/Water Nanofluid. International Communications in Heat and Mass Transfer, 2015;3.
6. Shrikhande NS, Kriplani VM. Heat transfer enhancement in automobile radiator using nanofluids: A Review Student, IV semester M. Tech (Heat Power Engineering). International Journal of Engineering Research & Technology, 2014.
7. Islam MR, Shabani B, Rosengarten G. Electrical and thermal conductivities of 50/50 water-ethylene glycol based TiO_2 nanofluids to be used as coolants in PEM fuel cells. Energy Procedia, Elsevier Ltd; 2017;110:101–8. https://doi.org/10.1016/j.egypro.2017.03.113
8. Karamallah AA, Habeeb Askar A, Habeeb L. The effect of magnetic field with nanofluid on heat transfer in a horizontal pipe the effect of magnetic field. Al-Khwarizmi Engineering Journal 2016.
9. Ertürk H, Koca T. Investigation of thermal performance of Fe_3O_4 nanofluid applied with magnetic field under constant heat flux. J Therm Anal Calorim 2025. https://doi.org/10.1007/s10973-025-14454-8
10. Bayareh M, S 2024. An Overview of the magnetic field effect on heat transfer and entropy generation in cavities: Application of the second law of thermodynamics and artificial intelligence 2024;151.
11. Zanzote M. CFD analysis of enhancement of heat transfer of automobile radiator with hybrid nanofluid as a coolant. Int J Res Appl Sci Eng Technol 2021;9:367–76. https://doi.org/10.22214/ijraset.2021.37971
12. Peyghambarzadeh SM, Hashemabadi SH, Jamnani MS, Hoseini SM. Improving the cooling performance of automobile radiator with Al_2O_3/water nanofluid. Appl Therm Eng 2011;31:1833–8. https://doi.org/10.1016/j.applthermaleng.2011.02.029
13. Ali HM, Azhar MD, Saleem M, Saeed QS, Saieed A. Heat transfer enhancement of car radiator using aqua based magnesium oxide nanofluids. Thermal Science 2015;19:2039–48. https://doi.org/10.2298/TSCI150526130A
14. Islam MR, Shabani B, Rosengarten G. Electrical and thermal conductivities of 50/50 water-ethylene glycol based TiO_2 nanofluids to be used as coolants in PEM fuel cells. Energy Procedia 2017;110:101–8. https://doi.org/10.1016/j.egypro.2017.03.113
15. Abdulhassan A. Karamallah, Laith Jaafer Habeeb AHA. The effect of magnetic field with nanofluid on heat transfer in a horizontal pipe. Al-Khwarizmi Engineering Journal 2017;12:99–109.
16. Jinsiwale N, Achwal V. Heat transfer enhancement in automobile radiator using nanofluids: A review. International Journal of Engineering Trends and Technology 2018;55:68–74. https://doi.org/10.14445/22315381/ijett-v55p214
17. Karamallah AA, Habeeb Askar A, Habeeb L. The effect of magnetic field with nanofluid on heat transfer in a horizontal pipe the effect of magnetic field. Al-Khwarizmi,Engineering Journal, 2016.
18. Ali KK, Hassan HA. A numerical-experimental study of turbulent heat transfer flow a cross square cylinder in a channel. International Journal of Mechanical Engineering and Technology 2018;9:447–61.
19. Abbas F, Ali HM, Shah TR, Babar H, Janjua MM, Sajjad U, et al. Nanofluid: Potential evaluation in automotive radiator. J Mol Liq 2020;297. https://doi.org/10.1016/j.molliq.2019.112014
20. Kharat PB, Somvanshi SB, Khirade PP, Jadhav KM. Effect of magnetic field on thermal conductivity of the cobalt ferrite magnetic nanofluids. J Phys Conf Ser 2020;1644. https://doi.org/10.1088/1742-6596/1644/1/012028
21. Ertürk H, Koca T. Investigation of thermal performance of Fe_3O_4 nanofluid applied with magnetic field under constant heat flux. J Therm Anal Calorim 2025;150:11339–51. https://doi.org/10.1007/s10973-025-14454-8