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Experimental Investigation of the Thermal Performance of Iron Oxide-Water Nanofluid Subjected To a Magnetic Field in a Horizontal Tube

Hamza ERTÜRK[1], **Tarkan KOCA**[2*]

[1]İnonu University, Engineering Faculty, Mechanical Engineering Department, Malatya, Türkiye
[2]İnonu University, Engineering Faculty, Mechanical Engineering Department, Malatya, Türkiye
Hamza ERTÜRK ORCID No: 0009-0001-0517-9949
Tarkan KOCA ORCID No: 0000-0002-6881-4153

**Corresponding author: tarkan.koca@inonu.edu.tr*

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Abstract: In this study, an experimental analysis was performed to evaluate the thermal behavior of iron oxide-water nanofluid as it traverses a straight copper tube, under the influence of a constant heat capacity and the application of a magnetic field. Four types of fluids were used in the experiment. These are pure water, 0.5% concentration of Fe_3O_4-water nanofluid, 1% concentration of Fe_3O_4-water nanofluid and 1.5% concentration of Fe_3O_4-water nanofluid. Experiments were conducted at two distinct flow rates as $10x10^{-5}$ m^3 s^{-1} and $13x10^{-5}$ m^3 s^{-1}. The inlet temperatures of the fluids and the surface temperature of the copper tube were maintained at the same level throughout all experiments. The Nusselt number was determined at Reynolds numbers of 4200 and 5400 in experiments conducted under turbulent flow conditions. The thermal performances of the fluids were compared by comparing the obtained Nusselt numbers. The experiments demonstrated that as the Reynolds number increased, the Nusselt number also increased, with the most notable enhancement of 20.7% observed in the iron oxide-water nanofluid at a 1.5% concentration and a Reynolds number of 5400 under a magnetic field. Additionally, both the heat transfer coefficient and the Nusselt number improved with the use of nanofluids.

Yatay Bir Boruda Manyetik Alan Uygulanan Demir Oksit-Su Nanoakışkanının Isıl Performansının Deneysel Olarak İncelenmesi

Anahtar Kelimeler
Nanoakışkan,
Manyetik alan,
Isı transferi,
Demir oksit

Öz: Bu çalışmada sabit ısı sığası ve manyetik alan etkisi altındaki düz bir bakır borudan akan demir oksit-su nanoakışkanının ısıl performansı deneysel olarak incelenmiştir. Deneyde dört tip akışkan kullanılmıştır. Bunlar; saf su, %0,5 konsantrasyonunda Fe_3O_4-Su nanoakışkanı, %1,0 konsantrasyonunda Fe_3O_4-Su nanoakışkanı ve %1,5 konsantrasyonunda Fe_3O_4-Su nanoakışkanıdır. Deneyler $10x10^{-5}$ m^3 s^{-1} ve $13x10^{-5}$ m^3 s^{-1} olmak üzere iki farklı debide gerçekleştirilmiştir. Akışkanların giriş sıcaklıkları ve bakır borunun yüzey sıcaklığı tüm deneylerde eşit tutulmuştur. Türbülanslı akış şartlarında gerçekleşen deneylerde iki farklı Reynolds (Re=4200 ve Re=5400) sayısındaki Nusselt sayısı hesaplanmıştır. Elde edilen Nusselt sayıları karşılaştırılarak akışkanların ısıl performansları karşılaştırılmıştır. Yapılan deneyler sonucunda Reynolds sayısının artması ile Nusselt sayısının da artış gösterdiği, nanoakışkanların kullanımı ile toplam ısı transfer katsayısının ve Nusselt sayısının artış gösterdiği gözlemlenmiştir. Nusselt sayısındaki en büyük artış, manyetik alan etkisi altında, Re=5400 değerinde %1,5 konsantrasyonunda demir oksit-su nanoakışkanda gerçekleşmiştir ve saf suya göre %20,7 oranında artış tespit edilmiştir.

1. INTRODUCTION

The movement of heat from an object at a higher temperature to one at a lower temperature occurs due to the existence of a temperature gradient. The process of heat energy transitioning between systems or objects is referred to as heat transfer. Naturally, heat transfer always occurs from high to low temperatures; however, modern systems equipped with advanced equipment also enable heat transfer from low to high temperatures.

With energy resources quickly running out, humanity is striving to utilize what we have in the most effective manner possible. In many energy systems, heat transfer occurs. Therefore, scientists want to increase heat transfer efficiency. The application of nanofluids in thermal systems represents a significant advancement in heat transfer technology. Nanofluids are produced by incorporating solid particles with dimensions ranging from 1 to 100 nanometers into a base fluid. The primary objective of this procedure is to enhance heat transfer due to the interaction of the solid particles within the fluid. The term nanofluid was first used by Maxwell in 1881. Maxwell [1] conducted studies by adding solid particles to liquids. Various studies in this area have been reviewed.

Tekir et al. [2] investigated the thermal properties of a nanofluid made from different proportions of iron oxide, copper, and water ($Fe_3O_4 - Cu - H_2O$) under the influence of a magnetic field. In their study, they conducted experiments between the values of 994<Re<2337. The researchers noted that the Nusselt (Nu) number rose as the fluid velocity increased. At the same time, they observed that water Fe_3O_4 and Cu nanoparticles increased the heat transfer. The study found that applying a magnetic field to the nanofluids improved heat transfer by 14% compared to when no magnetic field was present. They determined that the hybrid nanofluids used; $\%1\ Fe_3O_4 - \%1\ Cu - \%98$ water type showed the best performance under magnetic field. Demirpolat and Uyar [3], determined the thermal conductivities of the nanoparticles produced in order to evaluate the use of nanoparticle materials in thermal insulation materials, which a new perspective on energy is saving. The heat transfer coefficients of Al2O3 and CuO nanoparticles were found to be 34.2 and 65.4 W/mK, respectively. Uyar et al. [4] calculated that there was a 1.1% increase in thermal efficiency due to the MgO nanoparticle additive. Keklikcioğlu and Özceyhan [5] conducted a numerical analysis of the thermal performance of a hybrid nanofluid composed of graphene, iron oxide, and water, with varying concentrations between 0.5% and 1%. This analysis was performed within a flat heat exchanger tube featuring a circular cross-section, under conditions of constant surface heat flux, turbulent flow, and Reynolds numbers ranging from 10000 to 50000. The analysis revealed that the use of nanofluid significantly enhanced heat transfer while maintaining a relatively stable friction coefficient. The study found that using nanofluid instead of base fluid water increased the Nusselt number by up to 24%. The highest thermo hydraulic performance coefficient observed in this study was calculated as 1.2 for Re=10000 in the use of 1% graphene-iron oxide-water hybrid nanofluid. An experimental investigation was carried out by Çiftçi et al. [6] to assess the thermal performance of a closed heat pipe, particularly focusing on a thermo siphon that employed titanium dioxide-water ($TiO_2 - H_2O$) nanofluid. Three distinct cooling water flow rates (5g s^{-1}, 7.5g s^{-1}, 10g s^{-1}) and three varying heater power levels (200 Watt, 300 Watt, and 400 Watt) were utilized in the evaporation section of the study. The experiments employed both water and nanofluid as the working fluids. It was found that the titanium dioxide-water nanofluid enhanced thermal performance by 16.5% when subjected to a heating power of 200 Watt and a cooling water flow rate of 5 g/s. Kılınc et al. [7] conducted an experimental study to examine the cooling performance of vehicle radiators using nanofluids. This investigation incorporated pure water, along with graphene oxide-water and graphene nanoribbon-water nanofluids. The experimental setup included three different inlet temperatures and four varying flow rates as variable parameters. The experiments revealed an increase in the total heat transfer coefficient of 6.9% for a 0.001% GO-water solution, 32% for a 0.02% GO-water solution, and 18.9% for a 0.01% GNR-water solution. Kılınç [8] examined the thermal efficiency of a thermo syphon by employing nanofluid within a thermo syphon-type heat pipeIn the experiment, he used nanofluid containing 2% iron oxide particles and 0.2% surface activator in water. The cooling water flow rate of the condenser zone was used as 3g s^{-1}, 6g s^{-1}, 9g s^{-1}, and two different parameters were used for the heat value given to heat the evaporator as 300 Watt and 400 Watt. As a result, it was observed that the magnetic nanofluid increased the thermal performance by 20%. Sadeghinezhad et al. [9] examined the thermal performance of fluid flow in the pipe in the range of 5000<Re<22000 using graphene-water nanofluid with various weight ratios ranging from 0.025% to 1%. In their research, they found that using nanofluid enhanced heat transfer and Nusselt number. The thermal performance of graphene and iron oxide nanoparticles separately and in hybrid nanofluids was examined by Askari et al. [10]. The nanofluids they prepared had three different weight ratios of 0.1%, 0.2% and 1.0%. As a result of the experiments, they found an improvement between 14% and 32% in the thermal conductivity coefficient compared to the base fluid. For the value of Re=4248, the heat transfer coefficient increased by 8.5% in the iron oxide-water nanofluid, while it increased by 14.5% in the iron oxide-graphene-water hybrid nanofluid. The thermal transfer properties of water-based nanofluids containing copper oxide and iron oxide were investigated by Peyghambarzadeh et al. [11], who suggested using them in place of conventional water in car radiators. Three distinct volumetric concentrations of 0.15%, 0.4%, 0.65% were used to prepare the nanofluids. The total heat transfer coefficient increased by 9% in this experimental investigation. A study on the heat transfer properties of nanofluids based on carbon nanotubes in a horizontal pipe was carried out by Ding et al. [12]. The pipe used for the study was 970 mm long with an inner diameter of 4.5 mm. Under laminar flow and fixed wall heat flux boundary conditions, they discovered that the convection heat transfer coefficient increased by more than 350% at Re=800 and 0.5% nanofluid. Abreu et al. [13] observed a 23% increase in Nusselt number for 0.25% concentration under the condition of Re=1650 for multilayer CNT with 80mm outer diameter and $20x10^{-3}$ nm length in a 6 mm inner diameter and 200 mm long pipe. Based on the research undertaken, it has been noted that the incorporation of nanofluids in heat transfer systems significantly improves efficiency. As global energy resources continue to diminish at a rapid pace, the efficiency of current systems has gained paramount importance. Therefore, the high efficiency observed in nanofluids is anticipated to play a more significant role in our lives in the future.

This research examined the thermal performance of water-iron oxide $H_2O - Fe_3O_4$ nanofluid at volumetric ratios of 0.5%, 1%, and 1.5%, across various flow rates, while maintaining a constant heat capacity. The study also considered the effects of a magnetic field and the subsequent removal of the magnetic field. The findings were analyzed in the context of the thermal performance of water.

2. MATERIAL AND METHOD

In this experimental study, the thermal performance of water and iron oxide-water $(Fe_3O_4 - H_2O)$ nanofluids (volume ratios; 0.5%, 1%, and 1.5%) flowing through a straight copper pipe at two different flow rates $(10x10^{-5}\ m^3s^{-1}, 13x10^{-5}\ m^3s^{-1})$, under constant heat capacity (25,000 Wm^{-2}), constant inlet temperature (15°C), without a magnetic field and then under the influence of a magnetic field were investigated. During the experiments, the inlet temperature of all fluids was maintained constant. After each experiment, the fluids were cooled in refrigeration units, and the tests were repeated once the fluids returned to the specified inlet temperature conditions. Experiments were conducted for four different fluid types at two flow rates without a magnetic field. Following this, the identical experiments were conducted in the presence of a magnetic field. In total, 14 distinct experiments were carried out.

2.1. Nanofluid Preparation

In the experimental study, pure water and iron oxide-water nanofluids with three different volumetric ratios (0.5%, 1%, 1.5%) were used as fluids. Nanofluids were synthesized using a two-step approach. Iron oxide particles supplied in the form of nanoparticles were mixed in pure water and kept in an ultrasonic mixer for approximately 5 hours. As a result of the process, homogeneous and stable iron oxide-water nanofluids were prepared.

The formulas used to determine the thermal properties of fluids are as follows;

Volumetric concentration: Pak and Cho [14] proposed Equation 1;

$$\boldsymbol{\phi_v} = \frac{\mathbf{1}}{(\mathbf{100}\ \boldsymbol{\phi_m}^{-1})(\boldsymbol{\rho_p}\ \boldsymbol{\rho_f}^{-1}) + \mathbf{1}} \boldsymbol{x}\mathbf{100} \qquad (1)$$

Density: Equation 2 was utilized for density calculations;

$$\boldsymbol{\rho_n} = (\mathbf{1} - \boldsymbol{\phi})\boldsymbol{\rho_f} + \boldsymbol{\phi x \rho_p} \qquad (2)$$

Specific heat: Bhimani et al. [15] employed Equation 3;

$$\boldsymbol{c_{p_n}} = \frac{(\mathbf{1} - \boldsymbol{\phi})\boldsymbol{x\rho_f x c_{p_f}} + \boldsymbol{\phi x \rho_p x c_{p_p}}}{\boldsymbol{\rho_n}} \qquad (3)$$

Dynamic viscosity: Wen and Ding [16] provided Equation 4;

$$\mu_n = \mu_f(\mathbf{1} + \mathbf{2.5}\boldsymbol{\phi}) \qquad (4)$$

Thermal conductivity: Yu and Choi [17] used Equation 5;

$$\boldsymbol{k_n} = \left[\frac{\boldsymbol{k_p} + \mathbf{2}\boldsymbol{k_f} + \{\mathbf{2}(\boldsymbol{k_p} - \boldsymbol{k_f})(\mathbf{1} + \boldsymbol{\beta})^3\boldsymbol{\phi}\}}{\boldsymbol{k_p} + \mathbf{2}\boldsymbol{k_f} - \{(\boldsymbol{k_p} - \boldsymbol{k_f})(\mathbf{1} + \boldsymbol{\beta})^3\boldsymbol{\phi}\}}\right] \boldsymbol{x k_f} \qquad (5)$$

Prandtl number showed in Equation 6;

$$\boldsymbol{Pr} = \frac{\mu \boldsymbol{c_p}}{\boldsymbol{k}} \qquad \mathbf{(6)}$$

The formula includes the parameters: ρ_n for nanofluid density, ρ_f for base fluid density, and ρ_n for nanoparticle density.

The parameter ϕ refers to the volumetric or mass fraction, while ϕ_v signifies the volumetric fraction of the nanofluid, and ϕ_m indicates the mass fraction of the nanofluid. The specific heat capacities are represented as c_{p_n} for the nanofluid, c_{p_f} for the base fluid, and c_{p_p} for the nanoparticles. Furthermore, μ_n represents the dynamic viscosity of the nanofluid, while μ_f denotes the dynamic viscosity of the base fluid, k_n stands for the thermal conductivity of the nanofluid, k_f symbolizes the thermal conductivity of the base fluid, and k_p refers to the thermal conductivity of the nanoparticles. The parameter β represents the ratio of the thickness of the nanoparticle layer to the original particle radius, with a determined value of 0.1 in this study.

The thermophysical characteristics of the fluids were determined utilizing the designated formulas. These properties are detailed in Table 1.

Table 1. Thermophysical properties of fluids

	$\mathbf{H_2O}$ Water	$\mathbf{\%0.5\ Fe_3O_4 - H_2O}$ Iron Oxide-Water	$\mathbf{\%1\ Fe_3O_4 - H_2O}$ Iron Oxide-Water	$\mathbf{\%1.5\ Fe_3O_4 - H_2O}$ Iron Oxide-Water	$\mathbf{Fe_3O_4}$ Iron Oxide
Intensity (ρ) $\mathbf{kg\ m^{-3}}$	999.0	1019.9	1040.8	1061.7	5180
Specific Heat ($\mathbf{c_p}$) $\mathbf{J\ kgK^{-1}}$	4186	4082	3982	3887	104
Dynamic Viscosity (μ) $\mathbf{kg\ ms^{-1}}$	$1.120x10^{-3}$	$1.134x10^{-3}$	$1.148x10^{-3}$	$1.162x10^{-3}$	
Heat Conduction Coefficient ($\mathbf{k}$) $\mathbf{W\ mK^{-1}}$	0.59	0.6007	0.6116	0.6226	17.65
Prandtl Number (Pr)	7.940	7.706	7.475	7.255	

2.2. Experimental Setup

To facilitate the flow, a two-stage circulation pump with a total power of 250 Watts was utilized. In the experimental setup, copper tubing was used to effectively transfer heat energy to the fluid. The copper tube has an outer diameter of 28 mm, an inner diameter of 26 mm, and a length of 75 cm. Clamp heaters are placed on a 50 cm section of the copper tube. The remaining sections are equipped with magnets, thermocouple probes and manometer inlets. Twelve clamp heaters are utilized, each having an outer diameter of 30 mm and a length of 40 mm, with a power rating of 200 Watts per heater. To achieve a consistent heat flux of 25,000 W/m², the system's electrical power is controlled using a 3000W-15A dimmer. For insulation, the heaters were first wrapped with rock wool and then covered with aluminum sheathing.

In the experimental setup, copper pipes were used to effectively give heat energy to the fluid. The copper pipe is length of $l = 75\ \text{cm}$ and diameters of $D_d = 28\ \text{mm}, d_i = 26\ \text{mm}$. At the starting position of the heaters, 10 neodymium magnets were placed to generate a magnetic field. Each magnet had dimensions of 50 x 10 x 5 mm measurements with a gauss meter revealed that the total magnetic field intensity produced by the magnets was 1600 Gauss. Thermocouples were placed at the inlet and outlet of the copper tube to measure the fluid temperatures at both ends. Two more thermocouples were positioned between the heaters to monitor the surface temperature of the copper tube. Additionally, the pressure drops within the flow were investigated using a U-type manometer integrated into the system. The diagrammatic illustration of the experimental arrangement created using the computer software is presented in Figure 1, while the actual visual depiction of the experimental setup can be found in Figure 2.

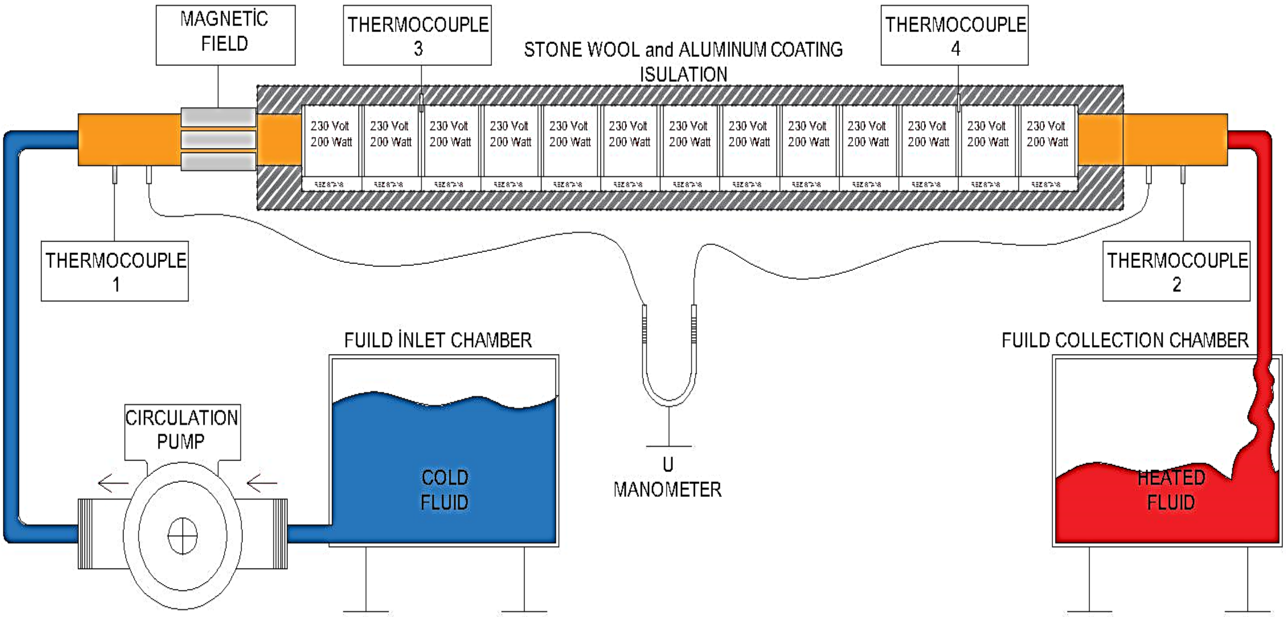

Figure 1. Schematic representation of the experimental set prepared in the computer program

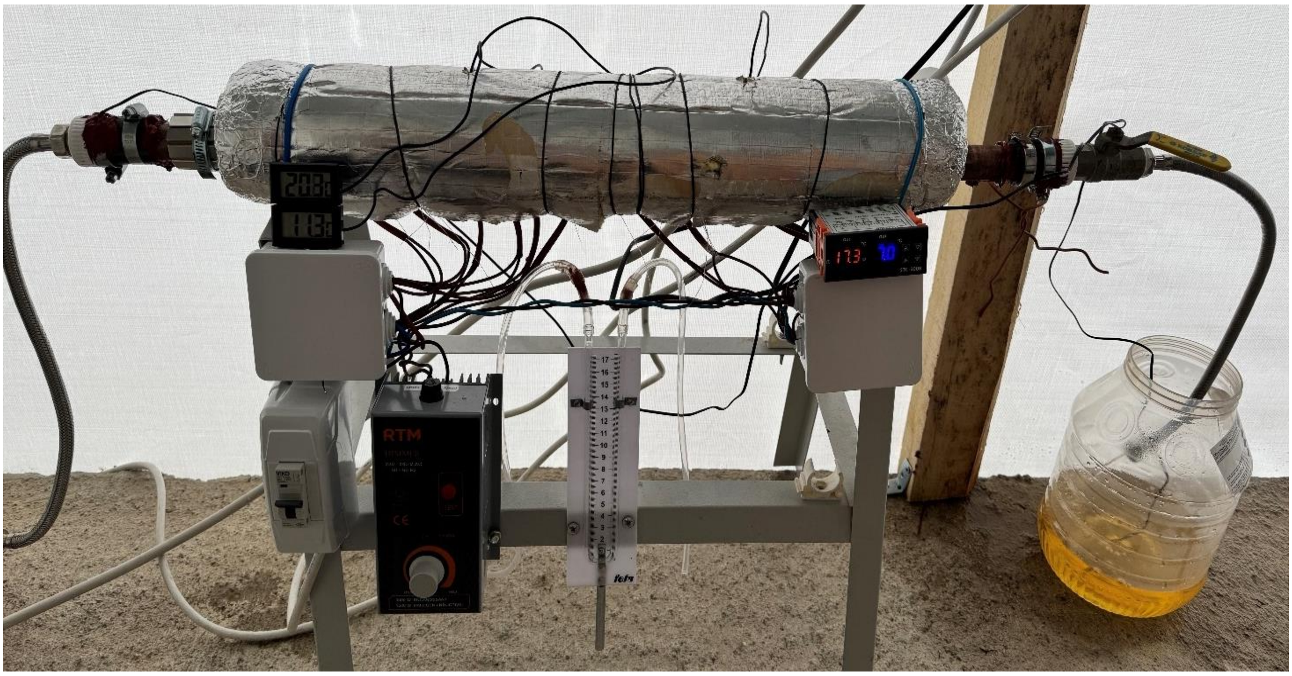

Figure 2. Visual of the experimental setup

3. CONCLUSION AND DISCUSSION

The thermal performance of an iron oxide-pure water nanofluid under the influence of a magnetic field was the main experimental focus of this study. Fourteen distinct experiments were conducted, and the outcomes were compared. Using the collected data, the necessary computations were carried out, and the thermal performance of nanofluids relative to pure water was evaluated. The formulas used in the calculations (Equation 7 to 15) are as follows;

Temperature difference;

$$\Delta T\ (K) = T_{ç} - T_{g} \quad (7)$$

Average temperature;

$$T_{ort}(K) = \frac{T_g + T_ç}{2} \quad (8)$$

Heat absorbed by the fluid;

$$\dot{Q}(W) = \dot{m}c_p\left(T_ç - T_g\right) \quad (9)$$

Heat transfer coefficient;

$$h\ (W\ mK^{-1}) = \frac{\dot{q}}{T_y - T_{ort}} \quad (10)$$

Thermal capacity;

$$\dot{q}(W\ m^{-1}) = \frac{\dot{Q}}{A} \quad (11)$$

Pressure drop;

$$\Delta P = \left(\rho_{Hg} - \rho\right) g x \Delta h \quad (12)$$

Reynolds number;

$$Re = \frac{\rho * V * D_h}{\mu} \quad (13)$$

Nusselt number;

$$Nu = \frac{h.Dh}{k} \quad (14)$$

Friction factor;

$$f = \frac{P_{in} - P_{out}}{\left(\frac{L}{D}\right) \cdot \left(\frac{\rho V^2}{2}\right)} \quad (15)$$

The formulas indicate the following parameters: ΔT represents the temperature difference between the inlet and outlet of the fluid; Tg denotes the inlet temperature of the fluid; Tç signifies the outlet temperature of the fluid; Ty refers to the surface temperature of the copper pipe; Tort is the average of the inlet and outlet temperatures; and ṁ indicates the mass flow rate, h heat convection coefficient, A Field, ρ_{Hg} density of mercury, ρ the density of the fluid, g Acceleration of gravity, Δh the difference in height on the pressure gauge, V velocity of the fluid, D_h hydrodynamic diameter, L characteristic length, P_{in} fluid inlet pressure, P_{out} the fluid outlet pressure.

3.1. Experiments without Magnetic Field

The experiments were conducted at two distinct flow rates while maintaining a constant temperature capacity in the absence of a magnetic field. The ambient temperature, the copper pipe's surface temperature, and the fluids' inlet temperatures were maintained constant during the experiment. The results indicated that as the Reynolds number increased, the Nusselt numbers also increased. When compared to pure water, nanofluids show higher Nusselt number values at equivalent Reynolds numbers. Figure 3 displays the Re-Nu graph, which was produced by computations using the experimental data. Furthermore, the graph of the computed friction factor is shown in Figure 4.

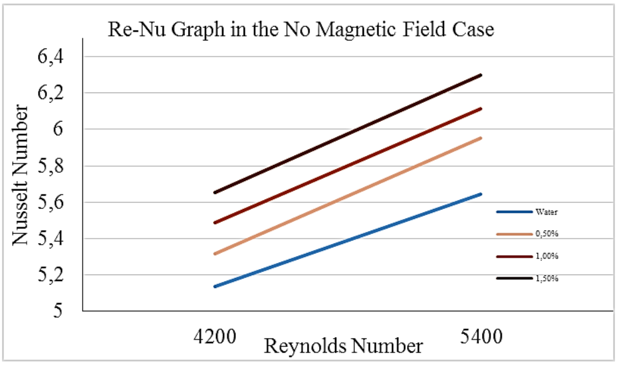

Figure 3. Re-Nu plot of fluids in the absence of magnetic field effect

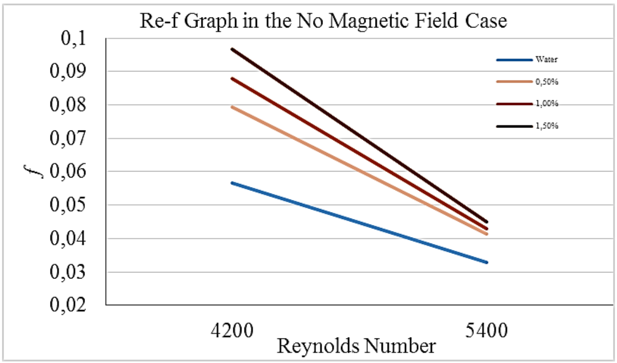

Figure 4. Re-f plot of fluids in the absence of magnetic field effect

3.2. Experiments under Magnetic Field

The studies were carried out with two different flow rates and a constant temperature capacity while being affected by a magnetic field. Throughout the experimentation, the inlet temperatures of the fluids, the surface temperature of the copper pipe, and the ambient temperature were maintained at constant levels. The results yielded graph curves that resembled those obtained in the absence of a magnetic field. The same data was utilized for pure water, as the magnetic field is not expected to affect it. In the experiments performed within the magnetic field, an increase in the Nusselt number of nanofluids was observed. No significant variations were observed in the fluid's inlet and outlet pressure values. Therefore, there is no obvious difference in the coefficient of friction. The Re-Nu graph formed as a result of the calculations made according to the experimental data is shown in Figure 5. The calculated friction factor is illustrated in Figure 6.

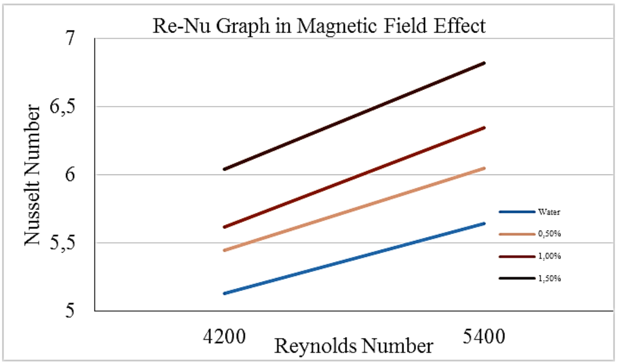

Figure 5. Re-Nu plot of fluids under magnetic field effect

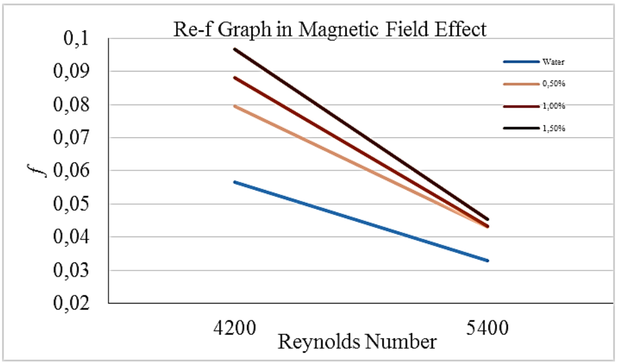

Figure 6. Re-f plot of fluids under magnetic field effect

3.3. Effect of Magnetic Field on Nanofluids

The experimental data collected without a magnetic field were compared to evaluate the effect of the magnetic field on nanofluids. Analysis of the results reveals that the magnetic field significantly influences the properties of the nanofluid. The Nusselt number increase value brought on by the magnetic field in the same nanofluid was compared with the graphs below in experiments conducted at two different Reynolds numbers. It is generally observed that the iron oxide-water nanofluid is affected by the magnetic field. Figure 7 and Figure 8 compare the Nusselt numbers of fluids with Re=4200 and Re=5400 values based on the magnetic field.

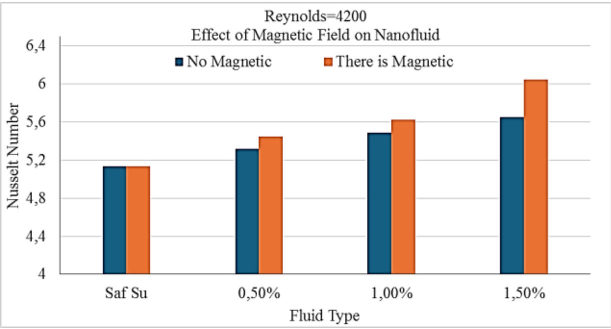

Figure 7. The effect of magnetic field at Re=4200 on the Nusselt number of fluids

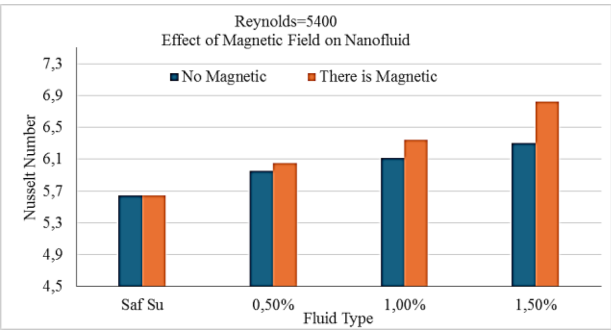

Figure 8. The effect of magnetic field at Re=5400 on the Nusselt number of fluids

3. RESULTS

The experiments demonstrated that the Nusselt number increased as the Reynolds number rose for all the fluids tested. It was also observed that the Nusselt number was further increased when pure water was replaced with an iron oxide-water nanofluid. In the experiments conducted without the influence of a magnetic field, it was noted that the Nusselt number rose as the volumetric ratio of the iron oxide-water nanofluid increased. In experiments conducted at Re=4200, the Nusselt number of pure water was 5.135, while the Nusselt number of 1.5% Iron oxide-water nanofluid increased by 10.1% and was found to be 5.653. In experiments conducted at Re=5400, the Nusselt number of pure water was 5.645, while the Nusselt number of 1.5% Iron oxide-water nanofluid increased by 11.6% and was found to be 6.299.

In experiments conducted under the influence of magnetic field, the Nusselt number of 1.5% Iron oxide-water nanofluid at Re=4200 was found to be 6.043. This value is 17.7% higher than the Nusselt number of pure water. At a Reynolds number of 5400, the Nusselt number of the 1.5% iron oxide-water nanofluid increased by 20.8% compared to water, reaching a value of 6.819. The observation indicated that the application of a magnetic field enhanced the thermal performance of nanofluids. The greatest effect of the magnetic field occurred in the 1.5% iron oxide-water nanofluid. While the Nusselt number of a 1.5% iron oxide-water nanofluid without a magnetic field is 6.299, the Nusselt number increases by approximately 8.25% to 6.819 when a magnetic field is applied to this fluid. It has been observed that it increases the Nusselt number by creating a linear effect in nanofluids at other concentrations. When the results are compared with previous studies, parallel results are seen. Like many nanofluids, the iron oxide-water nanofluid has increased heat transfer. The Nusselt number increases when a magnetic field is added to the nanofluid. Thus, we can conclude that magnetic nanofluids benefit from the magnetic field. There are multiple reasons for the iron oxide-water nanofluid's improved heat transfer. Initially, the total heat transfer coefficient of the nanofluid is higher than that of water alone, as iron oxide nanoparticles have a greater heat transfer coefficient than water. Additionally, the heat transfer coefficient increases due to the random motion of the nanoparticles within the fluid, along with their interactions and collisions. Moreover, the impact of the magnetic field on the movement of nanoparticles adds complexity to the fluid dynamics, thereby improving the heat transfer coefficient. The fact that nanofluids increase the heat transfer coefficient shows that their use in heat transfer systems is inevitable in the future. In today's technology, nanofluids are not widely used due to their high production costs and not at the desired level of homogeneity/stability. With the developing technology, nanoparticles in smaller sizes can be produced and nanofluids with high homogeneity and stability levels can be produced. With these nanofluids produced, it will be possible to obtain more heat transfer coefficient.

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REFERENCES

[1] Maxwell, JC. A treatise on electricity and magnetism. Oxford University Press. 1th ed. Cambridge: 1904.

[2] Tekir M, Taskesen E, Gedik E, Arslan K, Aksu B. Effect of constant magnetic field on $Fe_3O_4-Cu/Water$ hybrid nanofluid flow in a circular pipe. Heat and Mass Transfer. 2022; 58: 707-717.

[3] Demirpolat AB, Uyar MM. Investigation of the use of nanoparticles in thermal insulation materials. IJIEA. 2024; 8(2): 89-94.

[4] Uyar MM, Çıtlak A, Demirpolat AB. Investigation of performance and emission values of new type of fuels obtained by adding MgO nanoparticles to biodiesel fuels produced from waste sunflower and cotton oil. Industrial Crops and Products.2024; 222:1-12.

[5] Keklikcioğlu O, Özceyhan V. Grafen-demir oksit-su hibrit nanoakışkanlarının ısıl ve hidrolik performanslarının sayısal olarak incelenmesi. Erciyes Üniversitesi Fen Bilimleri Enstitüsü Dergisi. 2021; 37(2); 286-288.

[6] Çiftçi E, Sözen A, Karaman E. TiO_2 içeren nanoakışkan kullanımının ısı borusu performansına etkisinin deneysel olarak incelenmesi. Politeknik Dergisi. 2016; 19(3): 367-376.

[7] Kılınç F, Buyruk E, Karabulut K. Grafen tabanlı nanoakışkanların araç radyatörü soğutma performansı üzerindeki etkisinin deneysel analizi. Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi. 2019; 9(2): 1046-1056.

[8] Kılınç C. Manyetik Nanoakışkanın Termosifon Tipi Isı Borusunun Performansına Etkisi. Politeknik Dergisi. 2021; 24(3): 1309-1316.

[9] Sadeghinezhad E, Mehrali M, Tahan LS, Mehrali M, Kazi SN, Oon CS, et al. Experimental investigation of convective heat transfer using graphene nanoplatelet based nanofluids under turbulent flow conditions. Industrial & Engineering Chemistry Research. 2014; 53(31): 12455–12465.

[10] Askari S, Koolivand H, Pourkhalil M, Lotfi R, Rashidi A. Investigation of Fe_3O_4/Graphene nanohybrid heat transfer properties: experimental approach. International Communications in Heat and Mass Transfer. 2017; 87: 30-39.

[11] Peyghambarzadeh S, Hashemabadi S, Naraki M, Vermahmoudi Y. Experimental study of overall heat transfer coefficient in the application of dilute nanofluids in the car radiator, Applied Thermal Engineering. 2013; 52(1): 8–16.

[12] Ding Y, Alias H, Wen D, Williams R.A. Heat transfer of aqueous suspensions of carbon nanotubes (CNT nanofluids). Int. J. Heat Mass Transfer. 2006; 49(1): 240-250.

[13] Abreu B, Lamas B, Fonseca A, Martins N, Oliveira MSA. Experimental characterization of convective heat transfer with MWCNT based nanofluids under laminar flow conditions. Heat and Mass Transfer. 2014; 50(1): 65-74.

[14] Pak BC, Cho YI. Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles. Experimental Heat Transfer an International Journal. 1998; 11(2): 151– 170.

[15] Bhimani VL, Rathod PP, Sorathiya AS. Experimental study of heat transfer enhancement using water based nanofluids as a new coolant for car radiators. Internatıonal Journal of Emerging Technology and Advanced Engineering. 2013; 3(6): 295-302.

[16] Wen D, Ding Y. Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions. International Journal of Heat and Mass Transfer. 2004; 47: 5181-5188.

[17] Yu W, Choi SUS. The role of interfacial layers in the enhanced thermal conductivity of nanofluids: a renovated Maxwell model. Journal of Nanoparticle Research. 2003; 5: 167.