



DOI: [https://doi.org/10.71317/kjard.2.9\(s\).2026.748](https://doi.org/10.71317/kjard.2.9(s).2026.748)

Kashmir Journal of Academic Research and Development

Journal homepage: <https://rjsaonline.org/index.php/KJARD>



Pressure drops and friction factor analysis of a Double Pipe Heat Exchanger Using Iron Oxide Fe_2O_3 Nanofluid

Muhammad Kashif Abbasi

Industrial and Manufacturing Engineering Department, Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah-67480, Pakistan

Email: muhammadkashif@quest.edu.pk

Azhar Hussain Shah

Department of Mechanical Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah-67480, Pakistan

Email: s.azharshah@quest.edu.pk

Sajjad Bhangwar

Department of Mechanical Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah-67480, Pakistan

Email: Sajjadbhangwar@quest.edu.pk

Saira Akram Arain

Department of Mechanical Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah-67480, Pakistan

Email: sairaar826@gmail.com

Hassaan Kashmiri

Department of Mechanical Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah-67480, Pakistan

Email: hassaanaslam49@gmail.com

ARTICLE INFO

Received:

August 21, 2026

Revised:

August 30, 2026

Accepted:

September 16, 2026

Available Online:

September 30, 2026

Keywords:

Pumping power consumption, friction factor, pressure drop of a double-pipe heat exchanger, Fe_2O_3 nanofluid.

Corresponding Author:

Azhar Hussain Shah

Email:

s.azharshah@quest.edu.pk

ABSTRACT

Heat exchangers are widely employed in various industrial applications due to their ability to facilitate efficient heat transfer. This study investigates the performance analysis, friction factor, and pressure drop of a double-pipe heat exchanger using baseline water and Fe_2O_3 nanofluid at volume concentrations of 0.10% to 0.175% and flow rates of 1 to 2 LPM (liter per minute). The test-rig was operated at temperature of 70 °C for requirement. Initially, experiment was taken place using water coolant than operated by nanofluid. The whole experiment took place for measuring and analyzing friction factor, heat-transfer performance and pressure drop of a double-pipe heat exchanger using both fluids. However, nanofluid was prepared by certain volume concentration using hot plate and mechanical stirrer. The nanofluids stability was maintained up to 2 hours. Moreover, Reynolds number was set to analyze friction factor, and pressure drop of a double-pipe heat exchanger. The maximum friction factor was produced by Fe_2O_3 nanofluid compared to baseline water, and recorded as and 0.052 at a Reynolds number of 3530. The maximum increment in friction factor taken place 7% in under counter-flow conditions using Fe_2O_3 nanofluid. This enhancement attributed to increase due to more viscosity and density of Fe_2O_3 nanofluid than baseline water. This caused the overall reduction of Reynolds number of 3530. Additionally, pressure drop took place higher for Fe_2O_3 nanofluid compared to the water. More pressure drop caused the more pumping power consumption approximately by 6%. Thus, overall results increased the heat-transfer performance, and effectiveness of double-pipe heat exchanger using Fe_2O_3 nanofluid compared to conventional baseline water made it a suitable and best fluid for industrial applications.

Introduction

A nanoparticle is a very small particle with at least one dimension in the nanometer (nm) range, typically between 1 and 100 nm. Because of their extremely small size, nanoparticles often exhibit physical, chemical, thermal, and optical properties that differ from those of the same material in bulk form. In nanofluids, nanoparticles such as Al_2O_3 (aluminium oxide) and Fe_2O_3 (iron oxide) are dispersed in a base fluid such as water. Their high surface-area-to-volume ratio and enhanced thermal properties can improve the thermal conductivity and heat-transfer performance of the fluid. Nanoparticles are ultrafine solid particles having at least one dimension within the nanoscale range (approximately 1–100 nm), whose unique physicochemical properties make them suitable for enhancing the thermal and transport characteristics of conventional fluids when uniformly dispersed in a base fluid [1].

Effect of nanoparticle in water

When nanoparticles are dispersed in water, the resulting mixture is called a nanofluid. Nanoparticles can significantly change the thermal and flow properties of water. The inclusion of nanoparticles in water increases thermal conductivity, heat-transfer coefficient, pressure drop, pumping power and performance which may improve its ability to transfer more heat. Addition of solid nanoparticles increases density and viscosity of nanofluid. Thus improves heat-exchangers effectiveness. Despite the additional pressure drop and pumping-power requirements, nanoparticles can improve the overall heat-transfer performance of a heat exchanger [2-5].

Aluminum oxide (Al_2O_3) nanoparticles have attracted considerable attention in various industrial fields, including biomedical, pharmaceutical, manufacturing, and materials industries, due to their favorable thermal properties, durability, and stability at high operating temperatures. The nanoparticles can be synthesized using several techniques, including sputtering, pyrolysis, and laser ablation. When nanoparticles are dispersed in a base fluid, they can enhance the thermal and transport properties of the resulting nanofluid [6]. Ali et al. investigated various characteristics of nanofluids, with particular emphasis on their stability and thermal performance [7]. Similarly, Krishna et al. reported that water, Al_2O_3 -water, and TiO_2 -water nanofluids can be used as working fluids for improving heat removal from electronic and heat-transfer equipment [8]. Their investigation considered important performance parameters, including heat transfer and thermal conductivity [9]. Kaggwa et al. experimentally investigated the effects of two different nanofluids flowing through a double-pipe heat exchanger at different flow rates and nanoparticle volume concentrations [10]. Their results demonstrated that the use of nanofluids can improve heat-transfer characteristics and potentially reduce the required size and cost of heat exchangers [11].

Several effects have further examined the flow characteristics using nanoparticle concentration and also analyzed the heat-transfer performance. An experimental investigation of nanosized particles demonstrated that the Reynolds number and Nusselt number increased when nanoparticle volume concentrations of 0.25–0.5% were used under turbulent-flow conditions [12]. Another study reviewed the future applications of nanofluids in various engineering fields and discussed their use in different heat-transfer devices. The study also identified several challenges associated with the preparation, characterization, stability, and practical application of nanofluids [13].

The performance of different heat-exchanger configurations using Al_2O_3 nanofluids has also been investigated. An experimental study compared double-pipe, plate-type, and shell-type heat exchangers using Al_2O_3 nanofluids at volume concentrations of 0.2%, 0.5%, and 1%. The results indicated that the double-pipe heat exchanger provided favourable heat-transfer performance compared with the other configurations [14]. In another experimental investigation, the effects of mass flow rate, temperature, and nanoparticle concentration on the overall heat-transfer coefficient were examined. The results showed that a 1% $\text{Al}_2\text{O}_3/\text{CuO}$ nanofluid exhibited improved performance compared with the other investigated nanofluids [15].

In this study, the convective heat-transfer performance and pumping power of a helical coiled heat exchanger were investigated simultaneously under laminar water-flow conditions. A hybrid nanofluid consisting of MWCNT- Fe_3O_4 dispersed in water was used at volume fractions of 0.1% and 0.3%. Two different tube geometries, namely bare and ribbed tubes, were considered for the heat-exchanger section. The ribs were positioned orthogonally at an angle of 90° with respect to the inclined configuration. Three different Reynolds numbers within the laminar-flow regime were selected for the investigation based on the non-dimensional M number applicable to coiled tubes. Computational fluid dynamics (CFD) was employed to analyze the thermal and fluid-flow characteristics of the system. The convective heat-transfer coefficient was used as an important performance parameter for evaluating the effectiveness of the nanofluid in the heat exchanger, while pressure drop and pumping power were simultaneously considered to assess the hydraulic performance [16].

Effect on Friction Factor

Adding nanoparticles raises the dynamic viscosity of the fluid, which directly elevates the wall shear stress and the Darcy-Weisbach friction factor.

- **Particle Size Effect:** Smaller nanoparticle sizes lead to higher friction factors at a given volume concentration because of increased Brownian motion, particle-to-wall interactions, and localized flow disruptions. Higher volume fractions (e.g., moving from 0.01% to 0.06% or higher) and turbulent flow regimes cause moderate-to-significant increases in the friction factor compared to pure base fluids.

Effect on Pressure Drop

Pressure drops in a double-pipe heat exchanger is a function of fluid density, velocity, pipe geometry, and friction factor. Nanofluids have higher densities and viscosities than base fluids, leading to higher frictional losses along the flow path.

- **Magnitude of Increase:** Studies show that pressure drops can rise anywhere from a few percent at very low concentrations over 70% to 111% higher than pure water at higher concentrations (e.g., 3% volume fraction or specialized geometries).
- **Pumping Penalty:** The elevated pressure drop translates to an increased pumping power requirement (pumping penalty), meaning designers must balance the thermal conductivity enhancement (higher Nusselt number) against the extra energy required to circulate the fluid.

The volume concentrations of four different types of nanoparticles, Al_2O_3 , CuO and ZnO in the range of 0% to 3% and different nanoparticle diameters in the range of 20 nm to 50 nm are considered for each in this study. The results indicate that, the heat transfer coefficient and pressure drop increase with increasing Reynolds number and volume concentrations of nanofluids. All nanofluid types achieve better heat transfer enhancement compared to pure water with slight increases in the pressure drop. The Al_2O_3 nanomaterial has better thermal enhancement characteristics followed by CuO, ZnO respectively. The average heat transfer coefficient enhancement is 14% for the Al_2O_3 nanoparticles with a volume concentration of $\phi=3\%$ and nanoparticle diameter of 32 nm, while the increase in pressure drop reaches 5% and 72% of pure water for the Al_2O_3 nanoparticles with a volume concentration of $\phi=0.5\%$ and $\phi=3\%$, respectively [17]. The hot Fe_3O_4 nanofluid flows through the inner tube, whereas cold water flows through the annulus of the heat exchanger. The volume concentrations of Fe_3O_4 nanoparticles considered in this study are 0.005%, 0.01%, 0.03%, and 0.06%, with Reynolds numbers ranging from 15,000 to 30,000. The results indicate that the Nusselt number is enhanced by 14.7% at a nanoparticle volume concentration of 0.06% and a Reynolds number of 30,000 compared with the base fluid. Furthermore, the pumping penalty associated with the nanofluid is less than 10% [18]. An experimental investigation was carried out to assess the heat transfer and friction factor characteristics of an aluminum oxide (Al_2O_3)-water nanofluid flowing through a double-pipe heat exchanger. The study focused on heat transfer between hot and cold water and evaluated important thermal and flow parameters, including the Nusselt number, heat transfer coefficient, and Reynolds number. The Reynolds number was varied from 5710 to 18,366, and experiments were conducted using both plain water and Al_2O_3 -water nanofluids. The experimentally obtained results were subsequently compared with computational fluid dynamics (CFD) simulation results. The findings revealed that the Al_2O_3 -water nanofluid significantly improved the heat transfer rate compared with plain water, demonstrating enhanced thermal performance. In addition, the experimental results for the heat transfer and friction factor characteristics showed good agreement with the CFD predictions. Overall, the Al_2O_3 -water nanofluid demonstrated superior heat transfer performance compared with plain water in the smooth-tube double-pipe heat exchanger [19].

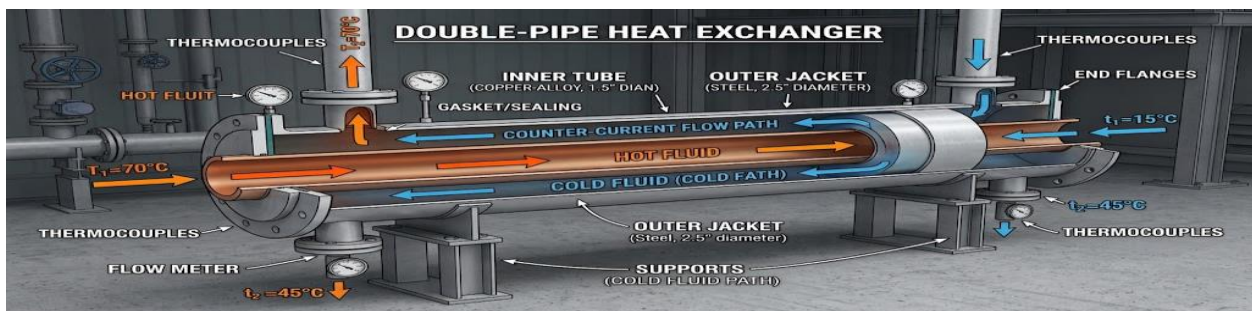


Figure 1: double pipe heat exchanger

Effect of friction factor on volume concentration and Reynolds Number

The friction factor increases with an increase in the volume concentration of nanoparticles. This increase can be attributed to the higher density and viscosity of the nanofluid compared with baseline water. The effect of volume concentration of nanoparticles in baseline water can be seen in figure 1.

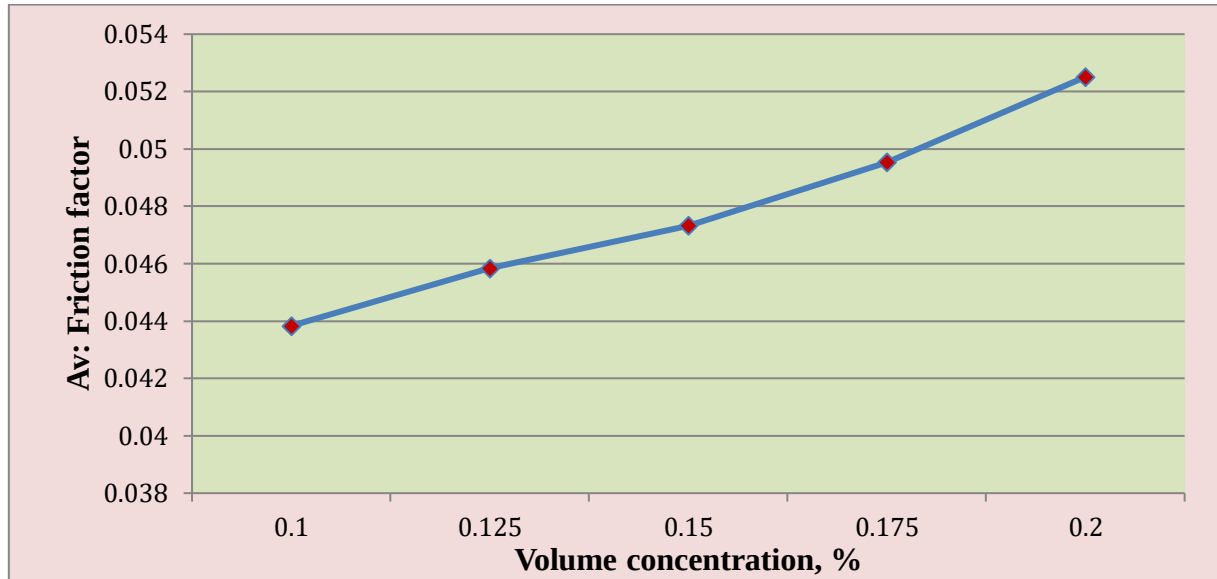


Figure 01. Effect of friction factor on volume concentration at various flow rate

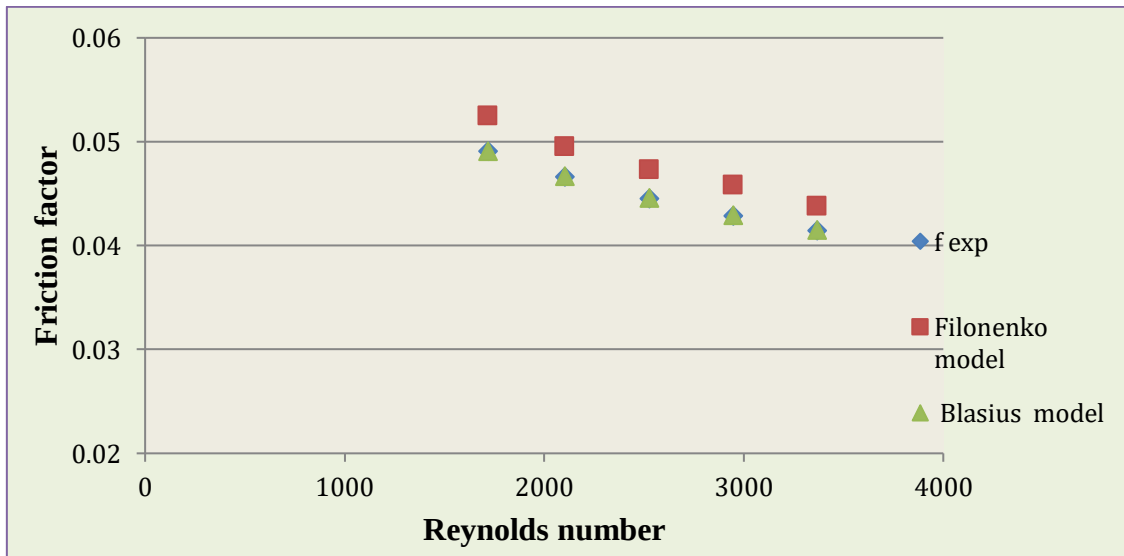


Figure 2. Effect of friction factor on various Reynolds numbers using correlations

Figure 1 shows the variation of the friction factor with respect to the volume concentration of nanoparticles. The experimental friction factor was evaluated using Equation (1), in which velocity, discharge, and pressure drop were measured experimentally using appropriate measuring devices. The results indicate that the addition of nanoparticles to baseline water increases the friction factor during fluid flow.

$$(L/D).(\rho V^2/2).f = \Delta P \quad (1)$$

Furthermore, as the volume concentration increases, nanoparticle agglomeration may also increase, resulting in greater resistance to fluid flow and, consequently, a higher friction factor [20]. The results show that the friction factor increases with increasing nanoparticle volume concentration at a given mass flow rate and decreases with increasing Reynolds number, as shown in Figures 1 and 2.

From Figure 1, it can be observed that the addition of 0.2% Fe_2O_3 nanoparticles to baseline water resulted in increases in the friction factor of 2% and 7%, respectively, compared with baseline water. The higher friction factor observed for the Fe_2O_3 nanofluid may be attributed to its higher density compared to the baseline water.

The friction factor was found to increase as the Reynolds number decreased. This can be seen in figure 2. This behavior is associated with the increased density and viscosity of the nanofluid compared with baseline water. The maximum friction factors recorded for the Fe_2O_3 nanofluid was 0.052 at a Reynolds number of 3530.

An empirical correlation for the friction factor is also presented in Figure 2. The development of the friction-factor correlation was intended to reduce the uncertainty associated with the experimental results and improve their precision. It was observed that increasing the volume concentration of Fe_2O_3 nanoparticles in baseline water resulted in an increase in the friction factor.

Figure 2 demonstrates good agreement between the empirical correlation and the experimental results. The Blasius correlation showed the least deviation from the experimental results for both baseline water and nanofluid. The following correlations were therefore used to evaluate and compare the deviations in the experimentally determined friction factors.

Table 1: Following correlations were used to evaluate determined friction factors

Sr #	Friction factor	Correlation
1	Friction model	$\frac{0.316}{(\text{Re})^{0.25}}$
2	Filonenko model	$\ln.\text{Re}.0.790-1.64$
	Blasius formula	$(100.\text{Re})^{-1/4}$

Effect of Pressure drop on volume concentration

For heat transfer applications, fluid-flow properties and characteristics are essential for determining the feasibility of nanofluids under various operating temperatures and flow-rate conditions. In this study, nanofluid was prepared by dispersing different volume concentrations of iron oxide (Fe_2O_3) nanoparticles in baseline water at a given mass flow rate.

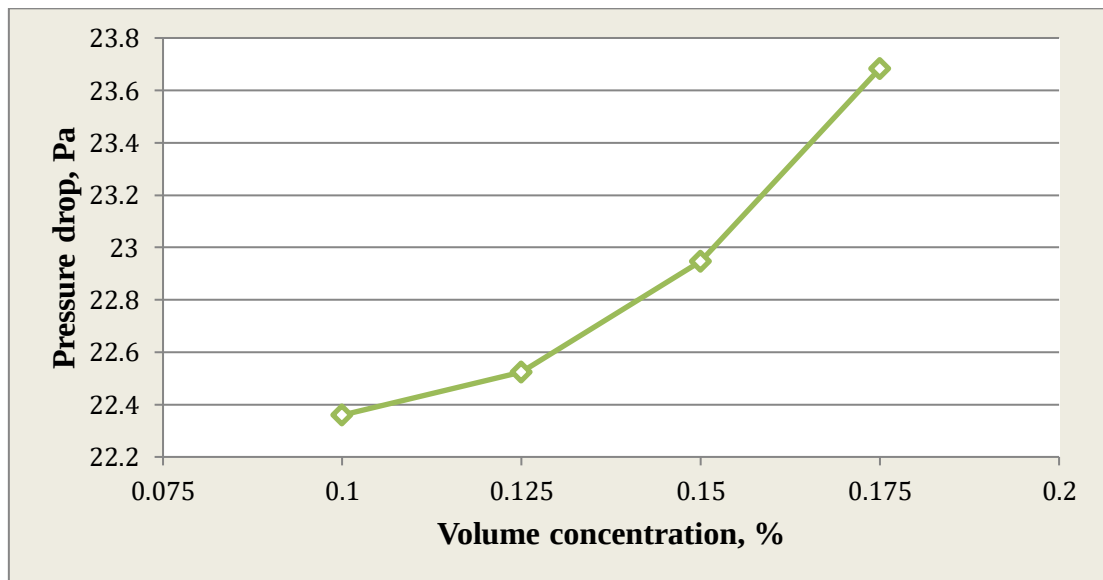


Figure 3. Effect of Pressure drop on volume concentration at various flow rates

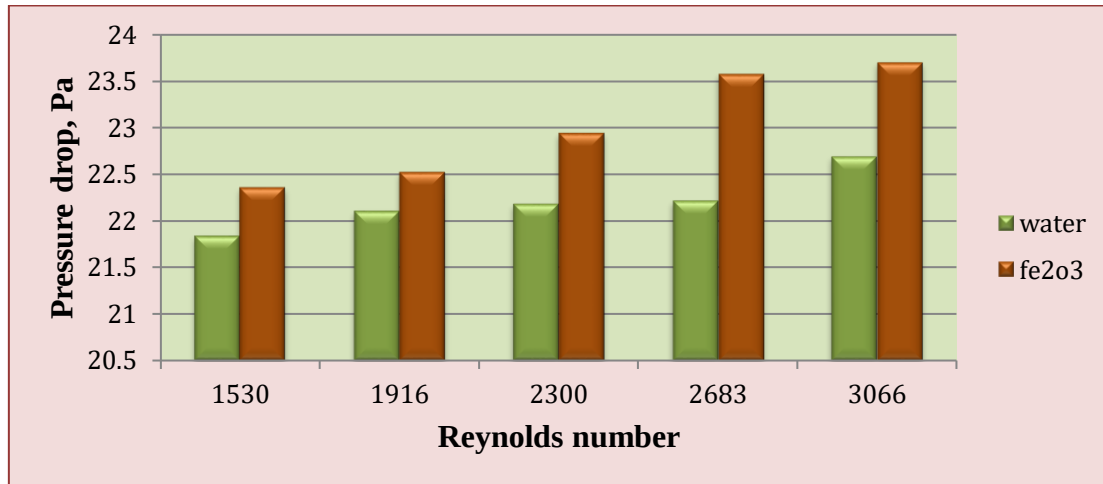


Figure 4. Effect of Pressure drop on Reynolds numbers

Figure 3 shows the pressure drop across the test tube for baseline water and nanofluids. It can be observed that the addition of Fe_2O_3 nanoparticles to baseline water results in a higher pressure drop than that of baseline water [21]. This behavior can be attributed to the higher density and viscosity of the nanofluids, which increase the resistance to fluid flow.

The pressure drop values were measured using calibrated manometers installed across the heat-exchanger tubes. Figure 4 presents the variation of pressure drop with Reynolds number for baseline water and nanofluid under the experimental conditions. The results indicate that the pressure drop increases with the addition of nanoparticles compared with baseline water [23]

For the same mass flow rate and operating conditions, the Fe_2O_3 nanofluid exhibited a higher pressure drop than the baseline water. The measured pressure-drop values for the Fe_2O_3 and baseline water were 23.7 kPa and 22.9 kPa, respectively. This difference can be associated with the higher density and viscosity of the Fe_2O_3 nanofluid, which results in greater resistance to fluid flow.

Effect of volume concentration on heat transfer coefficient

The purpose of adding Fe_2O_3 nanoparticles is to modify the thermal and flow properties of water. Because nanoparticles can have different thermal conductivity, density, viscosity, and heat-transfer characteristics than water, their addition can affect parameters such as: Convective heat-transfer coefficient, Nusselt number, Heat-transfer rate, Pressure drop, Friction factor, Overall thermal performance [24].

The addition of iron oxide (Fe_2O_3) nanoparticles to baseline water involves dispersing a specified concentration of these nanoparticles into water to prepare nanofluids. The incorporation of nanoparticles modifies the thermophysical properties of the base fluid, particularly its thermal conductivity, density, and viscosity, which can influence the heat-transfer and flow characteristics of the nanofluid. In heat-exchanger applications, these changes may affect the convective heat-transfer coefficient, Nusselt number, pressure drop, and friction factor. The nanofluid was prepared by dispersing Fe_2O_3 nanoparticles in baseline water at volume concentrations of 0.100%, 0.125%, 0.150%, and 0.175, 0.2%. Forced convection heat transfer was employed in the heat-exchanger tubes, with the nanofluids circulated through the tubes using a pump under laminar-turbulent flow conditions.

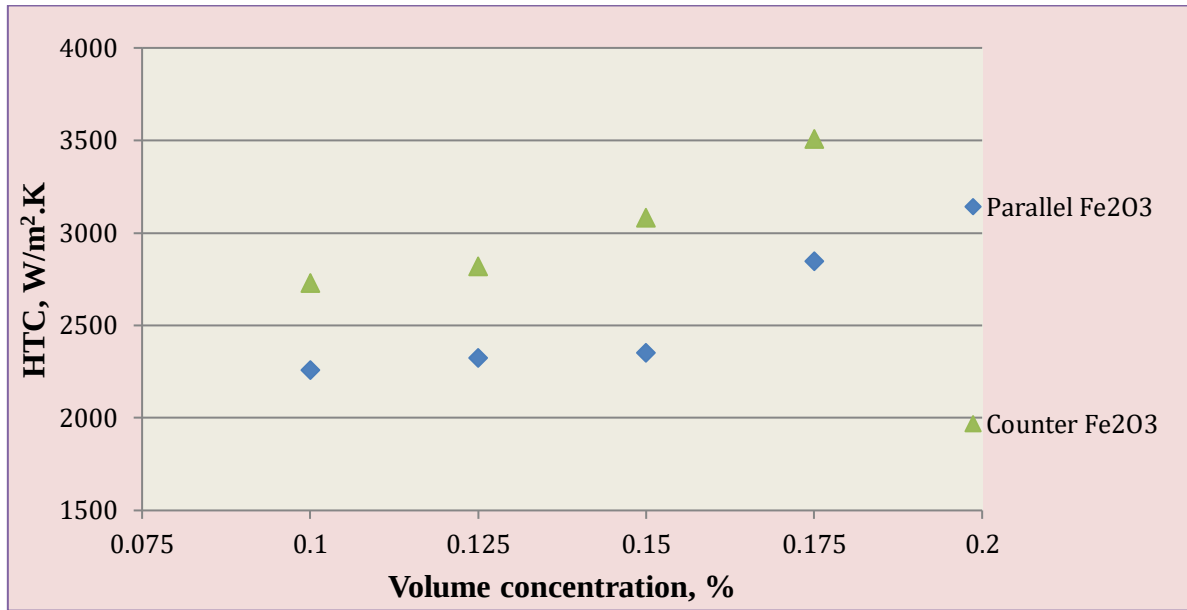


Figure 5: Effect of volume concentration on heat transfer coefficient

Figure 5 shows the variation in the heat-transfer rate for Fe₂O₃ nanofluids under parallel and counter-flow conditions. It can be observed that the counter-flow heat exchanger exhibited a higher heat-transfer rate for the Fe₂O₃ nanofluid. This behavior can be attributed to the differences in the thermophysical properties of the two fluids, particularly their thermal conductivity. The maximum convective heat-transfer coefficients for the Fe₂O₃ nanofluid under parallel and counter-flow conditions were recorded as 3502 W/m².K and 2943 W/m².K, respectively, at a volume concentration of 0.2%. The higher heat-transfer coefficient obtained at the higher nanoparticle concentration indicates that increasing the concentration of nanoparticles can improve the thermal performance of the nanofluid [25].

Conclusion

From the experimental investigation, it can be concluded that the use of Fe₂O₃ nanofluid (NF) at volume concentrations ranging from 0.10% to 0.2% at different volume flow rates resulted in higher friction factors, pressure drops, and heat transfer coefficients compared to baseline water. These improvements can be attributed primarily to the higher thermal conductivity of the Fe₂O₃ nanofluid compared with baseline water. The major investigations of this research work can be summarized as follows:

1. The average heat transfer coefficient increased with increasing nanoparticle volume concentration, which can be attributed to the improvement in the thermophysical properties of the nanofluids. At a concentration of 0.2%, the average heat transfer coefficient of nanofluid increased by approximately 10% to 25% compared to water under both parallel-flow and counter-flow conditions.
2. The addition of 0.175% Fe₂O₃ nanoparticles to baseline water resulted in increases in the friction factor of 7% compared with baseline water. This increase was mainly associated with the higher density of the nanofluid compared with water.
3. The use of volume concentration of 0.175% resulted in approximately 6% higher pumping power consumption than baseline water. The increased pumping power requirement was associated with the higher pressure drop and density of the nanofluid. In particular, Fe₂O₃ nanofluid exhibited a greater pressure drop and pumping power requirement than baseline water.

Nomenclature

Nf=nanofluid

Al₂O₃=aluminum oxide

GV=gate valve

HTC= heat transfer coefficient

Fe₂O= iron oxide

NF= Nanofluid

np=nanoparticle

TiO₂= titanium oxide

Nm= nanometer

CFD=computational fluid dynamics

LPM=liter per minute

References

- De Carli, M., Fiorenzato, S., & Zarrella, A. (2015). Performance of heat pumps with direct expansion in vertical ground heat exchangers in heating mode. *Energy Convers*, pp. 120–130.
- Hatami, M., Ganji, D. D., & Gorji-Bandpy, M. (2015). Experimental and numerical analysis of the optimized finned-tube heat exchanger for OM314 diesel exhaust exergy recovery. *Energy Convers, Volume 97*, pp. 26–41.
- Rashidi, M., & Abbasbandy, S. (2011). Analytic approximate solutions for heat transfer of a micro polar fluid through a porous medium with radiation. *Nonlinear Sci. Numer. Simul*, volume 16, 1874–1889.
- Eric C.okonkwo, Ismail w, yasser M abdullatif, & tariq Ansari. (2020). An updated review of nanofluid in heat transfer devices. *Journal of thermal analysis and calorimeter*.
- Suhail Khan, S. C Hegde, Pratheek S, S. Shettigar, & Satyanarayan. (2015). Effect of Sonication Time, Concentration, Shape and Size of Nano Particle on Thermal Conductivity of Al₂O₃ /Water Nano Fluid. Alva's Institute of Engineering and Technology, Moodbidri.
- YD Kokate, & SB Sonawane. (2019). Investigation of particle size effect on thermal conductivity enhancement of distilled water-Al₂O₃ nano fluids. *Fluid Mechanics Research International Journal*. eISSN: 2577-8242.
- Ali, N., Teixeira, J. A., & Addali, A. (2018). A review on nanofluids: fabrication, stability, and thermo physical properties. *J Nanomater*. <https://doi.org/10.1155/2018/6978130>
- Krishna, V. M., & Kumar, M. S. (2019). Numerical analysis of forced convective heat transfer of Nano fluids in micro channel for cooling electronic equipment. *Mater Today Proc.*, 17, 295–302. <https://doi.org/10.1016/j.matpr.06.433>
- Kaggwa, A., & Carson, J. K. (2019). Developments and future insights of using nanofluids for heat transfer enhancements in thermal systems: a review of recent literature. *Int Nano Lett.*, volume 9, issue 4, 277–88. <https://doi.org/10.1007/s40089-019-00281-x>
- Esam I. Jassim et.al. (2020). Experimental assessment of Al₂O₃ and Cu nanofluids on the performance and heat leak of double pipe heat exchanger. *Heat and Mass Transfer*, volume 56, pp. 1845–1858.
- Maria Terese et.al. (2021). Application of Nanofluids in enhancing the Thermal Conductivity of Heat Exchangers-A Review. *International Journal of Scientific and Research Publications*, Volume 11, Issue 6, 364. ISSN 2250-3153.
- Mingrui Zheng et.al. (2020). Effect of Al₂O₃/water nanofluid on heat transfer of turbulent flow in the inner pipe of a double-pipe heat exchanger. *Heat and Mass Transfer*, volume 56, 1127–1140.
- Eric C.okonkwo, Ismail w, yasser M abdullatif, & tariq Ansari. (2020). An updated review of nanofluid in heat transfer devices. *Journal of thermal analysis and calorimeter*.
- Dariush Mansoury, Faramarz Ilami Doshmanziari, Abolfazl Kiani, Ali J. Chamkha, & Mohsen Sharifpur. (2019). Heat Transfer and Flow Characteristics of Al₂O₃/ Water Nanofluid in Various Heat Exchangers: Experiments on Counter Flow. *Heat Transfer Engineering*, volume 41, issue 3, pp. 220-234.

- Mohamad hosein, & Mohamad fallahiyekta. (2018). Increasing thermal efficiency of double pipe heat exchangers by using nano hybrid. *Emerging science journal*.
- Misagh Irandoost Shahrestani. (2021). Convective Heat Transfer and Pumping Power Analysis of MWCNT + Fe₃O₄/Water Hybrid Nanofluid in a Helical Coiled Heat Exchanger with Orthogonal Rib Turbulators. *ORIGINAL RESEARCH*. Published: 23 February 2021. doi: 10.3389/fenrg.2021.630805
- Suhail Khan, S. C Hegde, Pratheek S, S. Shettigar, & Satyanarayan. (2015). Effect of Sonication Time, Concentration, Shape and Size of Nano Particle on Thermal Conductivity of Al₂O₃ /Water Nano Fluid. Alva's Institute of Engineering and Technology, Moodbidri.
- N.T. Ravi Kumar, & Bhramara Panitapu. (2017). Heat transfer, friction factor and effectiveness analysis of Fe₃O₄/water nanofluid flow in a double pipe heat exchanger with return bend. *International Communications in Heat and Mass Transfer*, 81, 155-163. DOI:10.1016/j.icheatmasstransfer.2016.12.019
- K.Sivakumar^{1*}, & N.Deepak. (2019). Analysis of Heat Transfer and Friction Factor Characteristics of Circular Tube Fitted Heat Exchanger Using Nano Fluids. *International Journal of Research and Scientific Innovation (IJRSI) | Volume VI, Issue II, February 2019*. ISSN 2321-2705.
- Rassol Hamed Rasheed. (2025). Enhancing the thermal performance of double-pipe heat exchangers using wire coil inserts: A focused review. *Scientific African* 29:e02896. DOI:10.1016/j.sciaf.2025.e02896
- Azhar Hussain Shah, Waqar Ahmed, & Liaquat Ali Memon. (2024). Heat Transfer Enhancement and Pumping Power Characteristics of Fe₂O₃ and ZnO Nanofluids in a Double-Pipe Heat Exchanger. *Journal of Hunan University (Natural Sciences)*, Volume 51 No. 4 (April 2024).
- Azhar Hussain Shah, Liaquat Ali Memon, & Sajjad Hussain Bhangwar. (2024). The Impact of Nanoparticles in Water Coolant on Heat Transfer Rate in Parallel and Counter Flow Heat Exchanger. *Journal of Applied Engineering & Technology (JAET)*, Volume 8 No. 1, 2024.
- Azhar Hussain Shah, Liaquat Ali Memon, & Muhammad Ramzan Luhur. (2024). JTEN-2023-328: Performance and fluid flow analysis of double pipe heat exchanger using Al₂O₃-nanofluid. *Journal of Thermal Engineering*, Volume 10 No. 5 (September 2024).
- Azhar Hussain Shah, Rashid Ali, & Tarique Ahmed Memon. (2025). Investigation of Thermal Performance Enhancement in Automotive Radiators Using Al₂O₃-Water Nanofluid. *Spectrum of Engineering Sciences*, Volume 3, No. 9, 2025.
- Azhar Hussain Shah, Jameel Ahmed, & Muhammad Kashif Abbasi. (2025). Thermal Analysis and Performance Characteristics of Double Pipe Heat Exchanger Using Aluminium Oxide Al₂O₃ and Iron Oxide Fe₂O₃ Nanofluid. *Annual Methodological Archive Research Review nline ISSN: 3007-3197, Volume3, No. 10,2025*.



2026 by the authors; Journal of Kashmir Journal of Academic Research and Development. This is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) license (<http://creativecommons.org/licenses/by/4.0/>).