Hindawi
Journal of Nanomaterials
Volume 2022, Article ID 9712065, 8 pages
https://doi.org/10.1155/2022/9712065

Research Article

An Empirical Analysis of Heat Expulsion and Pressure Drop Attribute in Helical Coil Tube Using Nanomaterials

Salem Algarni,[1] Vineet Tirth,[1] Talal Alqahtani,[1] Pravin R. Kshirsagar,[2] and Worku Abera[3]

[1]*Mechanical Engineering Department, College of Engineering, King Khalid University, Abha, 61421 Asir, Saudi Arabia*
[2]*Department of Artificial Intelligence, G.H. Raisoni College of Engineering, Nagpur, India*
[3]*Department of Food Process Engineering, College of Engineering and Technology, Wolkite University, Wolkite, Ethiopia*

Correspondence should be addressed to Vineet Tirth; vtirth@kku.edu.sa and Worku Abera; worku.abera@wku.edu.et

Received 1 March 2022; Accepted 5 April 2022; Published 16 May 2022

Academic Editor: Hiwa M. Ahmed

Water nanofluids were examined in a horizontal helical coil tube with constant temperature limitations for Dean values between 1000 and 10,000 to determine the rate of thermal radiation transmission and pressure drop characteristics. When conducting the tests, a variety of Al_2O_3 water nanofluid requirements were used, including varying mass flows, heat exchange rates for various nanoparticle volume concentrations, and changes in coil-side drop in pressure versus coil-side Dean number. Since nanoparticles have enhanced heat capacity, nanoparticles are developing as a transitional beginning of heat transfer fluids with significant potential in thermal management applications. Many applications require nanofluids to be used as heat transfer fluids; thus, scientists are concentrating their efforts on these fluids. The Reynolds values on the coil and shell were in the 1000 to 7000 range on either side of the wire. This paper discusses the impact of particle volume density on shell-side flow temperatures, heat expulsion rate, and thermal conduction. The result shows that the average heat transfer rises by 13% and 17% when nanoparticle volume fraction percentage density is 0.1%, 0.2%, and 0.3 percent. The results demonstrate that reducing the mass flow by an increase in particle volume density, pipe diameter, and coil radius improves heat exchanger performance. The efficiency of the model is enhanced by increasing the diameter of the tube while simultaneously decreasing the diameter of the coil.

1. Introduction

There is a significant difference in the thermal properties between water nanofluid and their underneath fluid counterparts. Heat transfer coefficients grow in conjunction with nanofluid thermal conductivity. This enhanced heat transfer velocity may be useful in resolving the primary problem of constructing a compact heat exchanger [1]. Helically coiled tubes are superior heat transfer apparatuses because of their stiffness and better heat transfer efficiency than those of sharp tube heat exchangers [2]. Shell and helical coil tubes, which have a single heat exchanger canal, are prevalent. There are two types of fluids in a cold/hot fluid system: flowing out of the shell through the helical coil tube, one travels towards the center, and another travels through the helix coil tube. Additional heat transfer in helical tubes is more reliable because of secondary flow. In the modern world, helically coiled pipes for heat transfer have gained great attention due to the numerous applications for which they may be used. Food and dairy production plants as well as chemical plants and natural gas processing facilities, as well as power plants, all use them heavily [3, 4], as do a wide range of other sectors as well. Another passive way to improve heat transmission is to introduce nanoparticles into the base fluid to generate nanofluid with high specific heat capacity than the base fluid [5].

The use of nanofluid in heat transfer activities has increased considerably in the last decade. For the most part, these experiments called for the use of water as a basic fluid. Nanofluids based on water show Newtonian behavior. The chemical and food industries all employ non-Newtonian fluids, as do the healthcare and biopharmaceutical industries as well as the polymer and oil industries. Methods for improving performance can be classified as passive or active [2, 3]. The active methodology makes use of surface vibration signals and fluid vibrations, whereas the passive approach employs various inserts and pitch adjustments. Active methods are harder to employ than passive ones due to their complexity [4]. Pitch variation aids heat transfer, but it also reduces shell-side heat transfer rate and causes a considerable pressure decrease. In terms of improving heat transfer without pressure decreases, we used Al_2O_3 nanofluids to increase the pressure loss heat transfer characteristics [3, 5].

2. Objective

The coiled tube heat exchangers are recommended based on the results of the analysis, and the paper's major objective is to improve heat transmission by utilizing nanofluids. To determine how much nanofluid is being used, these relationships are used. Then, that information is plotted against the amount of nanofluid used to show the shell and tube heat thermal resistance.

3. Literature Survey

Wang et al. [1] discussed how well a new helically tube test device transfers heat and how much water it moves. The helical tube shape of the coil was modified to increase its thermal efficiency. A 20 percent increase in heat transfer rates was reported when reversed loops were used as a design change. In addition, the increase in heat transmission and pressure drop was increased by reducing the reversed loop's size.

Ardekani et al. [2] examined the fluid flow and heat transmission in a circular tube of water nanofluids with constant heat limits. Different coil designs across a range of particle volume fractions and Reynolds numbers between 8,900 and 11,970 were examined to see how geometrical variables influenced the results. The researchers discovered that using nanofluids inside helical coils improved the heat transfer coefficient more than using straight tubes [3]. They also provided two correlation experimental results that predicted the Nusselt number and friction factor.

Job et al. [6] discussed that symmetrical wavy trapezoid container, Al_2O_3-water, and SWCNT-water nanofluids were shown to have unstable magnetohydrodynamics (MHD) free convection flows. The study discovered that for alumina-water nanofluids with low Hartmann numbers, the rate of heat transmission decreased (Ha).

Rakhsha et al. [7] discussed their Nusselt number that improved by around 21.53 percent, but their pressure remained the same. CuO nanofluid flow within helical coils with constant wall average temperature was studied computationally and empirically in steady-state turbulent forced convection.

Ahire et.al [8] demonstrated that many heat transfer activities benefit from the usage of nanofluid, and AL_2O_3 is a nanoparticle that is combined with a base fluid to produce nanofluids. For estimating the chemical and physical characteristics, there is correlation that is accessible.

Sharma et al. [9] investigated the fluid flow characteristics in straight tubes and helical coils with nanofluid. Both ethylene glycol and propylene glycol/water (EG/W) nanofluids included 0–2.5 vol percent alumina nanoparticles and were mixed in a 60 : 40 wt ratio. A higher friction factor was reported for nanofluids in both straight and helical coil tubes compared to base fluids.

Bhanvase et al. [10] systematically used a vertical helically coiled tube heat exchanger to comprehensively study the rise in water-based PANI (polyaniline) nanofluid heat transfer. PANI nonmaterial at 0.1 and 0.5 vol percent increased the heat transfer by 10.52 and 69.62 percent, correspondingly, according to the researchers' findings.

4. Application of Nanofluids

A broad range of heat transfer uses, such as transportation, cooling of electronics, energy storage, and mechanical applications have revealed that nanofluids have enhanced heat transfer characteristics and increased energy efficiency than conventional fluids. When it comes to the development of next-generation technology for a wide range of technical and medical applications, nanofluid is critical. The next parts go through a few of these use cases [11].

4.1. Automobile Applications. Standard engine coolants and oils can be improved by adding nanoparticles and nanotubes to produce nanofluids, increasing their thermal conductivity, and increasing heat exchange rates and fuel economy [12]. Use of these advances can reduce cooling system sizes or remove heat from vehicular emission inside the same cooling system, depending on your preference.

4.2. Solar Applications. As a consequence of the disparity in timing between energy supply and demand, it was required to build a storage system. With a concentration on effective use and preservation of heat losses and solar energy, thermal energy storage such as that found in solar thermal systems and buildings has emerged as an essential element of energy conservation [5, 12]. Due to a lack of power generation, solar energy is becoming increasingly important in energy applications. Fossil fuel usage will be restricted in the future based on perceived resource depletion concerns.

4.3. Friction Reduction. Minimizing wear and friction is a major focus of tribological development. Proved challenging may run more efficiently and reliably using improved fluids. Because of their high load-bearing capacity, high resilience to severe pressure, and friction-reducing properties, nanoparticles have recently attracted a lot of study attention [13]. In contrast to water-based Al_2O_3 fluids, the cast iron MQL grinding process included diamond nanofluids. A thick and solid sludge layer develops on the surface during nanofluid MQL grinding, which might improve grinding efficiency, reducing grinding force, better surface roughness, and burn protection of the workpiece due to the usage of nanofluid technology [6]. MQL grinding has the potential

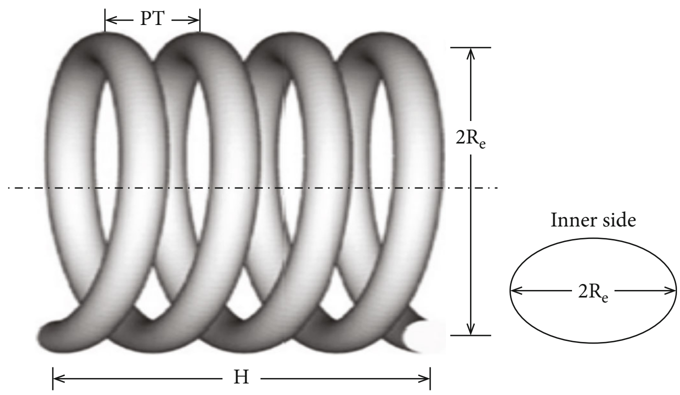

Figure 1: A schematic of the helical coil tube.

to considerably lower the grinding temperature when compared to dry grinding.

4.4. Electronics Cooling. Smaller computer chips and microelectronic elements have much higher power dissipation than larger ones. It is necessary to have superior heat control and cooling fluids with enhanced thermal transfer characteristics to operate safely [11, 13]. Nanofluids have been proposed as heat pipe working fluids for cooling applications because of their low thermal conductivity.

4.5. Magnetic Sealing. Because it is less expensive and has lower friction losses than mechanical seals, magnetic seals are an excellent choice for ecological and dangerous gas sealing in a range of industrial rotating equipment. There are unique nanofluids such as ferromagnetic fluid (ferromagnetic fluid). Magnetite and other tiny magnetic particles are suspended in a stable colloidal solution (Fe_3O_4). Nanoparticle magnetite [6], which is a component of magnetic nanofluids, may be made to have a different magnetic field strength by changing the size and protective coatings. Magnetic nanofluids are dispersed in nonpolar and polar carrier liquids to meet the dispersion requirements that responders verified [7].

5. Material and Methods

5.1. Helical Coil Tube Specifications. A helically shaped tube is seen in Figure 1. The inner diameter of the copper helical coil tube is "$2r$," and the coils have a helical shape to prevent tangling. When you see the letters "d" and "D" in this picture, it means that you are looking at the inner tube diameter and coil diameter, correspondingly [8]. Pitch is a term used to describe the amount of time between two successive rotations. The curvature ratio, represented by the symbol "d/D," is another critical parameter in helical coil tubes (HCT).

This relationship between Reynolds number and Dean value is evident in helical coil tubes (HCTs). The Dean value determines fluid flow in an HCT [14].

$$\mathrm{De} = \mathrm{Re}\sqrt{\frac{r}{R_c}}. \tag{1}$$

There are three variables in this equation: the Reynolds number (Re), the tube inner diameter (r), and the coil radius (R_C).

$$\mathrm{Re} = \frac{2rA_\tau}{\mu} \tag{2}$$

Average velocity is represented by "A" in this equation, density is represented by τ, and viscosity is represented by μ.

5.2. Proposed System. Figure 2 shows the experimental setup's flow map. The setup is comprised of two loops, which are designated as shell area loop and helically coiled region loop, respectively. Hot air is handled by the shell side loop, while Al_2O_3/water nanofluid is handled by the coiled tube loop [8, 14]. Aluminum insulating ropes, thermocouples with LCDs, and condensers for cooling nanofluid are all part of the experimental setup. The test area also includes an air-duct heating chamber and a power meter and rotameter [9].

5.3. Preparation of Nanofluid. Sustainable nanofluid may be made using a variety of methods. In addition, utilizing a stabilizing agent as well as a dispersing agent or an ultrasonic vibrator is an option. Surface treatment is a popular method among them because of its versatility, low cost, and benefits. The nanofluids can only be stabilized for 45 minutes without the use of appropriate chemicals [14]; however, surfactants can significantly improve the stability of nanofluids. Sigma-Aldrich chemicals provided the Al_2O_3 nanofluid (2 mg/ml) and nanoparticles with a diameter of 20-50 nm for the experiment. It was necessary to add the necessary nanoparticle volume proportion and the optimal quantity of the associated surfactant to the measuring jar to distribute the alumina nanoparticles in distilled water [9]. Acoustic pulses were generated for 12 hours using a magnetic stirrer (2000 rpm). This results in homogeneous dispersion and stable suspension. The "thermophysical" characteristics of the generated nanofluids were computed using the following models [12].

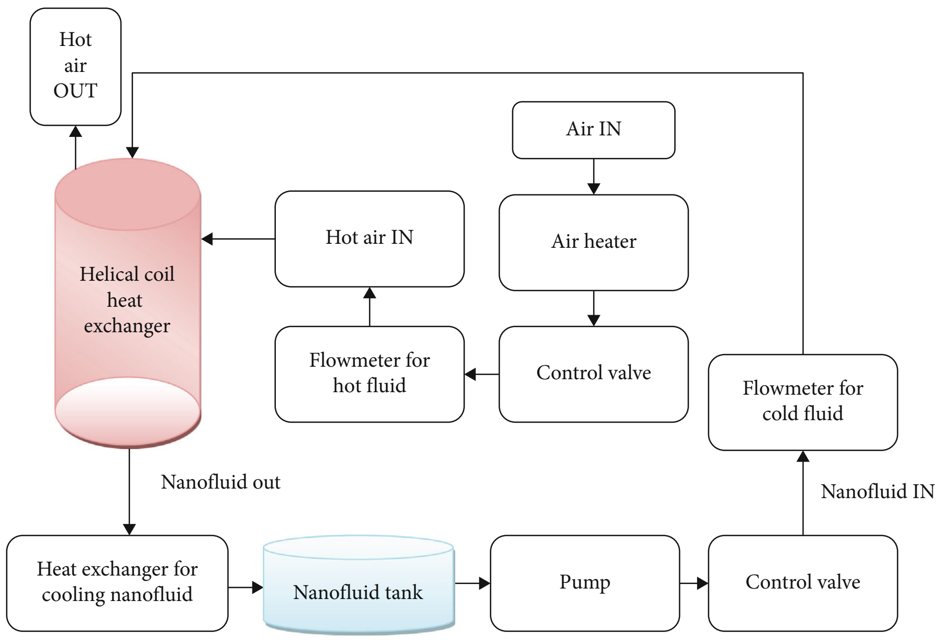

FIGURE 2: Block diagram of the experimental setup.

5.3.1. Thermal Conductivity. We compared the KD2 Pro thermal performance analyzer's Al_2O_3-water nanofluid resistivity results to two well-established formulae's anticipated values. The most often used formula for predicting the thermal conductivity of a solution is as follows [6, 12]:

$$h_{\mathrm{eff}} = \frac{h_b + (n-1)h_g - (n-1)\left(h_g - h_b\right)\varphi}{h_b + (n-1)h_g + \left(h_g - h_b\right)\varphi}. \quad (3)$$

Here, the heat transfer performance is represented by h_{eff}, and the shape factor n is represented by "$n^{1/4}3\psi$," where ψ "sphericity" is the radius of the curvature. It has values of 1 for spherical particles and 0.5 for cylindrical ones, depending on the form [10]. The quantities h_b and h_g indicate the thermal conductivity of particles and fluids, respectively.

5.3.2. Viscosity. It is accurate that the vast majority of the mathematical correlations that have been utilized to predict the viscosity of nanofluids have been derived from the well-known Einstein model [15].

$$\theta_{ng} = \theta_{bg}(1 + 2.5\varphi), \quad (4)$$

where the viscosity of the solvent is represented by θ_{bg}, the viscosity of the base fluid is denoted by θ_{ng}, and φ denotes the volume fraction of the solution.

5.3.3. Density. When considering nanofluid density, the volume fraction of solid (nanoparticles) to liquid in the process is directly proportional. There is a direct correlation between nanoparticle concentration in a fluid and its density, with the former being greater when there are more of them present [7, 9]. Nanofluid density has been claimed to be in line with the mixing theory proposed in the lack of experimental data.

$$\sigma_{\mathrm{nf}} = (1 - \varphi)\sigma_{\mathrm{bf}} + \varphi\sigma_{\mathrm{s}}, \quad (5)$$

where σ_{nf} represents the density of nanofluid, σ_{bf} denotes the density of the base fluid, σ_{s} represents the density of solid particles, and ϕ is the volume concentration.

5.3.4. Specific Heat. As the volume particle size of the nanofluid increases, the heat capacity of the nanofluid decreases continuously [6, 13]. The relationship between them demonstrates excellent correlation with the predictions made using the thermodynamic equilibrium technique; however, the simple mixing model fails to estimate the heat capacity of nanofluid properly. Specific heat is determined in an experiment by using the following formula:

$$T_{p\mathrm{nf}} = \frac{\varphi\rho(T_P)_P + (1 + \varphi)\rho T_{pf}}{\rho_{\mathrm{nf}}}, \quad (6)$$

The density and specific heat of a particle are represented by $\rho(T_P)_P$, the density and specific heat of fluid are represented by ρT_{pf}, and $T_{p\mathrm{nf}}$ indicates the density and specific heat of a nanofluid [16].

To determine the critical Reynolds number in helical coils,

$$\mathrm{Re}_{\mathrm{cr}} = 2300\left[1 + 8.6\left(\frac{r}{R_{\mathrm{c}}}\right)^{0.45}\right]. \quad (7)$$

Coil diameter (r) and tube diameter (d) are also important parameters to consider while determining this value (R_{c}). The coil's curvature ratio was 0.0552, resulting in a

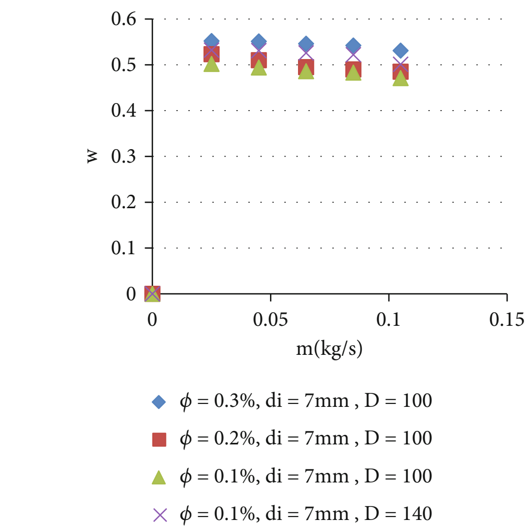

FIGURE 3: Effectiveness varies with mass flow rate due to a variety of factors.

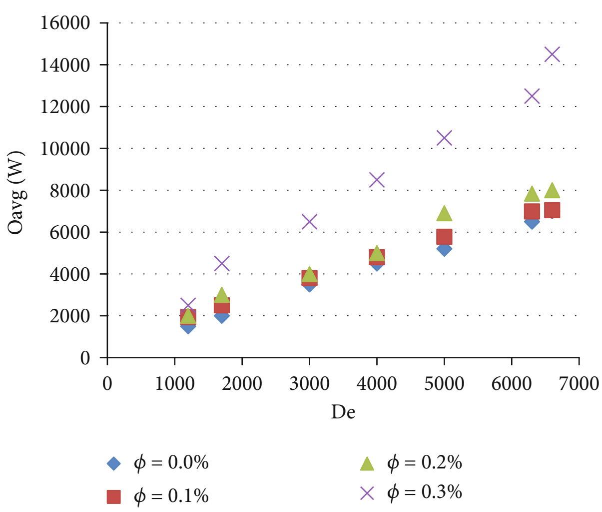

FIGURE 4: The rate of heat transmission for various concentrations of nanoparticles.

critical Reynolds number of 7671 for the system. The Reynolds numbers used in this paper span from 1837 to 6869.

5.4. Experimental Procedure. At different cold fluid flow rates under turbulent circumstances, a test was carried out in a tube heat exchanger with or without circular fins utilizing Reynolds numbers ranging from 1000 to 7000 and stable hot air velocity of 5 meters/seconds [10, 15]. A helical coil in the thermal storage tube bundle circulates cold distilled water, which swaps heat with hot air from the heat exchanger. The system takes 30-35 minutes to stabilize, according to the results of the preliminary tests [17, 18]. Stream temperatures are monitored at the entrance and outlet. To monitor the controlled flow of cold fluid, a rotameter was installed at the test section's inlet [19]. Circular fin designs with and without fins, as well as flow rates varying greatly, were also investigated. Al_2O_3 nanoparticles dispersed in distilled water were studied using the aforementioned technique in a coil in a shell heat exchanger with and without circular fins at volume concentrations ranging from 0.25 percent to 1 percent [12, 13].

To calculate the errors of dependent items, the following equation is used:

$$\delta D = \left[\sum_{i=1}^{N}\left(\frac{\partial D}{\partial Y_i}\partial Y_i\right)^2\right]^{0.5}. \quad (8)$$

Y_i and D are the independent and dependent variables, respectively, in this correlation.

5.5. Data Validation. To validate the reliability of trials, experts had to run accuracy tests with pure water first, then with nanofluids [20]. We provide the equations for laminar flows in helical coils with a constant heat flux as the beginning condition [16].

$$\mathrm{Nu} = \left[0.76 + 0.65\sqrt{\mathrm{De}}\right]\mathrm{Pr}^{0.175}, \quad (9)$$

$$\mathrm{Nu} = 0.7\mathrm{Re}^{0.43}\mathrm{Pr}^{(1/6)}\left(\frac{d}{D}\right)^{0.07}. \quad (10)$$

De indicates Dean value and Pr indicates Prandtl values, respectively, in the above equations. D is the diameter of the coil, whereas d is the inner diameter [17, 18].

Theoretical pressure drop in helically coiled tubes may be calculated with the help of the following formula:

$$\Delta P = g_c\left(\frac{1}{d}\right)\left(\frac{\tau U^2}{2}\right). \quad (11)$$

The friction coefficient of the circular tube is represented by g_c in this equation and may be determined using the following correlation [21]:

$$\frac{g_c}{g_s} = 0.47136\mathrm{De}^{0.25}. \quad (12)$$

Petukhov equation is used to calculate the friction coefficient in a tube bank.

$$g_s = (0.79\ln(\mathrm{Re}) - 1.64)^{-2}. \quad (13)$$

6. Results and Discussions

6.1. Performance Analysis of the Heat Exchanger. In real-world applications, it is better to have a higher heat transfer rate than to have a worse pressure drop, which necessitates greater pumping power. This means that in coiled tube heat exchangers, investigating and evaluating the opposing impact of increased heat transmission and higher pressure drop are essential. Equation ((14) is used to determine the heat exchanger's efficiency.

$$\varepsilon = \frac{O_{avg}}{O_{max}}. \quad (14)$$

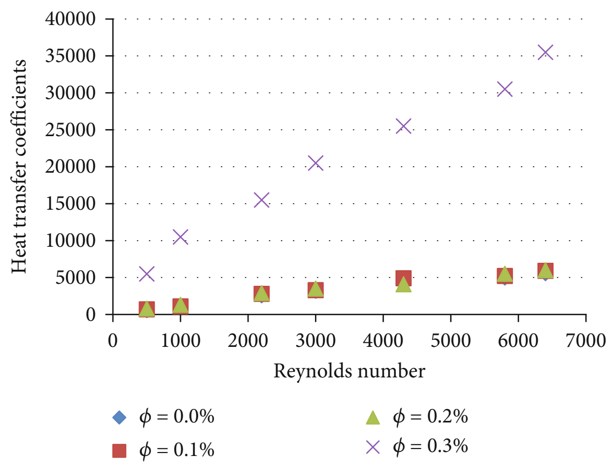

Figure 5: Heat transfer coefficient of coil side changes with Reynolds number on the coil side.

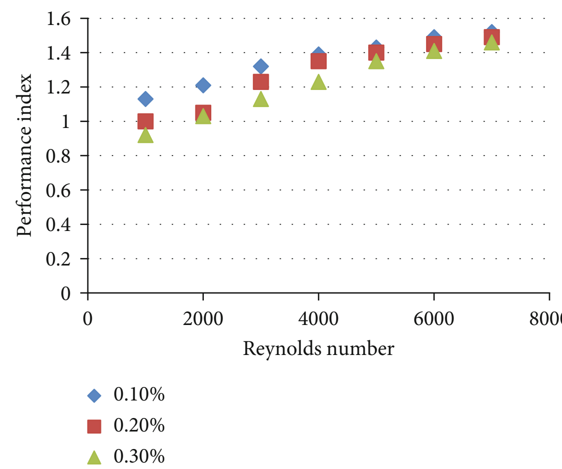

Figure 7: Performance index–Reynolds number variations.

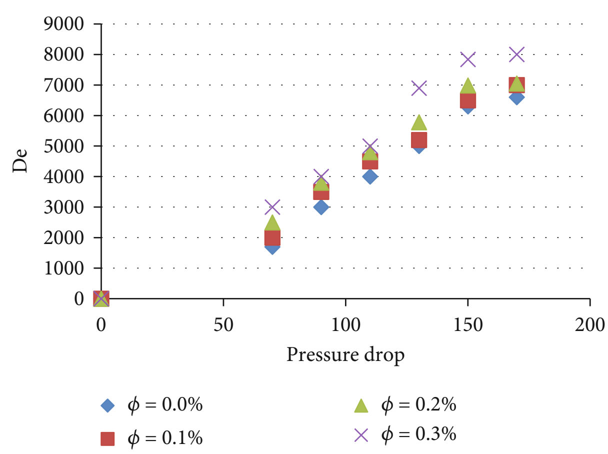

Figure 6: Variations of coil-side Dean number vs. coil-side pressure drop.

Equation ((15) is used to compute the heat exchanger's performance index, which measures how well it performs in terms of pressure drop.

$$\theta = \frac{O_{avg}}{\Delta P_{coil}}. \tag{15}$$

Figure 3 demonstrates that when the heat transfer rate increases, the efficiency rises with the mass nanoparticle concentration. As the mass flow rate increases, the temperature differential between the inlet and exit narrows, reducing efficiency. As tube and coil diameters increase, the heat transfer field expands, resulting in improved efficiency.

Figure 4 shows that raising the particle volume concentration increases the heat transfer rate. The reason for this is due to the nanofluid's thermophysical characteristics. First, as the volume concentration of nanoparticles increases, so does their thermal conductivity, increasing the rate at which heat is transferred. Second, greater nanofluid viscosity increases flow velocity for the same Reynolds number, resulting in higher heat transfer rates.

Figure 5 shows the connection between both the Reynolds number and the change in coil-side heat transfer rate. Heat transmission coefficients grow in direct proportion to the volume fraction of nanoparticles. As the Reynolds number rises, the heat exchanger's instability causes its heat transfer coefficients to rise as well.

For a given particle volume concentration and Dean number, the pressure decrease may be shown in Figure 6. Due to the increased viscosity that results from a rise in particle volume concentration, pressure drops increase as well.

The coefficient of heat transfer and the pressure drop are two unrelated variables that are not linked by an equation. There should be some criteria used to compare the different heat transfer improvement techniques so that they can be compared. To achieve this, the performance index, a PEC (performance evaluation criterion), is used.

$$\eta = \left(\frac{h_{NF}}{h_{BF}}\right)\left(\frac{\Delta P_{NF}}{\Delta P_{BF}}\right)^{-1}. \tag{16}$$

Nanofluid and base fluid are denoted by the subscripts "NF" and "BF," respectively. When the performance index exceeds unity, it appears that the heat transfer approach favors heat transfer enhancement above pressure drop increase. For nanofluids of various weight concentrations flowing in the louvered channel, Figure 7 illustrates the changes in performance index vs. Reynolds number. For all nanofluids except for 0.2 and 0.3 percent wt nanofluids at the lowest Reynolds number, the performance index is higher than 1.Additionally, the performance index increases dramatically with the Reynolds number, as can be seen in the graph below. Additionally, when the weight percentage of nanoparticles increases, so does the performance index. A maximum performance index of 3.967 is found at Reynolds number 7,200 for nanofluid with 0.10 percent weight concentration.

7. Conclusion

An Al_2O_3/water nanofluid inside a helical coil tube was analyzed for convective heat transfer using fluid heat transfer in this paper. As the number of particles grows, the nanofluid temperature decreases, while the water temperature rises, along with the amount of heat transferred. The results revealed that when nanoparticle volume concentrations of 0.1 percent, 0.2 percent, and 0.3 percent are present, the average heat transfer rate increases by 13% and 17%. It was found that when nanoparticle volume concentration increased, the thermal performance efficiencies on the coil, shell, and overall improved. When the mass flow rate is the same as water, the thermal transfer rate of nanofluids significantly increases, but the volume particle concentration rises slightly. The results of the analysis revealed that decreasing the mass flow rate while increasing the density of nanoparticles, tube diameter, and coil diameter all resulted in better performance. At Reynolds number 7,200, a nanofluid with a weight concentration of 0.10% has a maximum performance measure of 3.967.

Data Availability

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

The authors gratefully acknowledge the Deanship of Scientific Research, King Khalid University (KKU), Abha 61421, Asir, Kingdom of Saudi Arabia, for funding this research work under the grant number RGP.2/9/43.

References

[1] W. Yi, J. L. Alvarado, and W. Terrell Jr., "Thermal and flowcharacteristics of helical coils with reversed loops," *International Journal of Heat and Mass Transfer*, vol. 126, pp. 670–680, 2018.

[2] A. Mokhtari Ardekania and V. Kalantara, "Experimental study on heat transfer enhancement of nanofluid flow through helical tubes," *Advanced Powder Technology*, vol. 30, no. 9, pp. 1815–1822, 2019.

[3] H. Javaniyan Jouybari, S. Saedodin, A. Zamzamian, M. Eshagh Nimvari, and S. Wongwises, "Effects of porous material and nanoparticles on the thermal performance of a flat plate solar collector: an experimental study," *Renew Energy*, vol. 114, no. B, pp. 1407–1418, 2017.

[4] P. Naphon, "Thermal performance and pressure drop of the helical-coil heat exchangers with and without helically crimped fins," *International Communications in Heat and Mass Transfer*, vol. 34, no. 3, pp. 321–330, 2007.

[5] S. Aberoumand and A. Jafarimoghaddam, "Mixed convection heat transfer of nanofluids inside curved tubes: An experimental study," *Applied Thermal Engineering*, vol. 108, pp. 967–979, 2016.

[6] V. M. Job, S. R. Gunakala, B. Rushi Kumar, and R. Sivaraj, "Time-dependent hydromagnetic free convection nanofluid flows within a wavy trapezoidal enclosure," *Applied Thermal Engineering*, vol. 115, pp. 363–377, 2017.

[7] M. Rakhsha, F. Akbaridoust, A. Abbassi, and S.-A. Majid, "Experimental and numerical investigations of turbulent forced convection flow of nano-fluid in helical coiled tubes at constant surface temperature," *Powder Technology*, vol. 283, pp. 178–189, 2015.

[8] S. Ahire, B. S. PurushottamShelke, and N. Totala, "Fabrication and analysis of counter flow helical coil heat exchanger," *International Journal of Engineering Trends and Technology (IJETT)–Volume*, vol. 15, no. 5, pp. 229–240, 2014.

[9] P. Sharma, R. Gupta, and R. K. Wanchoo, "Hydrodynamic studies on glycol based Al_2O_3 nanofluid flowing through straight tubes and coils," *Experimental Thermal and Fluid Science*, vol. 82, pp. 19–31, 2017.

[10] B. A. Bhanvase, S. D. Sayankar, A. Kapre, P. J. Fule, and S. H. Sonawane, "Experimental investigation on intensified convective heat transfer coefficient of water based PANI nanofluid in vertical helical coiled heat exchanger," *Applied Thermal Engineering*, vol. 128, pp. 134–140, 2018.

[11] A. M. Fsadni, J. P. M. Whitty, M. A. Stables, and A. A. Adeniyi, "Numerical study on turbulent heat transfer and pressure drop characteristics of a helically coiled hybrid rectangular-circular tube heat exchanger with Al_2O_3-water nanofluids," *Applied Thermal Engineering*, vol. 114, pp. 466–483, 2017.

[12] M. Hemmat Esfe, H. Hajmohammad, R. Moradi, and A. A. Abbasian Arani, "Multi-objective optimization of cost and thermal performance of double walled carbon nanotubes/water nanofluids by NSGA-II using response surface method," *Applied Thermal Engineering*, vol. 112, pp. 1648–1657, 2017.

[13] A. Tahiri and K. Mansouri, "Theoretical investigation of laminar flow convective heat transfer in a circular duct for a non-Newtonian nanofluid," *Applied Thermal Engineering*, vol. 112, pp. 1027–1039, 2017.

[14] V. Bianco, "Numerical simulation of water/Al_2O_3 nanofluid turbulent convection," in *Dipartimento di IngegneriaAerospaziale e Meccanica*, SecondaUniversitàdegliStudi di Napoli, Via Roma 29, 81031 Aversa, Italy, 2010.

[15] V. Kumar, A. K. Tiwari, and S. K. Ghosh, "Effect of variable spacing on performance of plate heat exchanger using nanofluids," *Energy*, vol. 114, pp. 1107–1119, 2016.

[16] B. P. S. Singh and A. Tripathi, "Experimental study of heat transfer of a car radiator with nano fluid-Al_2O_3 water mixture as coolant," *International Journal of Advanced Research in Science, Engineering and Technology*, vol. 2, no. 9, pp. 830–837, 2015.

[17] R. Boonsri and S. Wongwises, "Mathematical model for predicting the heat transfer characteristics of a helical-coiled, crimped, spiral, finned-tube heat exchanger," *Heat Transfer Engineering*, vol. 36, no. 18, pp. 1495–1503, 2015.

[18] B. ChinnaAnkanna and B. Sidda Reddy, "Performance analysis of fabricated helical coil heat exchanger," *International Journal of Engineering Research*, vol. 3, no. Special 1, pp. 33–39, 2014.

[19] K. A. Amid, W. H. Azmi, R. Mamat, and K. V. Sharma, "Experimental investigation on heat transfer performance of TiO_2 nanofluids in water-ethylene glycol mixture," *International*

Communications in Heat and Mass Transfer, vol. 73, pp. 16–24, 2016.

[20] W. H. Azmi, K. Abdul Hamid, N. A. Usri, R. Mamat, and M. S. Mohamad, "Heat transfer and friction factor of water and ethylene glycol mixture based TiO_2 and Al_2O_3 nanofluids under turbulent flow," *International Communications in Heat and Mass Transfer*, vol. 76, pp. 24–32, 2016.

[21] R. N. Singh, P. Rajat, I. Lav, and P. K. Pandey, "Experimental studies of nanofluid TiO $_2$/CuOin a heat exchanger (double pipe)," *Indian Journal of Science and Technology*, vol. 9, no. 31, 2016.