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Review Article

Thermal Performance of a Helical Coil Heat Exchanger Utilizing Nanofluids: A Review

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ABSTRACT

The manufacturing process of heating systems involves incorporating various heat exchangers, each with distinct characteristics. Among these, the helical heat exchanger stands out due to its space-efficient design and enhanced heat transfer rate compared to other variants. Recently, heat exchangers have witnessed novel nanofluid explorations aiming to replace conventional working fluids. Nanofluids possess unique properties that hold the potential for substantial improvements, consequently influencing the efficiency of heat exchangers employing them. The effectiveness of these heat exchangers is intrinsically tied to the properties of the employed nanofluids. Recent years have witnessed remarkable strides in comprehending the distinct traits exhibited by diverse nanofluids. This comprehensive study amalgamates findings from multiple investigations focused on helical-tube heat exchangers utilizing nanofluids as the primary medium. Notably, it underscores the existence of varying conclusions and perspectives among different researchers. This variance arises from the complexity of nanofluid behavior and its interactions within heat exchangers. Consequently, the efficacy of helical heat exchangers leveraging nanofluids hinges on the specifics of the chosen nanofluid and its characteristics. This subject continues to stimulate vigorous research and discussions among scholars. In summation, the dynamic landscape of heat exchanger innovation has brought the spotlight onto helical heat exchangers and their integration with nanofluids, showcasing the intricate interplay between fluid properties and efficient heat exchange.

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1. Introduction

Cutting-edge technologies are required to keep up with the increasing demand for high heat flow operations and enhance heat transfer. The need to improve the effectiveness of existing heat transfer techniques is also rising. Heat transfer is critical in many industries, including power, air conditioning, mass transit, and optoelectronics. Authors from various fields have conducted numerous experimental and theoretical investigations on raising the efficiency of heat exchangers. Improving the efficiency of heat transfer equipment in these fields is critical for making devices smaller and cheaper. Several researchers have experimented with various modifications to these instruments to increase their heat transfer rate. Some of the techniques discussed in the literature include pitch ratio, coil curvature ratio, air bubble injection, using different types of nanofluid particle volume concentration, and so on. This study reviews the significant findings relating to the enhancement of nanofluids' thermophysical characteristics, and it concentrates on the benefits of employing nanofluids in shell and helical coil heat exchangers. Important

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factors such as particle size, concentration, base fluid, and flow regime were considered. The implications of various geometric features on the enhancement of heat transmission in nanofluid-based systems are also discussed.

2. Summarized Experimental and Numerical Studies involving Various Nanofluids

2.1. Experimental study

Bakhtiyar et al. [1] studied the effects of functionalized multi-walled carbon nanotubes (MWCNTs-COOH and MWCNTs-OH) on a unique indirect laboratory heater with a helical tube (Figure 1) at dosages of 0.025, 0.05, 0.075, and 0.1 wt %. The system worked better at greater concentrations. The MWCNTs-COOH nanofluid bath had a maximum heat transfer rate of 1709 W, 19.04% better than pure water, and a maximum Nusselt number of 15.61, 36.33% higher than water. Heat loss grows with the flow. Heat loss, heat transfer, and system efficiency increased with nanofluid concentration.

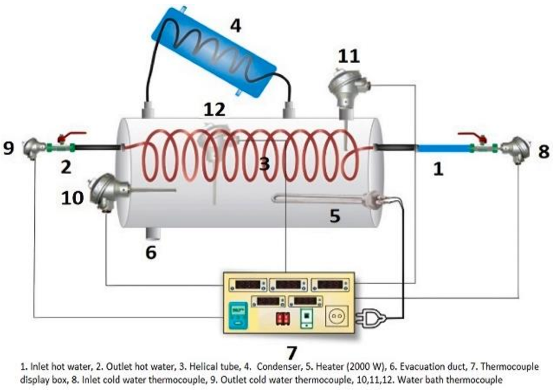

Figure 1. Schematic of the experimental heat exchanger

Abdelghany et al. [2] evaluated conically coiled tubes (CCTs) under continuous heat flux boundary conditions. Thermo-hydraulic performance was tested at 0.3%, 0.6%, and 0.9% volume concentrations of Al2O3/water nanofluid, Dean Numbers of 1148–2983, and coil torsions of 0.02–0.052. Reduced coil torsion increased conically coiled tube heat transfer. Dean's number boosts the average heat transfer coefficient and decreases the friction factor. From 0.3% to 0.9% nanofluid concentration, the heat transfer coefficient rose 32% for lower Dean number values and 26% at higher Dean number values. Lower coil torsions (0.052–0.02) improved thermal performance factor. Tuncer et al. [3] investigated nanofluid performance increase using fins. Through this respect, 1% (wt./wt) TiO2/water and CuO–TiO2/water nanofluids were created and circulated through both heat exchangers' hot sides. In finless and finned SHCHEs, TiO2/water working nanofluid increased the heat transfer coefficient by 7.5% and 8.6%, respectively. CuO–TiO2/water working nanofluid use in finless and finned SHCHEs averaged 10.8% and 12% heat transfer coefficient improvements. TiO2/water and CuO–TiO2/water nanofluid improved thermal performance in original and modified SHCHEs. In both SHCHEs, hybrid nanofluid performed better than solo nanofluid. Fins also improved the performance of single and hybrid nanofluids, as seen in (Figure 2).

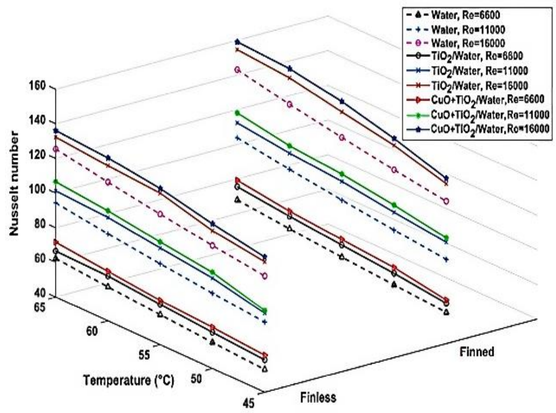

Figure 2. Nusselt number variation of finned and finless hot sides utilizing water and nanofluids

Hasan et al. [4] analyzed the efficiency of a vertical coiled heat exchanger using merging enhancement and air injection (Figure 3). Due to air bubble injection and increasing the bubble size, heat transfer and heat exchanger effectiveness improved. The experiment indicated that when the flow rate on the shell side and the injected air flow rate were increased, there was a noticeable increase in the thermal efficiency of the heat exchanger. The maximum improvement was observed in the U, NTU, and e, with values of 153%, 153%, and 68%, respectively.

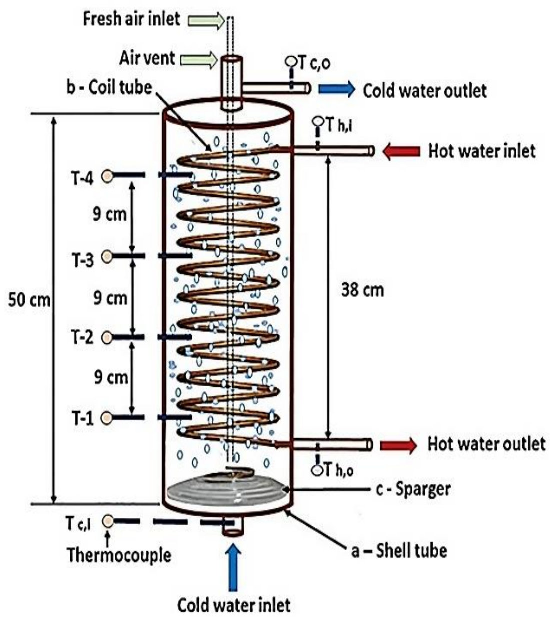

Figure 3. Vertical coiled heat exchanger with bubble generator

Zarei et al. [5] investigated cold thermal energy storage (CTES) using a bubble-injected helical coil heat exchanger. At airflow rates from 3 to 11 L/min, bubbles were injected from the storage tank's bottom (Figure 4). They found that bubble injection increased COP, heat transfer rate from the storage tank, exergy destruction, and Nusselt number (Nu). This increase was strongly reliant on bubble injection shape and flow rate. Bubble injection's best flow rate was 9 L/min in this investigation. The refrigeration cycle's COP and Nu number rose by 124% and 452%, respectively, compared to the non-bubble injection mode.

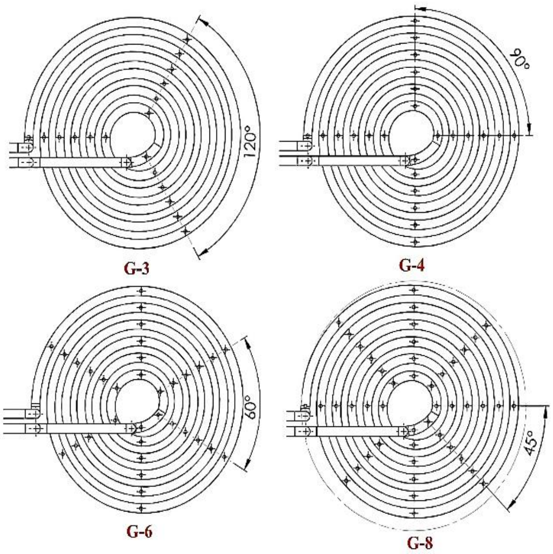

Figure 4. Bubble-injected type

Ahmed [6] Studied using Nanofluids in a secondary refrigeration loop. Nanofluids were used in the experiments. When Al2O3 Nanofluid was included in the redesigned system's secondary loop, the system's efficiency soared. There was a maximum COP that could be achieved, and it was 6.5. Compared to purified water, the thermal conductivity of Nanofluid is much more excellent. Shiravi et al. [7] studied the convective heat transfer coefficient (CHTC), Nusselt number, and pressure drop of carbon Nanofluid in turbulent conditions. Results showed that increasing the Reynolds number improved CHTC and reduced friction. At a constant Reynolds number, the CHTC of 0.21 mass% carbon Nanofluid was 40.7% higher than distilled water. Singh et al. [8] conducted a Nanofluid experiment using carbon nanotubes (CNTs) at Re=5000. The coefficient of heat transfer for Nanofluid was 62.6% higher than water, while the frictional resistance of water and CNT Nanofluid rose with increasing Re number. Incorporating CNT nanoparticles into a Nanofluid makes it a better heat conductor than water. Chandra et al. [9] Performed calculations to study a Cu-Ni/water hybrid Nanofluid. Heat transfer was measured by adding 0.02, 0.04, and 0.06 Nanofluid concentrations to the base fluid at Laminar flow, variable concentrations, and coil turn. 0.04 % vol Cu-Ni/water with 12 twists is more famous for processing food because of its consistent temperature. Hozien et al. [10] Studied TiO2, ZnO, and Ag water-based Nanofluids in a helically coiled pipe at a 0.25% volume concentration. Results show that Heat transmission was enhanced by 32%, 21%, and 16%, respectively, and 27.31%, 16.03%, and 10.38% of Nu number when using mentioned nanoparticles. Elshamy et al. [11] studied the exergy of water and water/Al2O3 Nanofluid using helically and conically coiled heat exchanger tubes. The helically and conically tubes have a curvature ratio of 0.0564. However, their coil torsions are different. Reducing coil twisting from 0.052 to 0.0202 increased Nanofluids' overall coefficient of heat transmission, convective heat transmission coefficient, Nu number of coil side, effectiveness, and efficiency of exergy. Nut's correlation with study variables:

Conically coiled tube is expressed as:

$$Nu_t = 0.111378\varphi^{0.3217}\, Re^{0.7701}\, Pr^{0.013}\, \lambda^{-0.0002} \quad (1)$$

Helically coiled tube is expressed as:

$$Nu_t = 0.21742\varphi^{0.3501}\, Re^{0.7664}\, Pr^{0.01}\, \lambda^{-0.0006} \quad (2)$$

Radwan et al. [12] Studied convective heat transfer and pressure drop. As shown in (Figure 5), six concentric coiled tubes were used:

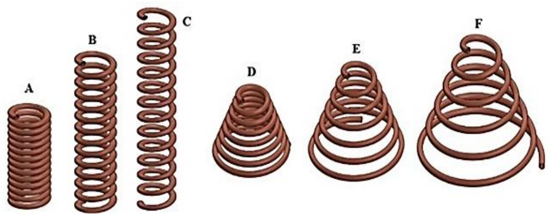

Figure 5. Schematic diagram of the coils

Conical heat exchangers have lower friction and heat transfer coefficients than helical coils. Cone angle, coil torsion, and water inlet temperature decrease an internal tube's heat transfer coefficient and friction factor. The 45-degree conical coil with 0.1044 torsions has more hydrothermal performance. Depending on the experimental data, this empirical correlations were obtained:

$$\overline{Nu_t} = 0.000157\, Re_t^{1.083} Pr_t^{0.735} \left(\frac{1+\theta}{180}\right)^{-0.044} \lambda^{-0.489} \quad (3)$$

$$f_t = 0.0645\, Re_t^{-0.2329} \left(\frac{1+\theta}{180}\right)^{-0.0454} \lambda^{-0.0975} \quad (4)$$

Table 1. Summarized results from an experimental study with various nanofluids

Researcher(s) Year	Nano Particles	Particle volume concentration	Flow Regimes	Finding(s)
Shankar et al. [13] 2023	Al_2O_3/ Water	0.1%, 0.3% and 0.5%	Turb.	1. Found that higher concentrations of nanofluid increased heat transfer. 2. The nanofluid performed much better than the regular fluid, with improvements of 27% to 78% depending on the concentration. 3. The nanofluids can enhance heat transfer due to increased thermal conductivity and particle movement. 4. Higher particle concentrations increased fluid viscosity, leading to more pressure drop.
Abdullah and Hussein [14] 2023	α-Al_2O_3/ Water	0.1%	Turb.	1. It was discovered that bigger pitch coils had higher heat transfer coefficients on the coil side than smaller pitch coils. 2. An exchanger's heat transfer coefficient increases using a nanofluid instead of water. Additionally, these factors rise as the nanofluid flow rate increases. 3. A helically coiled tube's internal friction rose as the flow rate dropped.
Algarni S. et al. [15] 2022	Al_2O_3/ Water	0.1%, 0.2%, and 0.3	Lam.	1. The average heat transmission increases by 13% and 17% when nanoparticle density is 0.1%, 0.2%, and 0.3%. 2. Increasing particle density, pipe diameter, and coil radius reduces mass flow and improves heat exchanger performance.
Maghrabie et al. [16] 2021	Al_2O_3/ Water SiO_2/ Water	0.1%, 0.2%, and 0.3	Lam. and Turb.	1. Switching the SHCT-HE orientation from horizontal to vertical increases the coil Nu Number by 11%, 8.3%, and 7.5% for 0.1 vol% water, Al_2O_3/water, and SiO_2/water nanofluids. 2. A vertically oriented, 0.1 vol% Al_2O_3/water nanofluid heat exchanger with a Re Number 6000 increases coil Nu Number and efficacy by 35.7% and 35.5% over base water.
Kulkarni et al. [17] 2021	$AgNo_3$/ Water	0.01% - 0.05%	Lam.	1. Green synthesis silver Nanoparticles increased heat transfer by 32% compared to basic fluid. 2. The thermal performance factor decreased as concentration increased, allowing 0.05% nanofluids.
Rai & Hegde [18] 2020	GO/Air	0.05–0.15%	Turb.	Hot air velocities of 3 m/s, 90°, and 45° Nanofluid fins improve Nu Number and heat transfer. Pressure drop and friction increased by 32.72 and 24.6% with 0.15% GO Nanofluid.
Lanjewar et al. [19] 2020	CuO–PANI/ Water	0.05 - 0.3%	Lam.	CuO–PANI nanocomposites increased heat transfer by 37%. Re Number and CuO nanoparticle loading (PANI) improve heat transfer coefficient (PANI).
Koshta et al. [20] 2020	rGO -TiO2/ Water	0.1–0.5	Turb.	The heat transfer coefficient was improved by 35.7% when 0.25 volume% nanoparticle was added to the base fluid.
Sunu et al. [21] 2020	Al_2O_3/ Water	0.1%	Lam.	Water-alumina is 2.2% more effective as a heat exchanger's cold fluid than pure water.
Ardekani et al. [22] 2019	Ag/Water SiO2/Water	0.01% and 0.05%	Turb.	Nanoparticles in coiled tubes have improved heat transfer rates than straight tubes.
Palanisamy & Kumar [23] 2019	MWCNT/ Water	0.1, 0.3, and 0.5%	Turb.	There was a 28%, 52%, and 68% increase in Nu Numbers for 0.1, 0.3, and 0.5% Nanofluids, respectively, compared to water.
Radkar et al. [24] 2019	Zno/ Water	0.5%	Lam.	0.5 vol% Nanofluids with ZnO nanoparticles increase thermal conductivity by 62.80% at 40 °C and 136% at 50 °C. Nu Number increased 18.6% in 0.25 vol% ZnO Nanofluids.
Daghigh and Zandi [25] 2018	MWCNT, CuO, and TiO_2/Water	0.1%	Lam.	Heat transmission in a coil was improved by 39%, 25%, and 53%, respectively, when using CuO, TiO_2, or MWCNT Nanofluids instead of water.
Naik & Vinod [26] 2018	Al_2O_3/ Water	0.1, 0.4, and 0.8%	Turb.	The overall coefficient of heat transmission, pressure drop, inner coefficient of heat transmission, and internal Nu number are 30%, 9%, 15%, and 56% greater than water at 0.8%.
Kabeel et al. [27] 2017	Al_2O_3/ Water	0% to 3%	Turb.	Lower mass flow rates are better for helical heat exchangers and solar collectors.
Fule et al. [28] 2017	CuO/ Water	0% and 0.5%	Turb.	At 0 and 0.5 vol% nanoparticles, the heat transfer coefficient was 37.3% higher than the base fluid; at 0.5 vol%, it was 77.7%.
Srinivas and Vinod [29] 2016	Al_2O_3, CuO, and TiO_2/Water	0.3, 0.6, 1, 1.5, and 2%	Turb.	Compared to water, Al_2O_3, CuO, and TiO_2/water nanofluids improve heat exchanger performance by 30.37, 32.7%, and 26.8%.
Tajik et al. [30] 2015	Al/Water Cu/Water	0.55 2.23	Lam.	1. Cu-water nanofluid has 18% higher thermal conductivity than Al-water at a 2.23 volume percentage. 2. There is a notable improvement in the convective heat transfer coefficient when using nanofluids. The Nusselt number also rises as the Gz Number is larger. 3. A new Nusselt number correlation is developed: $Nu= 2.117(1\text{-wt\%})^{-12.2}Gz_{nf}^{0.684}$
Sultan et al. [31] 2015	Cu, TiO2/ Water	15 – 35 wt %	Lam.	1. Results show that Nanofluids (Cu, TiO2 - Dw) can be used in place of distilled water to improve pressure drop and heat transfer coefficient and can improve heat transfer depending on the Nanofluid's size and composition.
Kahani et al. [32] 2013	Al_2O_3/ Water	0.25–1.0%	Turb.	1. The curvature of helical coils improves heat transmission and pressure loss more than straight ones. 2. Heat transmission improves as the coil pitch and curvature ratio increase.
Hashemi & Akhavan-Behabadi [33] 2012	CuO/Oil	0.5%, 1% and 2%	Lam.	1. The tube's curvature increases pressure drop. 2. Using a helical tube instead of a straight one increases the convective heat transfer coefficient more than nanofluids.

For forced convective heat transfer, Srinivas and Vinod [34] used a shell and helical coil heat exchanger with CuO/water nanoparticles. Experiments were run with 0.3, 0.6, 1, 1.5, and 2% weight of CuO nanoparticles in water. 2% CuO/water Nanofluid increased heat transfer. Nanofluids affect heat transfer more than stirrer speed or shell temperature. Air bubble injection on a horizontal helical shell and coiled tube heat exchanger was tested by Khorasani and Dadvand [35].

The NTU and efficacy of the heat exchanger rose 1.3-4.3 times owing to air bubble injection. Also, the exergy loss was 1.8-14.2 times the non-injected air bubbles condition value. Air bubble injection improved efficacy. Air bubble injection's greatest efficacy was 0.815 in the counter flow configuration with a shell side water flow rate of 5 l/min and a 5 l/min airflow. Kahani et al. [36] Compared Al2O3/water nanoparticles and TiO2/water nanoparticles flow through helical tubes at 0.25–1.0% volume concentration and 500–4500 Re numbers. Al2O3/water nanoparticles increased heat transfer owing to their better thermal conductivity and smaller size than TiO2 nanoparticles.

2.2. Numerical Study

Suresh [37] uses two inner tubes with helical and sinusoidal coils (Figure 6) to evaluate the thermal performance of this triple fluid heat exchanger. Helical coils utilize hot water, whereas sinusoidal coils use milk. Shell-side cooling water is utilized. The sinusoidal coil's heat transfer coefficient is 13% lower than the helical coil's for varied hot fluid flow rates. Helical coils pump more because their pressure loss overgrows.

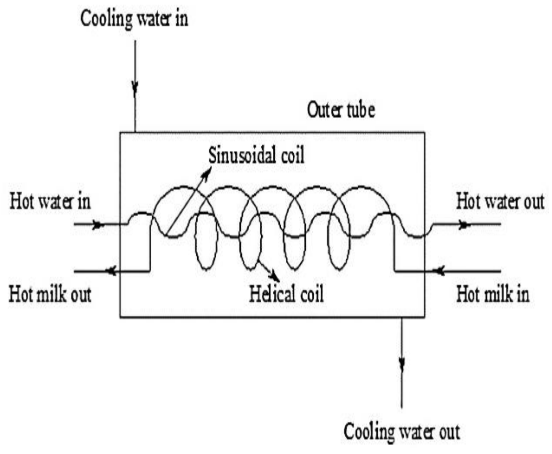

Figure 6. Triple-fluid heat exchanger schematic

Li et al. [38] simulated turbulent flow in spiral-corrugated helical tubes (Figure 7). Spiral corrugation improves heat transmission in smooth spiral tubes. Reduced spiral pitch improves tube heat transmission. The heat transmission of spiral-corrugated helical tubes increased by 50-80%, and the flow impedance increased by 50-300%.

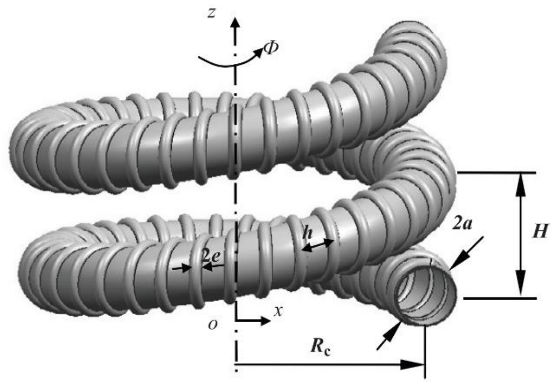

Figure 7. Spiral-corrugated helical tube

Abed and KOÇ [39] used the finite volume method to study the effects of twisted tape, as shown in (Figure 8), at Re numbers 3800 to 18000. Numbers and experiments agreed well. Heat transfer coefficient U increased from 965 to 1250 W/m2 with perforated twisted tape. Pressure drop is greatest with twisted tape. Perforated twisted tape increased from 0.35 to 0.85 as the Re Number increased.

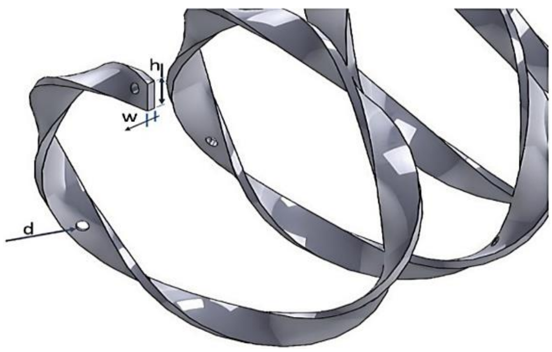

Figure 8. Perforated twisted tape

Heydari et al. [40] studied Shell and helically corrugated coiled tube heat exchangers using Taguchi's empirical method, as shown in (Figure 9). The fluid flow rate on the coil side affects thermal performance the most, followed by corrugation depth and pitch. At low Re numbers, the helically corrugated coiled tube is more efficient in the heat exchanger.

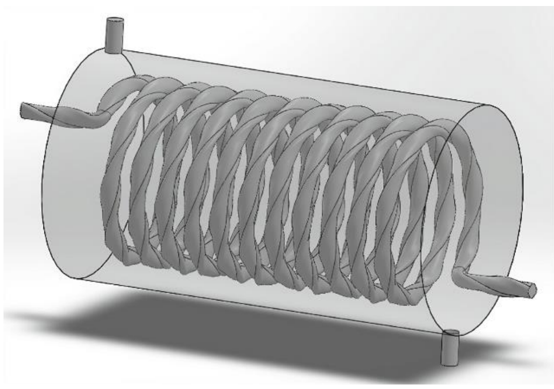

Figure 9. Display of shell and helically corrugated coiled tube heat exchanger

Miansari et al. [41] compared the thermal performance of a helical shell and tube heat exchanger, as shown in (Figure 10) The results showed that heat transfer is improved in simple and circular finned heat exchangers when the shell fluid velocity is greater than the tube fluid velocity. The circular finned heat exchanger had the most heat transfer. In conclusion, cutting circular fins in half does not affect the efficiency or heat transfer of a helical shell-and-tube heat exchanger.

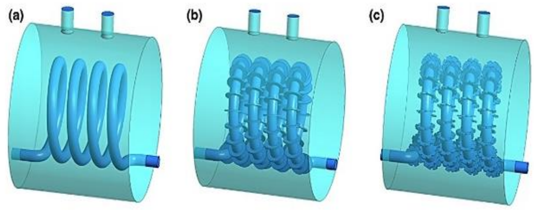

Figure 10. Display of the present study geometry in (a) simple, (b) circular finned, and (c) cut circular finned heat exchangers.

Hasan et al. [42] the effectiveness of a helix heat exchanger using varied head-ribbed shapes and coil turns was studied numerically using water-based nanoparticles (Figure 11). Nanoparticles consisting of Al2O3, CuO, SiO2, and ZnO at a concentration of 4% are the most effective in helix heat exchangers. When compared to SiO2, Al2O3 has a much higher heat transmission rate. A higher heat transfer rate was achieved by reducing the number of ribbed heads and increasing the coil's turn, as heat transfer was improved by up to 80% when a 2-rib head shape and 30 coil turn were used with 30 coil turns.

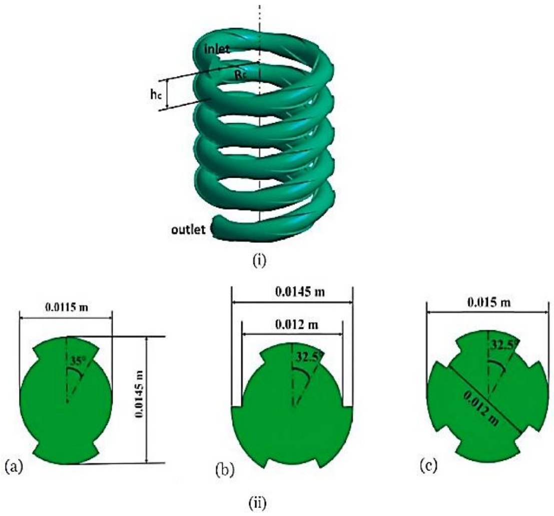

Figure 11. (i) A helix coil schematic (ii) Scheme of a head-ribbed coil

In a helical heat exchanger, Zaboli et al. [43] used analytical solutions to investigate the impact of turbulence on heat transmission and nanoparticle flow. The study showed that the Nu number and the pressure decreases are increased by 4.8% for high Re numbers when utilizing a five-lobed cross-section. The most efficient in terms of thermal efficiency are those with three lobes, where thermal efficiency decreases as nanoparticle concentration rises. Zaboli et al. [44] numerically evaluate heat transfer and fluid flow in a corrugate coil tube with different lobe-shaped cross-sections with twisted tape (Figure 12). The five-lobe cross-section increases Nusselt number and pressure drop by 9.1% and 3.7%, respectively, over the three-lobe. Adding spirally twisted tape to a five-lobe corrugated tube increases the Nusselt number and pressure drop by 30.7% and 37.1%, respectively. At a higher Reynolds number (Re = 35,000), the thermal efficiency of the three, four, and five-lobe models with center-cleared twisted tape is 16, 18.64, and 19.16%, respectively.

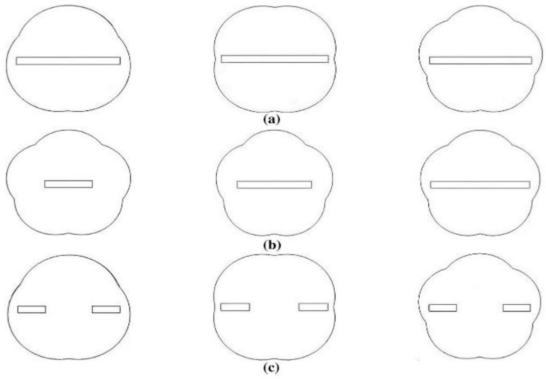

Figure 12. 2D schematic of the different studied geometries of the cross-section of coil tube equipped with different types of twisted tape

Omidi et al. [45] Used Al2O3 nanofluids in laminar flow to study lobed helical coils (Figure 13). Based on the data, the n=6 coil exhibits the most significant Nu number and the lowest friction. Nu number and friction rose with increasing coil diameter; moreover, the Nu number of Al2O3 nanofluid was higher than that of the base fluid and increased with increasing nanoparticle volume, where nanoparticles have zero effect on friction.

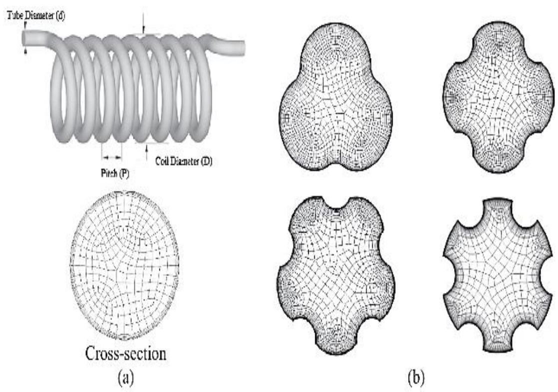

Figure 13. (a) Helical coil design and mesh generation. (b) Helical cross-sections with lobes

Wang et al. [46] studied the influence of fin geometry and shell inlet flow rate on Exergy loss (Figure 14).

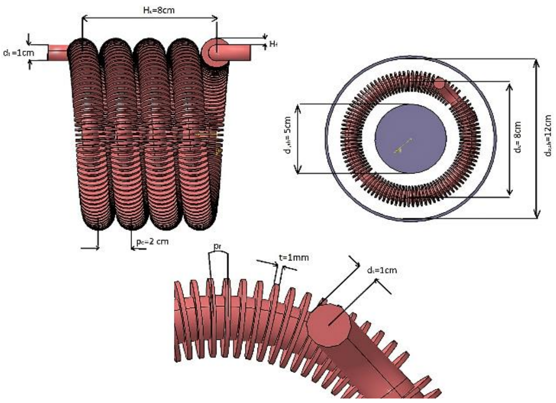

Figure 14. The heat exchanger's geometry

Exergy loss rises with the shell flow rate, fin height, number of Transfer Units (NTUs), heat transmission, and fan operation, which is always 23.4% of the heat transmission rate. Aly [47] Investigated the convective heat transmission and dropped in pressure of water/Al_2O_3Nanofluid flowing in helical heat exchangers at Nanofluid volume concentrations of 0.5%, 1.0%, and 2.0%. 0.18, 0.24, and 0.30 m coil diameters. With a constant pressure drop, increasing the curvature ratio raises the friction factor. Darzi et al. [48] Numerically studied turbulent heat transport in heated helically corrugated tubes using water-Al_2O_3nanofluids at 10,000–40,000 Reynolds numbers. Increasing nanoparticle volume fraction improves heat transmission. 2% and 4% nanoparticles by volume improve heat transmission by 21% and 58%.

2.3. Experimental and Numerical Study

Najm et al. [49] studied the effect of a double coil tube with a modified pitch (Figure 15) on heat transfer rate. This new design improved heat transfer by 22% at Re numbers $400<Resh<2000$. The new coil design (modified pitch) improved flow distribution and generated higher secondary flow than the traditional coil.

Ghaderi et al. [50] Studied numerically and experimentally Fe_3O_4 magnetic nanoparticles at three volume fractions (0.03%, 0.06%, and 0.1%) on helical heat exchanger efficiency. where 0.1% Fe_3O_4 improves water-EG heat transfer by 60%. Nu Number rises 22% with coil inlet temperature. As nanofluid flow increases heat transfer. Larpruenrudee et al. [51] used a semi-cylindrical coil heat exchanger (Figure 16) to improve heat transfer and the hydrogen absorption rate of Metal Hydride (MH) storage systems (SCHE). This study shows a semi-cylindrical coil heat exchanger improves MH storage performance (SCHE). Hydrogen absorption is 59% faster than a helical coil heat exchanger. Low coil pitch reduces SCHE's absorption by 61%.

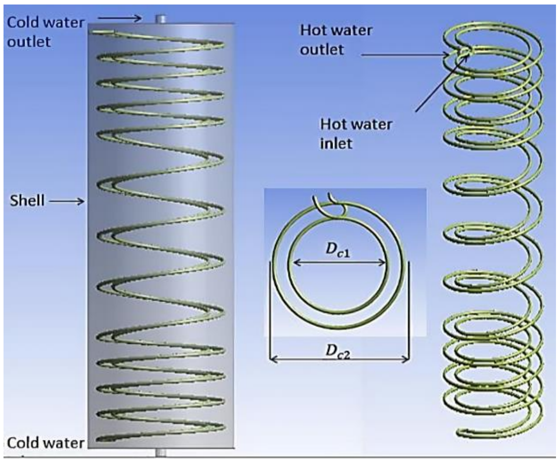

Figure 15. Schematic of shell and double coil tube

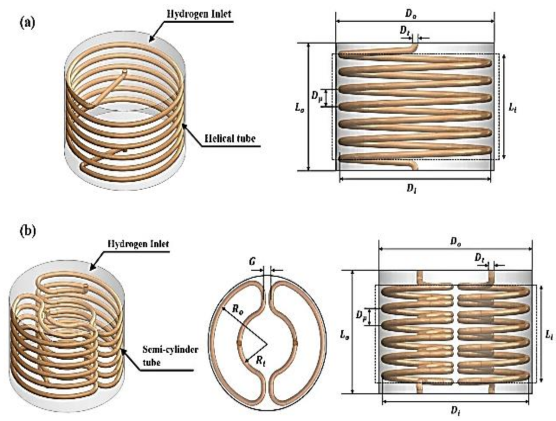

Figure 16. Characteristics of selected geometries for metal hydride reactors. (a) With a helical tube heat exchanger and (b) a semi-cylindrical tube heat exchanger

Mahdi et al. [52] Studied helical heat transfer and natural convection. Different coiled tube types' thermal performance (Figure 17) varied by 12%. Hexagonal, triangle and helically coiled tubes transfer heat best. Triangle coils are more efficient than helical coils. A hexagonal tube is better than a triangle.

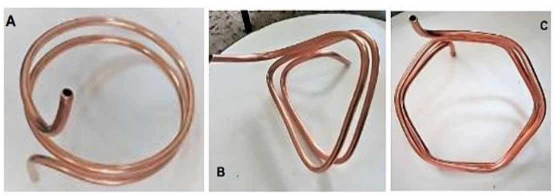

Figure 17. (A) Helical coil, (B) Triangular coil, and (C) Hexagonal coil

Sheeba et al. [53] studied convective heat transport in a helical heat exchanger. The helical heat exchanger pressure drop is higher than the straight tube when torsion and pitch vary. The Nu number correlation is:

$$Nu = 3.6063\ De^{0.2216}\ Pr^{0.0540}\ \psi^{0.0472} \quad (5)$$

Table 2. Summarized results from a numerical study with various nanofluid

Researcher(s) Year	Nano Particles	Particle volume concentration	Flow Regimes	Finding(s)
Boumari et al. [54] 2023	Al2O3/ Water	1% and 4%	Lam. And Turb.	1. An increase in the volume fraction of aluminum oxide nanofluid and the Reynolds number results in a 20.35% rise in the Nusselt number. 2. The Nusselt number rises by 18.75% when the continuous heat flow is raised from 4000-6000 W/m^2.
Prakash and Jha [55] 2020	MWCNT/ Water	0.05%, 0.1%, 0.3% and 0.5%	Turb.	1. The overall heat transfer coefficient of MWCNT/water nanofluids is 18%, 22%, 27%, and 32% higher than that of water at volume flow rates of 1-3 LPM. 2. The pressure drop due to MWCNT/water nanofluids may be more than 5%, 7%, 10%, and 13% higher than water.
Guo et al. [56] 2020	Al2O3/ Water	0.1%, 0.2%, and 0.3	Lam.	Under pulsation, the helical coil's heat transfer is improved by a counter-rotating vortex and secondary flow in the cross-region.
Ahmed and Syed [57] 2020	Al2O3/ Water	0.01% - 0.05%	Lam.	The pipe wall temperature was reduced at low Reynolds Numbers using Al2O3 rather than regular water.
Zaboli et al. [58] 2019	Al2O3, CuO, SiO2/ Water	2, 3, 4, and 5%	Lam. & Turb.	1. The exit temperature differential increases by less than 1% and 8% when the helix diameter is increased by 11% from 0.016 to 0.022. 2. Water/CuO has the highest Re among water-based nanofluids. 3. Heat transfer is unaffected by nanofluid concentration. 4. The coefficient is lowest for 2% and 4% nanofluids.
Mukesh Kumar and Chandrasekar [59] 2019	MWCNT/ Water	0.2%, 0.4%, and 0.6%	Lam.	1. Higher MWCNT/water nanofluid concentrations improve heat transfer and pressure drop. 2. 0.6% MWCNT/water nanofluids have a 30% higher Nu Number at a De Number of 1400 and an 11% higher Pressure drop.
Bahrehmand & Abbassi [60] 2016	Al2O3/ Water	0.2% and 0.3%	Lam.	0.2% and 0.3% nanoparticles boost heat transfer by 14% and 18%. Heat transfer efficiency in nanofluids increases with increasing nanoparticle volume concentration and is greater than that of water at a constant mass flow rate.
Sisodiya & Geete [61] 2016	Al2O3/ Water	1, 2, 3, 4, and 5%	Lam.	The results showed that due to the high specific heat of Al2O3, the coefficient of heat transfer increased significantly when fluid ran inside a helically coiled tube rather than a straight one.
Fsadni et al. [62] 2017	Al2O3/ Water	1–4%	Turb.	Nanoparticle concentration and curvature improve heat transfer and frictional pressure drop.
Ranjbar & Seyyedvalilu [63] 2014	Water/ Water	-	Lam. & Turb.	Reduced coil pitch and increased inner Dean number, inner tube diameter, and curvature ratio were shown to enhance heat transmission.
Khairul M. A. et al. [64] 2013	CuO, Al2O3, ZnO/ Water	1–4%	Turb.	1. Heat transfer enhancement and entropy production rate reduction for CuO/water nanofluid were 7.14% and 6.14%, respectively. 2. Increasing nanoparticle volume concentration and volume flow rate improved heat transfer and decreased entropy generation.

Mola et al. [65] Used $CuFe_3O_4$/water Nanofluids. Two helical coil heat exchangers were used for testing (Figure 18). The results show that the nanofluid numeric value increased by 15-22% for nanoparticle volume concentrations (0.02, 0.05, and 0.1%) for type A and by 14-17% and 20% for Volume concentrations of ferrofluid (0.02, 0.05, and 0.1%) for type B, respectively, of 0.01% and 0.05%.

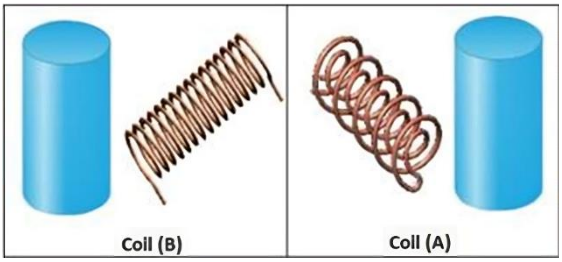

Figure 18. Schematic diagram of Heat Exchangers

Rakhsha et al. [66] Examined the impact of temperature profile on turbulent forced convection in helical tubes in various tube geometries and Re numbers. Experimental results suggest a 16-17% increase in heat transmission and a 14-16% rise in pressure drop, while numerical calculations show a 6-7% increase in heat transmission and CuO nanoparticles' pressure drop over distilled water. Akbaridoust et al. [67] Used 0.1% and 0.2% CuO Nanofluids to study drop in pressure and heat transmission in helical tubes. Heat transmission rates and pressure drop were more efficient with higher particle volume concentration nanoparticles. The curvature and torsion ratios were kept constant with a small coil pitch. In the spectrum of curvature ratios tested, high-curvature coils performed better. Heat transmission was best in a helical tube, not a straight one.

Amori and Sherza [68] studied a novel heat exchanger unit developed for a solar water heater under outdoor conditions at (1.8, 3, 6, and 9 l/min). The outer coil transitions from laminar to turbulent flow faster than the middle coil at 6 l/min. All coils become turbulent at 9 l/min, and with more solar radiation, pressure drops. Increased circulation flow reduces friction. Naphon and Suwagrai [69] tested horizontal spirally coiled tubes with curvature ratios of 0.02, 0.04, and 0.05 at constant wall temperature. Because of centrifugal force, the spirally coiled tube's Nu number and pressure drop are 1.49 and 1.50 times higher than the straight tube.

3. Nanofluid Challenges

Several obstacles need to be overcome before studying nanofluids. There is a discrepancy between experimental evidence and theoretical predictions; little is known about nanofluid anomalies. Nanofluids are not suspensions and require stability to prevent particle clumping. This can be achieved by mixing fluids with stable chemical properties. The practical applications of nanofluids depend on their stability, which is impacted by the shape of suspended nanoparticles and the chemical structure of the base fluid. While TEM and SEM can observe nanoparticles in nanofluids, Dynamic Light Scattering (DLS) is necessary to quantify particle size. Nanofluids have higher synthesis costs, thermal conductivity, viscosity, specific heat, and pressure drop than basic fluids, so cost-effective synthesis methods must be developed. However, the benefits of nanofluids include improved energy efficiency, performance, and cost-effectiveness, making them promising for various engineering applications such as HVAC and refrigeration systems. Nevertheless, the challenges of manufacturing costs, instability, aggregation, and erosion must be addressed to commercialize nanofluids for use in solar thermal systems.

In summary, using nanoparticles and helical coils can improve heat transfer, but it has some drawbacks, like higher pressure and costs. Depending on the situation, the benefits may outweigh the downsides, making it a good solution. However, careful evaluation and cost analysis are vital to ensure the heat transfer system works optimally. An essential aspect of a nanofluid-based helical coil heat exchanger is its pressure drop. So, the authors must carefully evaluate the trade-off between improved heat transfer and the potential increase in pressure drop to ensure optimal system performance and cost-effectiveness.

Conclusions

Nanofluids (NFs) were the focus of this review, which looked at how they performed in helical heat exchangers (HEXs) of varying geometries. High-efficiency heat exchangers can benefit from several techniques for enhancing their thermal performance, including Nanofluids and helical coils. By combining these methods, it may be possible to boost the energy efficiency of various pieces of machinery dramatically. In which the researchers found, through their empirical and numerical results, that:

- The overall coefficient of heat transfer, Nu number, effectiveness, and Exergy efficacy are all greater for nanofluids than for distilled water. These values keep rising as the particle volume concentration increases.
- The small size of the Nanoparticles enhances the heat transfer rate. However, they lack stability.
- Nanofluids with a more significant particle volume percent showed better heat transfer coefficients and pressure decreases than those with a lower particle volume fraction.

- Compared to a straight tube, the helically coiled tube considerably increases both Nanofluids' coefficient of heat transfer and pressure drop.
- The investigations show that the curvature ratio affects the heat transmission rate less than the aspect ratio of the coil's pitch.
- A coil's pressure drop (ΔPc) and SHCT-HE effectiveness (ε) increase with a decreasing inclination angle, whereas the Nu Number increases with a rising inclination angle.
- The pressure drop in a helically coiled heat exchanger is more significant than that of a straight pipe when the curvature and pitch are both changed.
- The heat exchanger's efficiency and the heat transfer coefficient were increased by injecting air bubbles.
- Based on the evaluated factors, it was concluded that combining nanoparticles and corrugation might increase heat transfer efficiency.

Nomenclature

Al_2O_3	Alumina
Ag	Silver
$CuFe_3O_4$	Copper iron oxide
SiO_2	Silicon dioxide
EG	ethylene glycol
ZnO	Zinc oxide
GO	Graphene Oxide
CuO	Cupric Oxide
PANI	Polyaniline
TiO_2	Titanium dioxide
Fe_3O_4	Iron (III) oxide
CNT	Carbon nanotubes
Pr	Prandtl number
Nu	Nusselt Number
Re	Reynolds number
Gz	Graetz number
SDS	Sodium Dodecyl Sulfate
Dw	Distilled water
wt%	Weight percent
vol%	Volume percent
MWCNTs	Multi-walled carbon nanotubes
COP	Coefficient of performance
U	Overall heat transfer coefficient [W/m^2K]
LPM	Liter per minute
SHCT-HE	Shell and helically coiled tube heat exchanger

Conflicts of Interest

No competing interests exist in the publishing of this work, we confirm. All ethical considerations have been strictly adhered to, such as plagiarism, lack of informed consent, misconduct, data fabrication/falsification, duplicate publication/submission, and redundancy.

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