Diyala Journal of Engineering Sciences

Journal homepage: https://djes.info/index.php/djes

ISSN: 1999-8716 (Print); 2616-6909 (Online)

Effect of Using A Double Coil Tube with Modified Pitch on The Overall Heat Transfer Rate

Ali Najm [1], Itimad D.J. Azzawi [1,*] and Abdul Mun'em A. Karim [2]

[1]Department of Mechanical Engineering, University of Diyala, 32001 Diyala, Iraq
[2]Department of Chemical Engineering, University of Diyala, 32001 Diyala, Iraq

ARTICLE INFO

Article history:
Received January 1, 2022
Accepted January 27, 2022

Keywords:
Double coil heat exchanger
CFD
Coil pitch
Dean vortices
Reynolds number
Overall heat transfer coefficient
Pitch

ABSTRACT

The goal of this work was to design a simple and cost-effective technique for improving the performance of heat exchangers, and the emphasis was on the experimental side while not neglecting the necessity of validating our findings with theoretical results using CFD. A new method was used to enhance the heat transfer inside the heat exchanger by using a coil with modified steps, as the published papers did not previously address this method, which proved its effectiveness. For varied coil pitches, the numerical findings were in good agreement with the experimentally obtained results, with an error rate of less than 8%. To compare results and confirm effective correlation between pitch changes, a double coil tube is manufactured with a fixed pitch and a double coil tube with modified pitches, while maintaining the basic design parameters of tube diameter (d_c), shell diameter (D_{sh}), height of shell (H_{sh}), and coil height (H_c) in order to try to increase the overall heat transfer coefficient and heat transfer. This new design enhanced heat transfer and total heat transfer coefficient at Reynolds number ($400<Re_{sh}<2000$), with a 22% improvement in overall heat transfer coefficient. The new design of the coil (modified pitch) also gave an improvement in the flow distribution, which generated a higher secondary flow than the traditional pitch coil.

1. Introduction and Background

The most acceptable definition and formulas for heat transfer in recent published papers and books is the definition that states that " heat transfer is the science that seeks to predict the energy transfer that may occur between physical bodies as a result of the temperature difference" [1]. Because of their huge heat transfer surfaces and capacity to promote good liquid mixing, which enhances heat transfer coefficients, helical coiled tubes are widely used [2]. Because of their high heat transfer coefficient and small size when compared to straight tubes, helical coil tube heat exchangers have been widely investigated as one of the passive heat transfer improvements [3-4]. A numerical investigation of the influence of laminar flows on coil friction factor and wall shear stress was given by Anwar et al [5]. The maximum pressure was observed to drop from 71 Pa for a 0.01 m pitch coil to 68.8 Pa for a 0.05 m pitch coil. According to Etghani et al [6], the tube diameter and cold flow rate are the most essential design parameters for heat transmission and energy loss via the heat exchanger, respectively.

Ahmadloo et al [7] conducted a computational fluid dynamics investigation of isothermal single-phase laminar water flow in a hollow helical tube with various Reynolds values. During the study, it was discovered that centrifugal forces formed a high velocity zone on the outer side of the hollow helical tubes' walls, where the friction factor fell with a

[*] Corresponding author.
E-mail address: itimaddawood_eng@uodiyala.edu.iq
DOI: 10.24237/djes.2022.15104

propensity to enhance turbulence. Also, when the number of turns through a double-tube helical heat exchanger is altered, the findings revealed that as the number of rotations increases, the rate of heat transmission increases [8]. Fouda et al [9] analyze the heat transfer properties and performance of a multitube in tube helically coiled heat exchanger statistically and it has been found that with increasing Reynolds numbers of hot and cold water, the total heat transfer coefficient (Uo) increased by 23% and 28%, respectively. Huttl et al [10] investigated the influence of curvature and torsion on fully developed turbulent flow in straight, curved, and helically coiled pipes. The results revealed that pipe curvature, which creates a secondary flow, has a significant impact on flow amounts, whereas the torsion effect is smaller. Kushwaha et al [11] examined the heat transfer and fluid flow properties of Newtonian and non-Newtonian fluids in helical coil heat exchangers computationally. The results demonstrated that in helical coil heat exchanger with baffles in the annulus, f and Nu are greater than in a helix coil heat exchanger without baffles. Furthermore, the baffles have a substantial impact on heat transport at low Prandtl numbers.

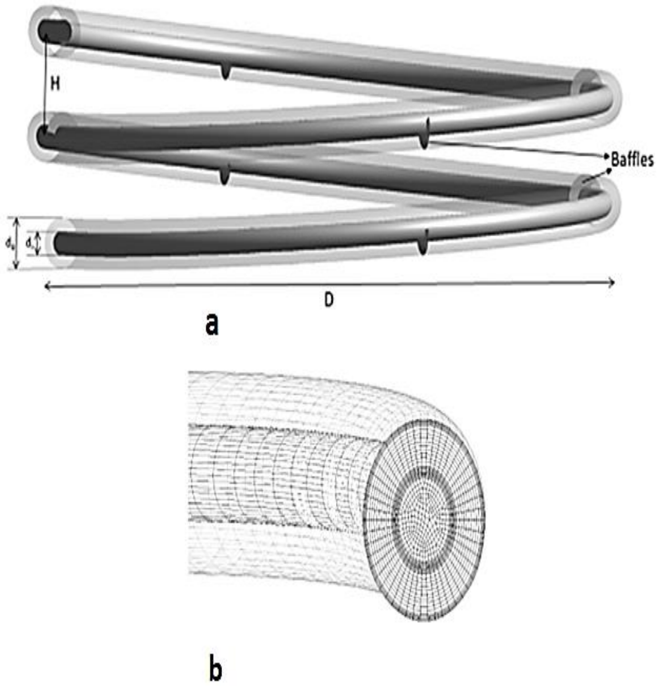

Figure 1. a) Tube in tube helical coil heat exchanger, and b) Grid topology [11]

Kurnia et al [12] found that adding twisted tape insert in helical heat exchanger can enhance heat transfer performance by up to four times as compared to traditional straight tube heat exchanger. The results of other practical experiments also indicated the possibility of increasing the heat transfer through the heat exchanger by inserting baffle in the heat exchanger shell-type coil [13]. Shokouhmand et al. [14] conducted experiments on shell and coiled tube heat exchangers by changing the coil pitches and curvature ratios. Experiments were carried out for heat exchangers with three different coil pitches. The results showed that the shell-side heat transfer coefficients of the coils with smaller pitches are less than the ones with larger pitches. Kongkaitpaiboon et al. [15] carried out the experiments for a round tube fitted with circular ring turbulators at various diameters ratio, pitch ratio and varied range of Reynolds number for constant heat flux condition with air as working fluid. The results reported that the smallest pitch ratio and diameter ratios exhibit the highest heat transfer rate. Kareem [16] conducted a numerical study to compare four shapes of double helical coil (circular, triangle, square, and rectangle). It was found that the rectangular shape has the best heat transfer properties. At the same time, the rectangular shape has a higher pressure drop than the other shapes. It was also found that the increase in taper angle of the double helical coil increases the heat transfer rate significantly and the pressure drop also increases.

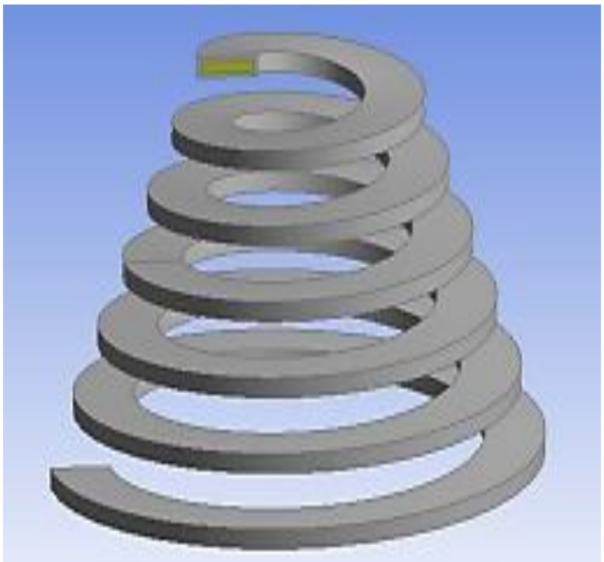

Figure 2. Optimized shape of double coil in terms of shape and taper angle [16]

Al-damook, and Azzawi [17] performed numerical simulations of six geometric shapes (circular, square, diamond, triangular, rectangular, and elliptical) to study heat transfer by natural convection in a concentric annular horizontal pipe. The results indicated that the heat transfer rate of elliptical tubes increased by 40% compared to the other shapes, and the heat transfer rate of circular tubes increased by 37% compared to the other shapes. The same researchers conducted research to address the ability of radial porous heat sink solutions to enhance thermo hydraulic properties and reduce the effect of the second law of thermodynamics. It is observed that in terms of flow direction, the optimal radial porous heat sink for the 100% PM model is recognized as providing the best results and the best choice (fully saturated porous media) [18].

Faraj et al [19] found during numerical simulation that the dean number has a stronger effect in reducing the coil friction factor compared to the increase in pitch dimension during turbulent flows. Another research by the same researchers was conducted to study the effect of changing the pitch size on laminar flows numerically. The results indicated that the model (P = 0.01m) gave good results and has a similar behavior to the annular tube in its conduction compared to the model (P = 0.05m) [20].

Kh. Ali et al [21] conducted a numerical study to determine the effect of a double coil on improving heat transfer. The results showed that by 18.2%, the Nusselt number for the casing side of the double tube was higher than that of the single tube. Kowalski et al [22] experimentally studied the effect of Reynolds number and operating temperature on heat transfer coefficients and pressure drop at laminar flow. The results showed that the heat transfer performance of the spiral tube at the same dimensions is higher than that of the straight tube.

Nikheel Joshi [23] has theoretically attempted to improve thermal conductivity by adding nanoparticles in a double-tube heat exchanger. The results showed that the nanofluid with a concentration of 2% has a heat transfer coefficient more than that of 0.5%, 1%. Safari et al [24] experimentally found that the use of water-titanium oxide nano fluid in the spiral tube with greater curvature increases heat transfer more effectively compared to the use of pure water. Sivalakshmi et al [25] conducted an experimental study on the effect of helical fins on the performance of double tube heat exchanger. Found at a high flow rate, the introduction of the fins increases the heat transfer coefficient by 38.46% and the efficiency of the heat exchanger by 35%.

According to previous studies, most of the researchers conducted their experiments using a single-shell and single-helical coil heat exchanger to enhance the heat transfer rate and thermal efficiency at different operating parameters.

The overall heat transfer coefficient, which is one of the most important parameters to know the improvement of the new design, is improved by increasing the contact area of the coil surface using double coil heat exchanger instead of single coil. As a result, the total heat transfer coefficient of two double coils, one with a constant pitch and the other with a changing pitch, was compared. Furthermore, numerous papers focused on modifying the coil diameter, adding nanofluids, or employing fins to improve heat transfer in heat exchangers, but no more than one pitch will be employed in the same coil. By determining the overall heat transfer coefficient, the modified pitch technique will be compared to the conventional pitch in this study. Figure 3 shows the major structures of the present study.

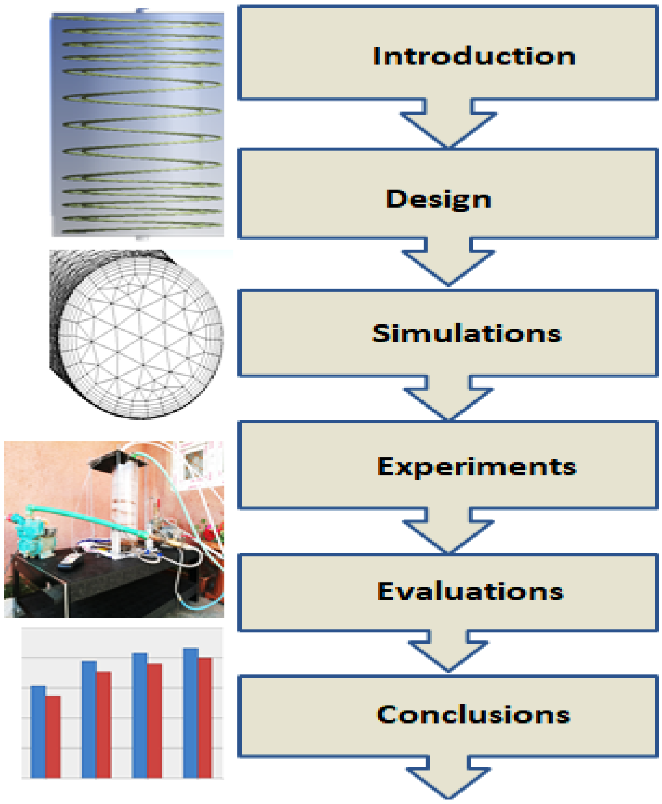

Figure 3. Diagram showing the work carried out during this paper

2. Numerical methodology

2.1 Problem description and boundary conditions

Three-dimensional models are created using SolidWorks as shown in Figure 4, these models were transferred to ANSYS R16.1 to evaluate the flow and heat transfer efficiency. Various boundary conditions were simulated for the shell and coil regions at various mass flow rate ((1L/min for hot water), (2, 4, 6, and 8 L/min for cold water)) and constant temperatures of 36°C to cold water and 65°C to hot water.

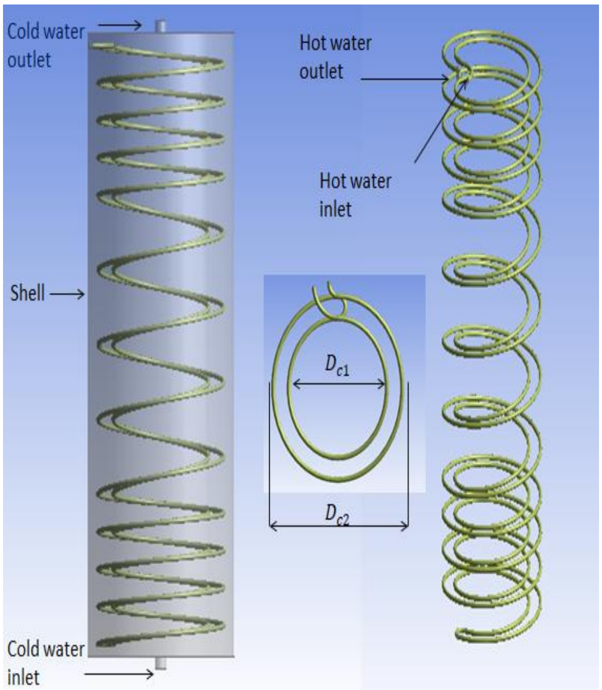

Figure 4. Schematic of shell and double coil tube (baseline case)

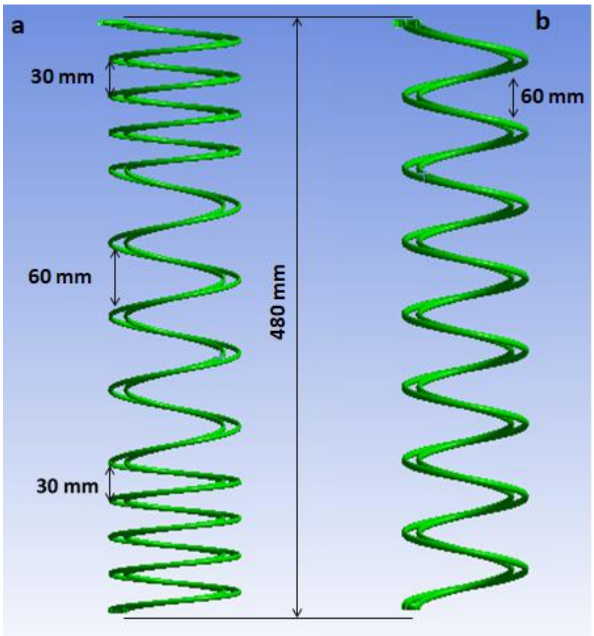

Figure 5. The design of double coil heat exchanger a) modified pitch, b) conventional pitch

The new design of the coil shown in Figure 5a is proposed to try to improve the performance of the heat exchanger under the same conditions of mass flow quantity of water on both sides of the shell and coil and also under the same coil height and main and secondary diameter of the double coil. This optimization attempt, which has proven to be effective, can be applied to single coils, and the performance of the heat exchanger can be improved by changing only pitch.

2.2 Mathematical formulation and assumptions

The governing equations were the continuity, momentum, and energy equations, and the turbulent RNG k-model was utilized to simulate the turbulent flow during the present study. These equations are mentioned in detail [26].

To determine the effect of heat transfer through the shell and coil, the following relationships were used for numerical and experimental analysis:

$$Q_{sh} = m_{sh}.c_{p_{sh}.}\left(T_{co,o} - T_{co,i}\right) \tag{1}$$

$$Q_c = m_c.c_{p_c.}(T_{h,i} - T_{h,o}) \tag{2}$$

To calculate the effect of overall heat transfer coefficient through heat exchanger, the following relationship was used:

$$U_o = \frac{Q_{avg}}{A_o.\Delta T_{LMTD}} \tag{3}$$

where $Q_{avg} = \frac{Q_{sh}+Q_c}{2}$ (4)

The average binary conversion value Q_{avg} was used because the deviation between the heat transfer rate of the shell and the coil side is not more than 2.37%.

A_o Represent the outer surface area of the coil while the logarithmic mean temperature difference can be calculated by the following relationship:

$$\Delta T_{LMTD} = \frac{\Delta T_{in} - \Delta T_{out}}{ln\frac{\Delta T_{in}}{\Delta T_{out}}} \tag{5}$$

The boundary conditions were set as seen in Table 1. The inlet boundary condition was set as the mass flow rate for both cold and hot water, the outlet boundary condition was select as pressure outlet with zero back flow pressure. Semi Implicit Method for Pressure Related Equations was utilized to solve coupling between pressure and velocity fields. For discretization pressure, momentum, energy and RNG k-ε turbulence equations, the first order upwind system was used.

Table 1: Boundary conditions during numerical validation

Parameters	Shell side	Coil side
Working fluid	water	water
Material	Acrylic	Copper
Inlet temperature	36 ℃	65 ℃
Inlet mass flow rate	2-8 L/min	1 L/min
Outlet	Pressure	Pressure
Wall	No slip, No heat flux	Coupled

2.3 Grid structure study

During the present investigation, five different numbers of Quadrilateral Dominant cells were produced (see Figure 6). The mesh size for the study is determined by which mesh has the best capacity to capture the majority of the flow characteristics. In grid numbers G4 and G5 of Figure 7, the tiniest difference in the temperature of the departing water is detected. As a result, the G4 grid was employed in the study since increasing the mesh size had no discernible influence on the monitoring data.

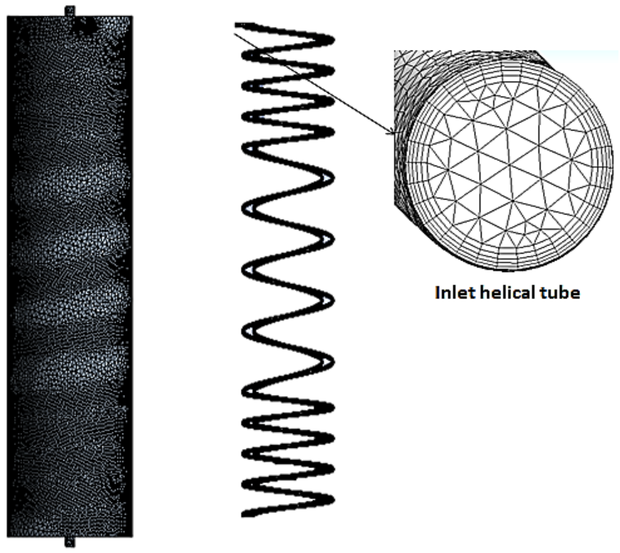

Figure 6. Generated mesh for shell and, double coil heat exchanger

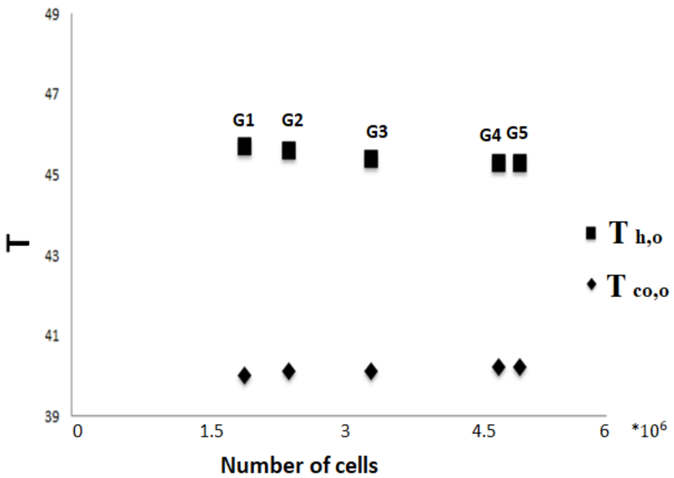

Figure 7. Number of cells versus Temperature

Table 2: The study of mesh independency

Grids	Total mesh	$T_{co,o}$	$T_{h,o}$
G1	1934762	40	45.7
G2	2434640	40.1	45.6
G3	3357188	40.1	45.4
G4	4789894	40.2	45.3
G5	5023730	40.2	45.3

3. Experimental setup

3.1 Model setup and materials

Figure 8 (a, and b) displays an image and a schematic design of the experimental setup used in the present study. The present study employed two distinct types of heat exchangers: double coils with variable pitch and double coil with fixed pitch. The present helical coil was made of copper tube and was inserted in an acrylic sleeve with a diameter of 175 mm that was placed vertically during experiments. Experimental system consisted of shell and coil, with four K thermocouples (uncertainty of ±1.5 °C) linked to a manual data logger of HT-9815 type, pump, ball valves, and two flow meters of LZM (uncertainty of 0.25 L / min) used to calculate volumetric flow rates for both hot and cold water. The four thermocouples were distributed at the inlet, outlet of hot water and inlet and outlet of cold water to determine the hot water inlet and outlet ($T_{h,i}$, $T_{h,o}$) as well as the cold-water inlet and outlet ($T_{co,i}$, $T_{co,o}$).

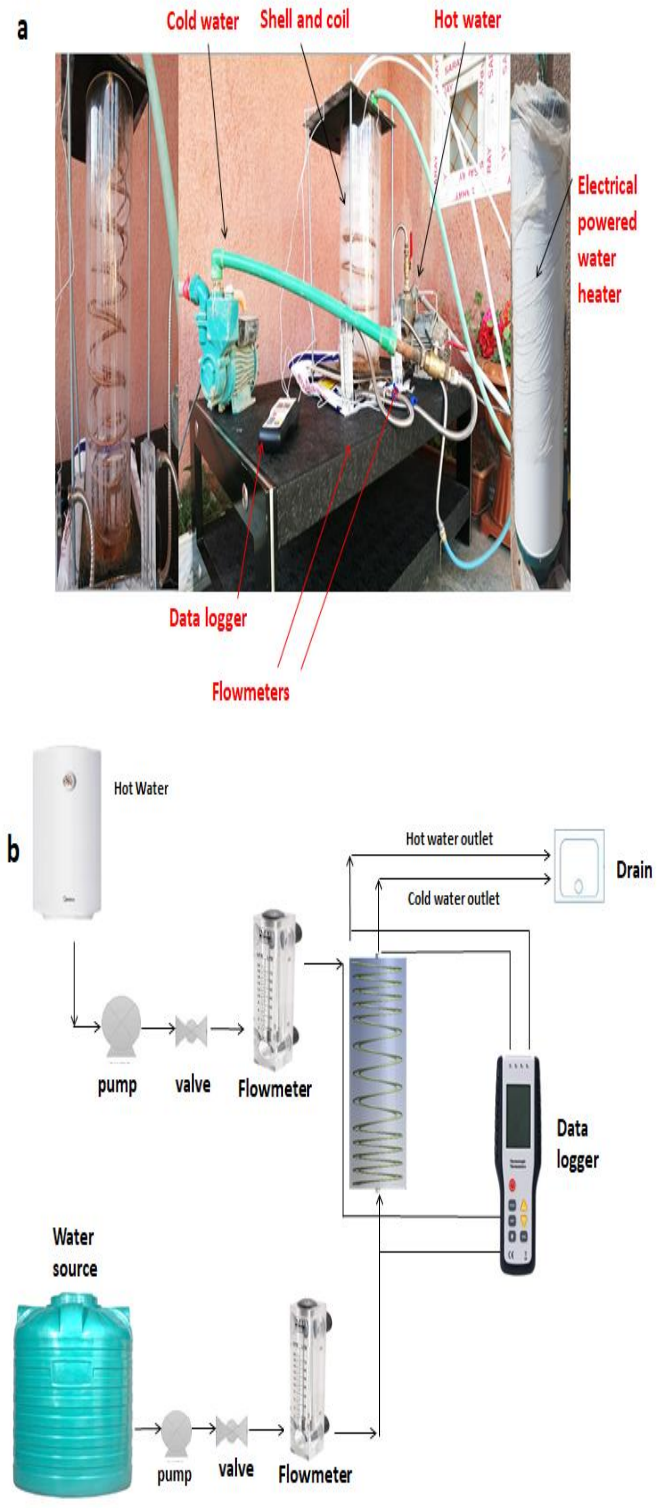

Figure 8. a) Image setup experimental work of double coil, b) Schematic for experimental setup

4. Results and discussion

This section explains the experimental and computational results of studying helical coil heat exchangers in detail.

4.1 Numerical study results

The Numerical model created in ANSYS Fluent was validated by comparing the Numerical findings for hot water output temperature with experimental data for two different models. The numerical and experimental findings for the hot water outlet temperatures are in good agreement, as shown in Figures 9 and 10, with an error of 1.30 % for double coil with conventional pitch and 2.83 % for double coil with modified pitch.

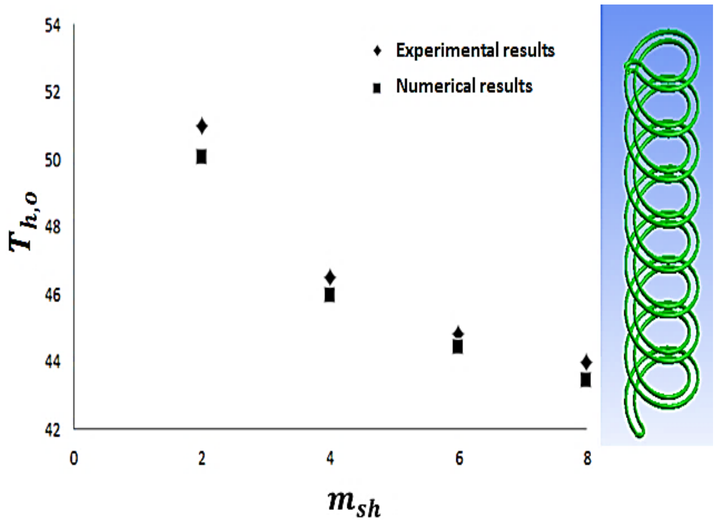

Figure 9. Validation study for a double coil (conventional pitch) inside the shell

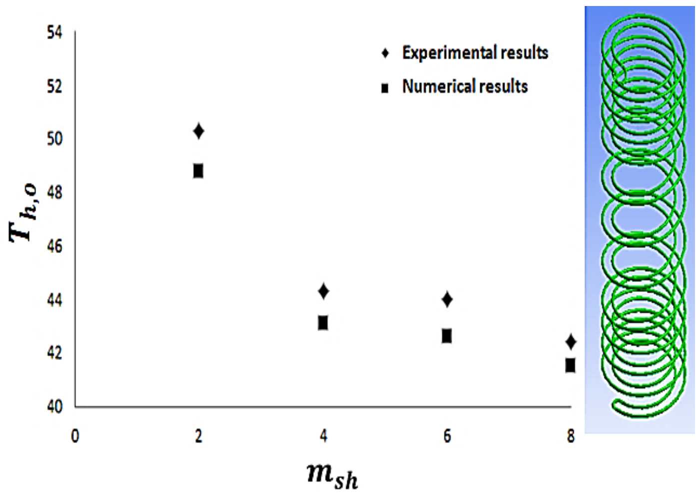

Figure 10. Validation study for a double coil (modified pitch) inside the shell

Figure 11 shows the temperature distribution in the shell side of a double coil heat exchanger (conventional pitch) and a double coil heat exchanger with a modified pitch. Figure 11 depicts how cold water enters and exits the heat exchanger. Cold water in the modified heat exchanger acquired more energy than cold water in the conventional heat exchanger. The major reason for getting more energy from cold water in a modified heat exchanger is increased secondary flow (Dean vortices) in the coil side due to increased coil curvature diameter and flow distribution adjustment.

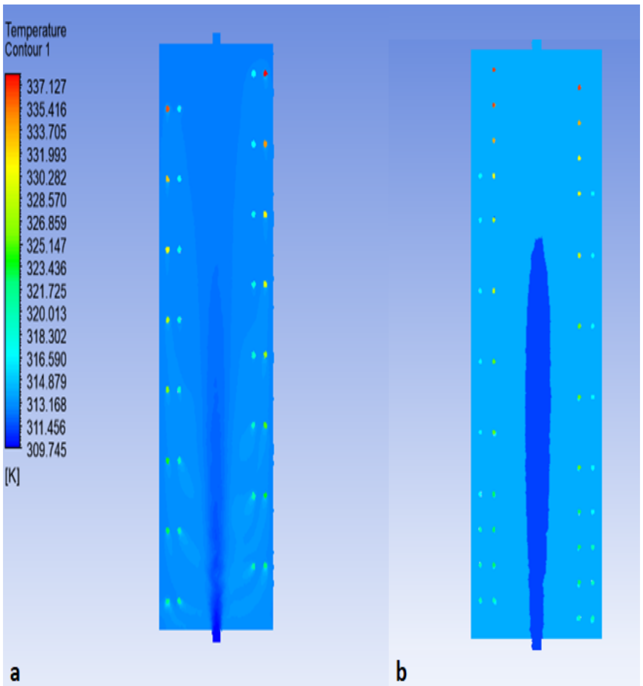

Figure 11. Temperature distribution in shell side from side view; a) Conventional pitch, b) Modified pitch

Velocity distribution in the shell side of shell and helically coiled heat exchanger from the side view is demonstrated in Figure 12. Figure 12 a depicts the velocity distribution in the shell side of the shell and helically coiled heat exchanger for cold water at a mass flow rate of 2 l/min, while Figure 12b depicts the velocity distribution in the shell side of the shell and helically coiled heat exchanger for cold water at a mass flow rate of 8 l/min. It is clear from the figure that the distribution of water flow on the side of the shell did not vary between the two cases, but the increase in the mass flow rate of cold water modified the water flow pattern and increased the heat exchange rate, implying an increase in the heat exchanger's thermal efficiency.

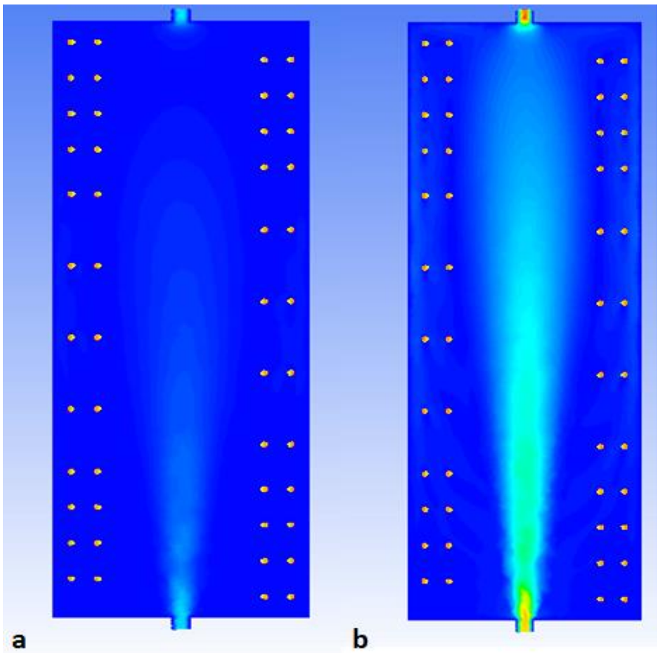

Figure 12. Velocity distribution in shell side from side view at a) m_{sh} = 2 l/min. b) m_{sh} = 8 l/min

4.2 Experimental study results

The overall heat transfer coefficient is one of the most important main parameters through which to compare the amount of improvement between heat exchangers of different designs. The overall heat transfer coefficient has been discussed in previous publications as one of the critical parameters to determine the amount of improvement in the heat transfer process of the heat exchanger [27-34]. Figure 13 presents a comparison of the overall heat transfer coefficient of a conventional pitch double coil tube with a modified pitch. These results at a mass flow rate of 1 L/min for the tube side and a Reynolds number of Re= 11100. From the figure, we notice that the overall heat transfer coefficient increases with the increase in the mass flow rate of the cold water for shell side. We also note that the use of modified pitch P-2P-P of the double coil has increased the overall heat transfer coefficient in the heat exchanger by 22% compared to the conventional heat exchanger, which indicates that the simulation results support the effective design of the modified helical tube. By using more than one step of the double coil the secondary flow rate through the heat exchanger is increased which means a higher heat transfer rate.

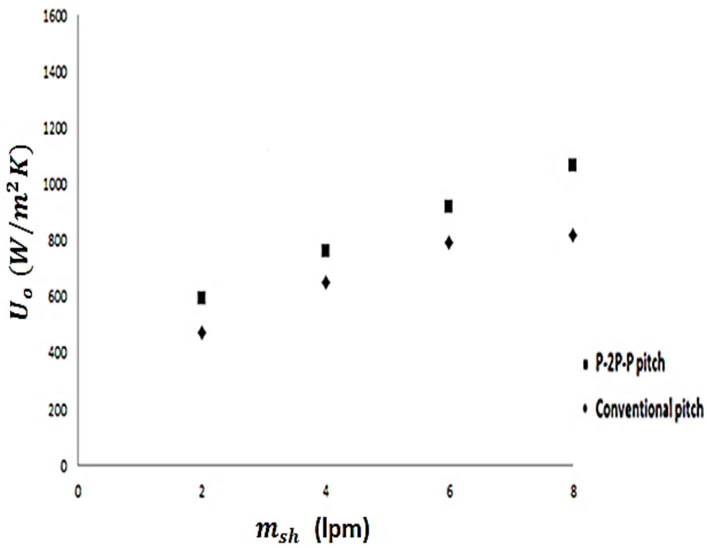

Figure 13. Overall heat transfer of two double helical coil models

The overall heat transfer coefficient in double helical coil heat exchanger with more than one pitch (P-2P-P) was estimated during this research of 400-1200 W/m^2k indicating that a good agreement between the present findings and previous papers [27-34] which are illustrated through the Table 3.

Table 3: A general comparison between this work and similar studies in the literature

Ref	$\dot{m}$	U ($\mathrm{W/m^2k}$)
Jamshidi [27]	1-4 l/min	625-1500
Bahrehmand [28]	6.78- 18 l/min	1000-1550
Salem [29]	1.7-11.158 l/min	100-1600
Mirgolbabaei [30]	1.8- 7.8 l/min	100-500
Salem [31]	1.7-11.158 l/min	100-2500
Tuncer [32]	1.5-3.5 l/min	1600-3150
Kumar [33]	1800-2500 l/hours	500-1000
Moosavi [34]	1-5 l/m	400-2200
Present study	1-8 l/m	400-1200

5. Conclusions

The influence of operational parameters (hot and cold flow rate) on the overall heat transfer coefficient is investigated experimentally and numerically in the present study for a shell and double coil (fixed and modified pitch) heat exchanger. The experimental and numerical findings illustrated that the temperatures of outlet cold water and outlet hot water were in good agreement. The use of modified pitch across the double coil has a substantial influence on the secondary flow through the coil, resulting in an increase in the heat transfer rate and overall heat transfer coefficient. Finally, the pitch correlation and investigate the improvements in the evaluation of double coil and shell heat exchangers cab be studied in the future research.

Nomenclature

A Area, m^2
c_p Specific heat, J/ (kg. K)
D_c Curvature diameter, m
De Dean Number
D_h Hydraulic diameter, m
f friction factor
H Height, m
h heat transfer coefficient, W/m^2
k thermal conductivity, W/(m ◦C)
L Length, m
$\dot{m}$ mass flow rate, kg/s
N number of turns
Nu Nusselt number
P coil pitch, m
Pr Prandtl number
Re Reynolds number
T water temperature, ℃
t thickness, m
U overall heat transfer coefficient, W/(m^2 K)
V Velocity, (m/s)

Greek letters

γ dimensionless pitch ratio
ρ density, kg/m^3
μ dynamic viscosity, kg/(m s)
ε effectiveness
$\Delta TLMTD$ logarithmic mean temperature difference, K

Subscripts

Avg Average
c Coil side
co Cold
h Hot
i Inlet
o Outlet
sh Shell side

References

[1] J. P Holman, "*Heat Transfer Sixth Edition*", Singapore: McGraw-Hill, 1986.

[2] T. A. Pimenta, J. B. Campos, "Friction Losses of Newtonian and Non-Newtonian Fluids Flowing in Laminar Regime in a Helical Coil," *Exp. Therm. Fluid Sci*, Vol. 36, pp. 194–204, 2012.

[3] Ali S.h. Baqir, Hameed B. Mahood, Ahmed R. Kareem, "Optimization and evaluation of NTU and effectiveness of a helical coil tube heat exchanger with air injection", *Therm. Sci. Eng. Progr*. vol. 14, pp. 100-420, 2019.

[4] Ruthven, "The residence time distribution for ideal laminar flow in a helical tube" *Chem. Eng. Sci. 26 (7) 1113–1121*, 1971.

[5] Anwer F. Faraj, Itimad D.J. Azzawi, Samir G. Yahya, "Investigate the Effect of Pitch Variations on Helically Coiled Pipe for Laminar Flow Region Using CFD," International Journal of Heat and Technology vol. 38: pp. 447-456, 2020.

[6] M M Etghani, SA. Hosseini Baboli, "Numerical investigation and optimization of heat transfer and exergy loss in shell and helical tube heat exchanger", *Applied Thermal Engineering*, vol. 121, pp. 294-301, 2017.

[7] Ebrahim Ahmadloo, Najmeh Sobhanifar, Fatemeh Sadat Hosseini, "Computational Fluid Dynamics Study on Water Flow in a Hollow Helical Pipe", *Open Journal of Fluid Dynamics*, no. 4, pp. 133-139, 2014.

[8] Priyanshu Dradhomar, Subhashini Verma, Vikas Singh, Pallavi Dradhomar, Manjunatha. M, "CFD analysis of double tube helical coil heat exchanger for different heat transfer characteristics", *International Journal of advanced Research*, Article DOI: 10.21474/IJAR01/4006, 2017.

[9] A. Fouda, S.A. Nada, H.F. Elattar, H.A. Refaey, A. Bin Mahfouz, "Thermal Performance Modeling of Turbulent Flow in Multi Tube in Tube Helically Coiled Heat Exchangers", *International Journal of Mechanical Sciences*, doi: 10.1016/j.ijmecsci.2017.12.015, 2017.

[10] T.J. Huttl, R. Friedrich, "Influence of curvature and torsion on turbulent flow in helically coiled pipes", *International Journal of Heat and Fluid Flow* 21, 345±353, 2000.

[11] Naveen Kushwaha, Tara Chand Kumawat, Krishna Deo Prasad Nigam, Vimal Kumar, “Heat Transfer and Fluid Flow Characteristics for Newtonian and Non-Newtonian Fluids in a Tube-in-Tube Helical Coil Heat Exchanger”, *Industrial & Engineering Chemistry Research*, vol. 59, no. 9, pp. 3972-3984, 2020.

[12] Jundika C. Kurnia, Benitta A. Chaedir, Agus P. Sasmito, “Laminar convective heat transfer in helical tub e with twisted tape insert”, *International Journal of Heat and Mass Transfer* 150, 119309, 2020.

[13] Rafal Andrzejczyk, Tomasz Muszynski, “Thermodynamic and geometrical characteristics of mixed convection heat transfer in the shell and coil tube heat exchanger with baffles”, *Applied Thermal Engineering*, vol. 121, pp. 115-125, 2017.

[14] H. Shokouhmand, M.R. Salimpour, M.A. Akhavan-Behabadi, “Experimental investigation of shell and coiled tube heat exchangers using wilson plots”, *International communications in heat and mass transfer*. 35, pp. 84-92, 2008.

[15] V. Kongkaitpaiboon, K. Nanan, Smith Eiamsa-Ard, “Experimental investigation of convective heat transfer and pressure loss in a round tube fitted with circular-ring turbulators”, *International Communications in Heat and Mass Transfer*, vol. 37, no. 5, pp. 568-574, 2009.

[16] Rashid Kareem, “Optimisation of Double Pipe Helical Tube Heat Exchanger and its Comparison with Straight Double Tube Heat Exchanger*”, Journal of The Institution of Engineers* (India): Series C, Volume 98, Issue 5, pp.587-593, 2017.

[17] A. Al-damook, I.D.J. Azzawi, “Multi-objective numerical optimum design of natural convection in different configurations of concentric horizontal annular pipes using different nano fluids”, *Heat Mass Transfer* vol. 57, pp. 1543–1557, 2021.

[18] A. Al-damook, and I.D. Azzawi, “The Thermo hydraulic Characteristics and Optimization Study of Radial Porous Heat Sinks Using Multi-Objective Computational Method” *ASME. J. Heat Transfer*; 143(8): 082701, August 2021.

[19] A. F. Faraj, I. D. Azzawi, S. G. Yahya, “Pitch variations study on helically coiled pipe in turbulent flow region using CFD”, *International Journal of Heat and Technology*, Vol. 38, No. 4, pp. 775-784, 2020.

[20] A. F. Faraj, I. D. Azzawi, S. G. Yahya, A. Al-Damook, “Computational Fluid Dynamics Investigation of Pitch Variations on Helically Coiled Pipe in Laminar Flow Region” *ASME. J. Heat Transfer*; 142(10): 104503, October 2020.

[21] Senaa Kh. Ali, Itimad D.J. Azzawi, Anees A. Khadom, “Experimental validation and numerical investigation for optimization and evaluation of heat transfer enhancement in double coil heat exchanger”, *Thermal Science and Engineering Progress*, Volume 22, 100862, ISSN 2451-9049, 2021.

[22] Krzysztof Kowalski, Dorota Downarowicz, “Heat transfer in helical coil heat exchanger: An experimental parametric study”, *Chemical and Process Engineering*, vol. 40, no. 1, pp. 101–114, 2019.

[23] Nikheel Joshi, “Simulation and Analysis of Double Pipe Heat Exchanger”, DOI: 10.22214/ijraset.35554, 2021.

[24] Ali Safari, Majid Safar Avval, Abbas Gholami, “Experimental investigation of laminar forced convection flow of nano fluid in helical pipe”, In Conference: *27th Annual International Conference on Mechanical Engineering* (ISME 2019).

[25] S. Sivalakshmi, M. Raja, G. Gowtham, “Effect of helical fins on the performance of a double pipe heat exchanger”, *Department of Mechanical Engineering, Government College of Engineering, 636011, India*, 2020.

[26] C Ranganayakulu, K N Seetharamu, “*Compact heat exchangers-Analysis design and optimization using FEM and CFD approach*”, Wiley-ASME Press Series, 2018.

[27] N. Jamshidi and M. Farhadi, D.D. Ganji, K. Sedighi,” Experimental analysis of heat transfer enhancement in shell and helical tube heat exchangers,” *Applied Thermal Engineering*, vol. 51, pp. 644-652, 2013.

[28] S. Bahrehmand, A. Abbassi, “Heat transfer and performance analysis of nanofluid flow in helically coiled tube heat exchangers”, *Chemical Engineering Research and Design*, vol. 109, pp. 628-637, 2016.

[29] M.R. Salem, K.M. Elshazly, R.Y. Sakr and R.K. Ali, “Experimental investigation of coil curvature effect on heat transfer and pressure drop characteristics of shell and coil heat exchanger”, *J. Therm. Sci. Eng. Appl.* 7, 011005-1 to 011005-9, 2014.

[30] H. Mirgolbabaei, H. Taherian, G. Domairry, N. Ghorbani, “Numerical estimation of mixed convection heat transfer in vertical helically coiled tube heat exchangers”, *International Journal for Numerical Methods in Fluids*, Int. J. Numer. Meth. Fluids; vol. 66, pp. 805–819, May 2011.

[31] Mohamed Reda Salem, K. M. El-Shazly, Ramadan Youssef Sakr, Ragab Ali, “Effect of γ-Al2O3/Water Nanofluid on the Thermal Performance of Shell and Coil Heat Exchanger with Different Coil Torsions”,*Heat and Mass Transfer*, DOI: 10.1007/s00231-016-1949-4, June 2017.

[32] A. Dogus Tuncer, A. Sozen, A. Khanlari, E. Yag ız Gurbuzb, H. İbrahim Variyenli, “Experimental and Numerical Analysis of a New Modification for Enhancing Thermal Performance of a Shell and Helically Coiled Heat Exchanger”, *Applied Thermal Engineering,* October 2020.

[33] Vimal Kumar, Supreet Saini, Manish Sharma, K.D.P. Nigam, “Pressure drop and heat transfer study in tube-in-tube helical heat exchanger”, *Chemical Engineering Science* vol. 61, pp. 4403 – 4416, 2006.

[34] A. Moosavi, M. Abbasalizadeh, H.S. Dizaji, “Optimization of heat transfer and pressure drop characteristics via air bubble injection inside a shell and coiled tube heat exchanger”, *Experimental Thermal and Fluid Science,* doi: http://dx.doi.org/10.1016/j.expthermflusci.2016.05.011, May 2016.