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The Role of Nanoparticles and Different Tube Diameter on Thermal Performance in Shell and Helically Coiled Tube Heat Exchangers with Single Phase and Sub-cooled Boiling Flow

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A B S T R A C T

In the present research, effects of nanoparticles and changing of tube diameter have been scrutinized on heat transfer parameters in the shell and helically coiled tube heat exchanger. A CFD analysis and also a modeling of the mentioned heat exchager have carried out by writing a code in MATLAB software for two regimes involving forced convection heat trasnfer in single phase fluid flow and sub-cooled boiling. In the case under analysis, considered nanoparticles in this research was Nickel nanoparticles with 0.1 and 1% volumetric concentration. Based on the results, both going up of volume concentration of nanoparticles and increasing of tube diameter are cause to make better heat transfer parameters. In truth, heat transfer coefficient and Nusselt number have been enhanced by 0.1 and 1 % volumetric concentration of Nickel nanoparticles.

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NOMENCLATURE

c_p	Specific heat at constant pressure, J/kg.K
D	Diameter, m
G	Mass flux, kg/m^2. s
h	Convective heat transfer coefficient, W/m^2. K
h_L	heat transfer coefficient on single-phase section, W/m^2. K
h_{lv}	Latent heat of vaporization, J/kg
k	Thermal conductivity, W/m.K
l	Length of each element, m
m	Mass, kg
$\dot{m}$	Mass flow rate, kg/s
N	Number of loop
p	Pressure, N/m^2
Pr	Prandtl number
q	Heat transfer rate, W
$\dot{q}$	Heat transfer rate per unit length, W/m
Ra	Rayleigh number
Re	Reynolds number
T	Temperature, K
V	Volume, m^3

Subscripts

a	Absorber
P	Particle
c	Cavity
$cond$	Conduction
$conv$	Convective
e	Environment
eff	Effective
ex	External
f	Fluid
in	Internal, Inlet
l	Liquid
m	Middle
nf	nanofluid
out	Outlet
Sat	Saturation

Greek symbols

μ	Viscosity, kg/s.m
π	Pi number, 3.14
ρ	Density, kg/m^3
σ	Stefan-Boltzmann constant
Δ	Different
θ	Circumferential angle

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INTRODUCTION

In heat exchanger, heat transfers between fluids at different temperatures, and intersection between the fluids is a major parameter for enhancement of its efficiency. A heat exchanger was possessed of plenty advantages pertinent to heat transfer parameters due to the stronger secondary flow induced in the coiled tube [1]. Lin et al. [1] have studied the flow and heat transfer peculiarities of the single-phase section so that the pure water has been used in their research. Zhou et al. [2] have developed a novel optimization model based on a reduction in the available work loss for tube-in-tube helically coiled heat exchangers. Also, their numerical model takes into account available work losses, i.e. irreversibility, due to heat transfer and friction pressure drops of heat exchangers. Mirgolbabaei [3] has executed appraisal of vertical helically coiled tube in shell and heat exchanger, at both of various mass flow rate and different coil pitches. The best important peculiarity of this study is the boundary conditions for the helical coil. Most studies have made clearon simplified thermal conditions on the coil surface, whereas in his study a fluid to fluid heat transfer was considered.

Alimoradi et al. [4] have carried out a numerical analysis on an increasing of heat transfer coeficient heat exchangers of the type shell and helically coiled tube via annular fins. In fact, their study indicated the effect of material distribution (for construction of the fins) on the heat transfer rate. Wang et al. [5] have established a numerically analysis about the effect of fin geometry and mass flow rate of the shell, on the exergy loss and the helically coiled finned tube heat exchangers with aninternal core inside the shell. Exergy is a significant tool in optimization of complicated thermodynamic systems. Alimoradi [6] has presented an important exergy analysis for forced convection heat transfer in a heat exchanger from kind of shell and tube. The effect of functional and geometrical parameters on the exergy efficiency have investigated. Sadighi Dizaji et al. [7] have experimentally studied effects of some thermodynamic parameters on exergetic peculiarities for tube-in-tube helically coiled heat exchangers. The effect of coil pitch on exergy loss is negligible in their study. Sajjadi et al. [8] have been executed a simulation to investigate natural convection in a cubic cavity by new means of the Lattice Boltzmann method with double Multi-Relaxation-Time (MRT) model. They have used from new method to solve the momentum and energy equations so that it is two different populations with various lattices. Atashafrooz [9] has carried out a numerical investigation as three-dimensional simulation of effects of Ag-water nanofluid on hydrodynamics and thermal behaviors of three-dimensional separated step flow. The results revealed an increase in volumetric concentration impress on thermal distribution.

Atashafrooz et al. [10]] have been studied on forced convection heat transfer and flow unchangeability by interaction effects of an inclined magnetic field and nanofluid. They have revealed nanoparticles volumetric concentration increased heat transfer rates and the flow irreversibility. An external convection from type of forced on water was experimentally investigated in a 24 meter long full-scale helically coiled tube, similar tube boiling used in small modular nuclear reactor systems by Santini et al. [11]. Gou et al. [12] have presented an assessment of the heat transfer models under different heat transfer models for water flow in helically coiled tubes based on the compiled datasets from the reviewed studies. Wang et al. [13] have carried out computational fluid dynamic (CFD) simulations for one of the best important regimes that it means single-phase fluid flow in a helically coiled tubes by Reynolds Stress Model. In other study, Jayakumar et al. [14] have done a CFD simulations for helicallycoils by differentcoil parameters such as pitch circle diameter, tube pitch, and pipe diameter. On the other hand, in order to study the effects of someforces and buoyancy on the local and convection heat transfer peculiarities of single-phase fluid flow. Wang et al. [15] have conducted experimentally investigationon heated helical pipes. The objective of their study is to investigate local heat transfer distribution pattern wide thermal hydraulic conditions. Also, Hardik et al. [16] have been scrutinized the influence of both significant parameters involving curvature and Reynolds number on local heat transfer coefficient in a helicallytube.

Despite ofexecuted othernumerical and experimental investigations as yet, Mirfendereski et al. [17] have executed a study with steady state flow in helically tubes with constant wall heat flux boundary condition. Han et al. [18] have used from the MOGA optimization for designation of the helically tube. As a result, the entropy generation number cannot fully represent the heat transfer and flow resistance executiones. Abu-Hamdeh et al. [19] have executed a numerically analysisto study thermal peculiarities of a new type of helically coiled tube heat exchangers called “sector-by-sector heat exchangers” Regarding nanofluid and heat exchangers, there are some researches that have revealed remarkable progresses. Arevalo-Torres et al. [20] have executed an empirical investigation on forced convective heat transfer in a coiled flow inverter that they have scrutinzed effect of Titanium Dioxiednanoparticles on its thermal performance. Also, some parameters involving enhancement of heat transfer and pressure drop were studied by Baba et al. [21] in a double tube counterflow by scattering of Fe_3O_4 nanoparticles into water. A numerical analysis was conducted by Sheikholeslami et al. [22] that has scrutinized effects of magnetic force and radiation on nanofluid conveyance so that they have considered Al_2O_3 nanoparticles. In another research, Atashafrooz [23] has executed an effort to study the buoyancy force effects on the MHD mixed convection nanofluid flow and entropy production over an inclined duct. Also, he has investigated effects of Brownian motion on the viscosity and thermal conductivity of Cu-water nanofluid. Regarding Lorentz force, a study was conducted by Atashafrooz et al. [24] so that manages the analysis of its interacting effects and bleeding on the hydrothermal behaviors of magnetohydrodynamic (MHD) nanofluid and entropy production in a trapezoidal recess. One of the best important effects on nanofluids is influence of radiative heat transfer. Atashafrooz [25] executed an analysis for it and Brownian movement on the thermal characeristics of nanofluid flow over an inclined step in presence of an axial magnetic field so that he considered Al_2O_3 and CuO as nanoparticles inside pure water. In a research by Asadikia et al. [26] the thermal and electrical conductivities of CuO nanoparticles and carbon nanotubes to attainsuitable heat transfer peculiarities with especial nanofluid as hybrid nanofluid were investigated. Fathian et al. [27] have executed an experimental investigation to study the influence of compounding single-walled and multi-walled carbon nanotubes to condensed water upon the heat trsnfer characteristics of the flow in helical anulus. One of the best important applications of nanofluid is in oil and gas industry. Rashidi et al. [28] have executed a simulation of wellbore drilling energy saving of nanofluids so that they have used from an experimental Taylor-Couette flow system and also have used Al_2O_3, TiO_2 and SiO_2 nanoparticles in their investigation. In other research pertinent to nanofluid and nanoparticles, some researcheres have studied about role of nanoparticles on performance and emission improver of comparession ignition engine fuels. Also, influence of Mn doping on Fe_3O_4 nanoparticles compounded by wet chemical reduction methode [29, 30]. Also, Afroozi and Farhadi [31] have scrutinized mixed convection flow by Lattice Boltzmann approach in a lid driven enclosure filled by nanofluid with Cu nanoparticles.

Hence, the executed study efforts to scrutinize of effect of nanoparticles and altering of tube diameter on thermal characteristics in a heat exchanger with type of shell and helically coiled tube so that it is significant for special industries such as nuclear reactors, power plants, refrigeration and air conditioning systems, heat recovery systems. It has been used from a CFD method regarding thermal analysis and turbulent flow based on large eddy simulation (LES) technique so that, a coding has been performed for single-phase fluid flow and sub-cooled boiling flow. Also, BDL method has been used concerning the sub-cooled boiling calculations in performing code. As a result, heat transfer coefficient and Nusselt enhancement has been obtained by both enhancing of volume concentration of Nickel nanoparticles and tube diameter. In the following, there are some descriptions regarding used equations and obtained results.

GOVERNING EQUATIONS AND CONSIDERED MODEL

Modelling approach in this research is energy balance in the helically coiled heat exchanger so that, there are two fluids including hot fluid and cold fluid. As it is shown in Figure 1, the hot fluid is between tube and shell and on the other hand, there is the cold fluid within helically coiled tube and in this energy balance, the heat of hot fluid transfer to cold fluid and eventually it caused enhancing of cold fluid temperature. Due to the nature of heat transfer in this model, there are two fluid flows involving single-phase fluid flow and sub-cooled boiling flow. Also, heat transfer path from the hot fluid toward cold fluid including convection heat flux from hot fluid to the wall, conduction heat flux in the wall and ultimately convection heat flux from the wall to cold fluid. In the following, the respective equations have been expressed.

In the beginning, convection heat flux occur from hot fluid to external surface of tube with entrance hot fluid within space between shell and tube. Equations (1) to (3) point out this process [32].

$$q''_{g-t,conv} = h_g(T_{t,ex} - T_{m,g}) \tag{1}$$

$$h_g = \frac{Nu_{local} k_g}{D_{t,ex}} \tag{2}$$

$$T_{m,g} = {(T_{g,in} + T_{g,out})}/{2} \tag{3}$$

The heat was passed from the wall by conduction mechanism of heat transfer when it reached external surface of tube. Equations (4) and (5) reveal correlations regarding the heat flux [32].

$$q''_{t,cond} = \frac{k_t}{r ln\left({r_{t,ex}}/{r_{t,in}}\right)}(T_{t,ex} - T_{t,in}) \tag{4}$$

$$r = {(r_{t,ex} + r_{t,in})}/{2} \tag{5}$$

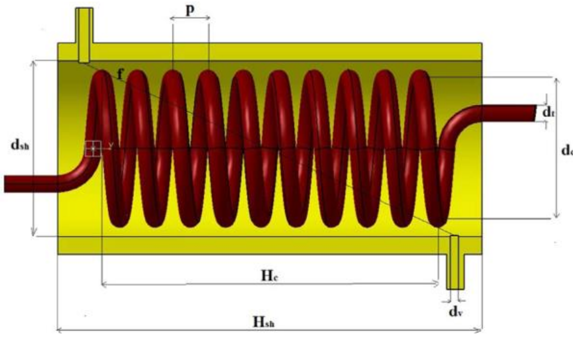

Figure 1. The considered model for shell and helically coiled tube heat exchanger [6]

In the following of heat transfer path, the heat transferred within the cold fluid by convection heat flux. Alteration in type of fluid flow is a considerable point in this section so that, this changing is related to the inside surface temperature of tube and fluid temperature. As we know already, there are two fluid flows including single-phase fluid flow and sub-cooled boiling flow that the inside surface temperature tube is difference of this two flows. When the mentioned temperature reached saturated temperature of fluid, the single-phase fluid flow exchanged sub-cooled boiling flow. Equations regarding single-phase fluid flow reveal in the following [20].

$$q''_{t-f,conv} = h_f(T_{t,in} - T_m) \quad (6)$$

$$q''_{t-f,conv} = h_f(T_{t,in} - T_m) \quad (7)$$

$$h_f = \frac{Nu_{local} k_f}{D_{t,in}} \quad (8)$$

For the Nusselt number, it ought to use from local Nusselt number in the calculations that for this reason Jayakumar et al. [14] have announced two correlations for local Nusselt number based on two boundary conditions including constant wall temperature and constant heat flux. According to the considered model in the current study, correlation regarding the constant heat flux has been selected for the local Nusselt number so that, it reveals in Equation (9).

$$Nu_{local} = Nu_f(-2.331e^{-5}\theta^2 + 8.424e^{-3}\theta + 0.4576) \quad (9)$$

The secondary flow is a significant point in the physics of fluid flow inside helically coiled tube that ultimately the Reynolds number altered from center of tube to the wall. Since the Reynolds number depend on the Nusselt number, so the Nusselt number has two different correlations based on turbulent and laminar flow. As a matter of fact, the flow has been assumed fully developed in the current study and in this type of flow, the critical Reynolds number corresponding to the onset of turbulence is 2300. Therefore, the Nusselt number for laminar flow is equal to 4.36 [32] and for turbulence is obtained from Gnielinski's correlation [20] that they reveal in the following equations.

If $Re_f < 2300$

$$Nu_f = 4.36 \quad (10)$$

If $Re_f > 2300$

$$Nu_f = \frac{({}^{f}/_{8})(Re_f - 1000)Pr_f}{1+12.7\left({}^{f}/_{8}\right)^{0.5}\left((Pr_f)^{2/3} - 1\right)} \quad (11)$$

$$f = \frac{2\Delta P D_{t,in}}{\Delta l \rho_f {u_m}^2} \quad (12)$$

$$u_m = {}^{\dot{m}}/_{(A_{t,in}\rho_f)} \quad (13)$$

Also, the sub-cooled boiling flow finished when the fluid temperature reached saturated point and so, the fluid enter to drum structure to exchange steam.

$$q_w = q_{fc}\phi + q_{nb}S_{chen} \quad (14)$$

$$q_{fc} = h_{fc}(T_{t,in} - T_m) \quad (15)$$

$$T_m = {}^{(T_{in} + T_{out})}/_2 \quad (16)$$

$$h_{fc} = \frac{Nu_{local} k_f}{D_{t,in}} \quad (17)$$

$$q_{nb} = h_{nb}(T_{t,in} - T_{sat}) \quad (18)$$

The best important point is the heat transfer coefficient in the sub-cooled boiling flow that it is introduced correlation by forster-zuber, in the current calculations so that, the Equation (19) reveal it. Also, for the parameter S has been considered the obtained equaton by Steiner et al. [33].

$$h_{nb} = 0.00122\frac{{k_f}^{0.79}{C_{p,f}}^{0.45}{\rho_f}^{0.49}}{\sigma^{0.5}{\mu_f}^{0.29}{h_{fg}}^{0.24}{\rho_g}^{0.24}}(T_{a,in} - T_{out})^{0.24}{\Delta P_{sat}}^{0.75} \quad (19)$$

$$S_{chen} = \frac{1}{1+2.53\times10^{-6}(Re_f\phi^{1.25})^{1.17}} \quad (20)$$

In sub-cooled boiling flow the vapour mass fraction are typically the small, eventually ϕ can be assumed unity.

In addition to what has been explained about convection heat transfer between hot fluid and tube and also between tube and cold fluid, by energy balance we can calculate the changes of average temperature, as well as obtain the relation between convection heat flux and input-output temperature difference. In Figure 2 the scheme of fluid's energy balance inside a tube is represented that it could be used for shell and helically coiled tube [32].

The fluid is flowing into the shell and tube with $\dot{m}$ constant rate and convection heat transfer occurs between the helically coiled tube's surface and the hot and cold fluid. Energy balance of fluid element is as follows [32].

$$q''_{g-t,conv} = \frac{\dot{m}_g c_{p,g}}{l_{shell}\pi(D_{shell} - D_h)}(T_{g,in} - T_{g,out}) \quad (21)$$

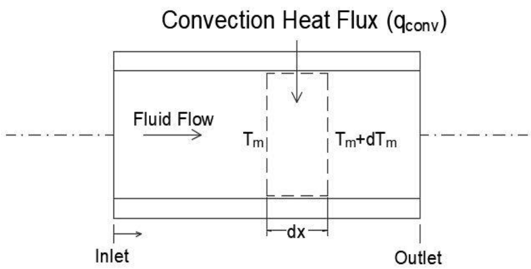

Figure 2. Energy balance inside a tube

$$q''_{t-f,conv} = \frac{\dot{m}_f c_{p,f}}{l_t \pi D_{t,in}} (T_{f,in} - T_{f,out}) \quad (22)$$

In the heat transfer equations, the fluid tempeature impress on some thermo-physical peculiarities so that changed with temperature in the whole flow. These equations reveal in the following [14].

$$\mu(T_{fluid}) = (2.1897e-11)T_{fluid}^{\ 4} - (3.055e-8)T_{fluid}^{\ 3} + (1.6028e-5)T_{fluid}^{\ 2} - 0.0037524T_{fluid} + 0.33158 \quad (23)$$

$$\rho(T_{fluid}) = (-1.5629e-5)T_{fluid}^{\ 3} + (0.011778)T_{fluid}^{\ 2} - (3.0726)T_{fluid} + 1227.8 \quad (24)$$

$$k(T_{fluid}) = (1.5362e-8)T_{fluid}^{\ 3} - (2.261e-5)T_{fluid}^{\ 2} + (0.010879)T_{fluid} - 1.0294 \quad (25)$$

$$C_p(T_{fluid}) = (1.1105e-5)T_{fluid}^{\ 3} - (0.0031078)T_{fluid}^{\ 2} - (1.478)T_{fluid} + 4631.9 \quad (26)$$

The nanofluid equations

As it mentioned,in order to consider the nanofluid in the analysis, the effective parameters in the heat flux of absorber to fluid have got to be based on the nanoparticle equations.

In Figure 3, we can show nanoparticles in the base fluid. There are some parameters involving the fluid mass density, fluid viscosity, coefficient of thermal conductivity, specific heat capacity, and fluid enthalpy that they change with volumetric concentration. For this reason, there are some equation so that they reveal in the following [32].

$$\rho_{nf} = \rho_p \phi + \rho_l (1-\phi) \quad (27)$$

$$\mu_{nf} = \frac{\mu_l}{\left(1 - 34.87\left(\frac{d_p}{d_l}\right)^{-0.3} \phi^{1.03}\right)} \quad (28)$$

$$d_l = 0.1\left(\frac{6M}{N\pi\rho_{l,ref}}\right) \quad (29)$$

$$k_{nf} = k_l \left[\frac{k_p + (n-1)k_l - (n-1)\phi(k_l - k_p)}{k_p + (n-1)k_l + \phi(k_l - k_p)}\right] \quad (30)$$

$$C_{p,nf} = \frac{(\phi \rho_p C_{p,p} + (1-\phi)\rho_l C_{p,l})}{\rho_{nf}} \quad (31)$$

The enthalpy for nanofluids is calculated from the experimental Equation (32). The coefficients C1 and C2 Have also obtained from the experimental Equations (33) and (34) and Table 1.

$$h_{lv} = C_1 P^{C_2} \quad (32)$$

$$C_1 = A\phi^5 + B\phi^4 + C\phi^3 + D\phi^2 + E\phi + F \quad (33)$$

$$C_2 = \alpha\phi^5 + \beta\phi^4 + \gamma\phi^3 + \sigma\phi^2 + \varepsilon\phi + \omega \quad (34)$$

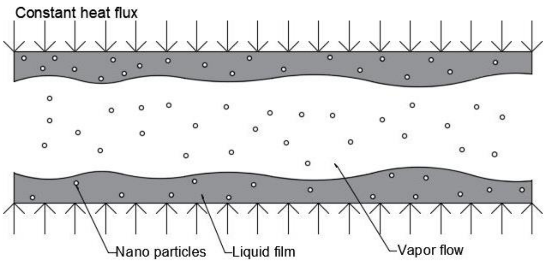

Figure 3. A schematic of added nanoparticles in the base fluid [34]

The solution algorithm

In the current research, a CFD code was writen in MATLAB software for modelling of shell and helically coiled tube heat exchanger and thermal analysis as numerical investigation so that, natural convection and sub-cooled boiling have been considered in the writen code. It is necessary that validation executed in order to proof of code accuracy for two flow sections involving single-phase fluid flow and sub-cooled boiling flow. In this process, iteration method has used for calculation of system of linear equations including 5 equations and 5 unknown.

Due to existing of hot fluid between shell and helically tube, the solution process is based on thermal energy transfer from hot fluid to external surface of tube by a convection heat flux. So, the heat convey from wall by conduction heat flux and eventually, the heat transfer to cold fluid by convection heat flux.

The best important point in the heat transfer inside of fluid is existing of single-phase fluid flow and sub-cooled boiling flow sections so that, essence of these sections

Table 1. Data of the coefficients used in enthalpy relations for each nanofluid type [35]

Coefficients	Nanoparticles
	Nickel
A	190.64014
B	-1342.57684
C	3297.41269
D	-3279.42042
E	973.51481
F	2271.34941
α	-0.01948
β	0.13902
γ	-0.34826
σ	0.35976
ε	-0.12291
ω	-0.00173

depend on fluid temperature and inside temperature of tube surface. At first, when fluid entered into tube, fluid temperature increase by convection heat flux from surface tube. Also, inside temperature of tube surfaceenhance in the whole tube, too. While the inside temperature of tube surface reach saturated temperature of fluid, so sub-cooled boiling flow start and in the following both fluid temperature and inside temperature of tube surface augment and ultimately, sub-cooled boiling flow will be over when fluid temperature fits saturated temperature. The solution algorithm of this analysis is shown in Figure 4.

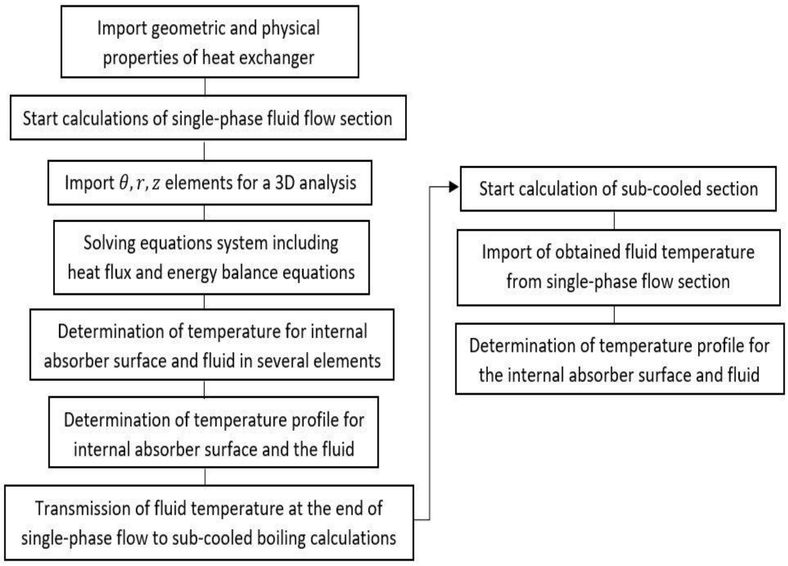

Figure 4. Solution algorithm

Validation of numerical analysis

In this study, validation has been executed with Mirfendereski et al. [17] experimental study and in truth, the considered model are revealed in Figure 5. Also, the geometrical characteristics of coil exhibited in Table 2.

According to literature [14], the pure water has considered as the heat transfer fluid that Table 3 reveal its thermo physical properties in the saturate temperature.

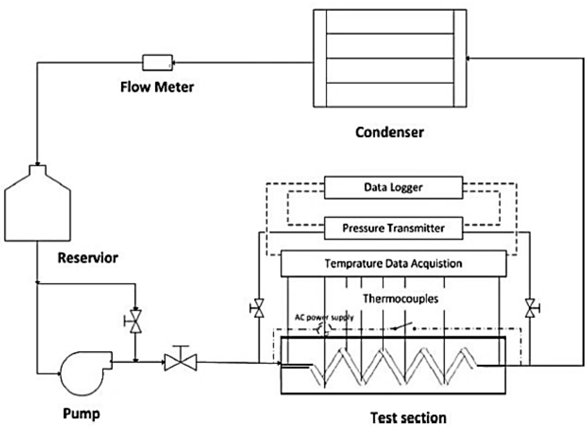

Figure 5. Considered model for validation [17]

In the current validation, the obtained result about Nusselt number versus dean number has been used so that, its comparison revealed in Figure 6. The best important point in the current study and validation is about boundary condition so that, it is about wall heat flux that is constant.

Table 2. Geometrical properties for validation [17]

Parameters	Size (mm)
Coil Diameter (m)	0.275
Coil Pitch (m)	0.055
κ	0.02716
τ	0.00172

Table 3. Thermo physical properties of pure water in saturated temperature

Parameter	Quantity	Unit
Density	957.85	$\frac{kg}{m^3}$
Thermal Conductivity	0.680	$\frac{W}{m.K}$
Viscosity	279 e -6	$\frac{m^2}{s}$
Heat Capacity	4217	$\frac{j}{kg.K}$

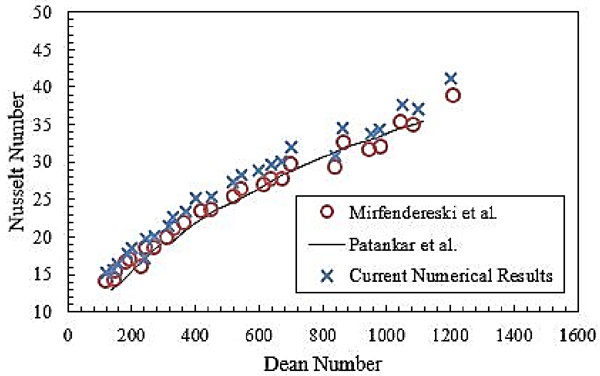

Figure 6. Validation diagram with Nusselt number versus De number

As be seen in Figure 6, after putting of inputs of Mirfendereski et al. [17] in the performing code, deviation of Nusselt number in the current analysis than Nusselt number in the Mirfendereski et al. [17] was obtained equal to 7.3% on average. According to the obtained validation, the numerical results show adequate concurrence with Mirfenderesli et al. [17] prediction.

RESULTS

In the current analysis on the considered heat exchanger, some parameters have been calculated including distribution of heat transfer coefficient, Nusselt number, local heat transfer coefficient, and exergy. Geometrical and thermo physical properties for heat exchanger and used hot and cold fluid are visible in Table 4.

Also these properties of the nanoparticles are available in Table 5.

In this study, it has been used from performing code for calculating of thermal parameters. The executed calculations and code are based on linear numerical methods with approaching of iteration method for solution of the system of equations. The most important effects of variation in the inside diameter of tube and

Table 4. Helically coiled tube heat exchanger characteristics

Parameter	Value
External Diameter of Tube	0.0185
Internal Diameter of Tube	0.0135
Coil Diameter	0.203
Coil Pitch	0.135
Thermal Conductivity of Tube	207
Mass Flow Rate of Fluid	0.1163
Mass Flow Rate of Gas	0.14333

Table 5. Thermo-physical properties of the mentioned nanoparticles [29]

Nanofluid	Nickel
Specific Heat ($^{J}/_{kg.K}$)	444
Thermal Conductivity ($^{W}/_{m.K}$)	90.7
Density ($^{kg}/_{m^3}$)	8900

dispersing of Nickel nanoparticles to based fluid on thermal performances have been investigated in the current study, so that the obtained results reveal improvement of thermal performance. It is necessary to mention that local position has been considered equal 360 degree on circumference of inside surface of tube. Also, volume concentrations of nanoparticles are equal 0.1 and 1%. Distribution of heat transfer coefficient in considered heat transfer regimes revealed in Figure 7.

As it reveals in Figure 7, when volume concentration of nanoparticles be 0.1 and 1%, heat transfer coefficient enhancing by 1.77 and 20.90%, respectively in the end of heat exchanger. In other words, the amount of enhancement of heat transfer coefficient in volume concentration 1% to volume concentration 0.1% of nanoparticles is equal 11.79%. On the other hand, increasing of Nusselt number has been obtained with scattering of nanoparticles in base fluid in the same local position, so that its results is observable in Figure 8.

As it reveals in Figure 8, Nusselt number has been enhanced with adding nanoparticles in base fluid, so that with volume concentration of nanoparticles equal 0.1 and 1%, its increasing has been obtained 1.47 and 17.27% respectively at the end of heat exchanger.

Also, the significant results have been obtained regarding the effect of changing inside diameter of tube

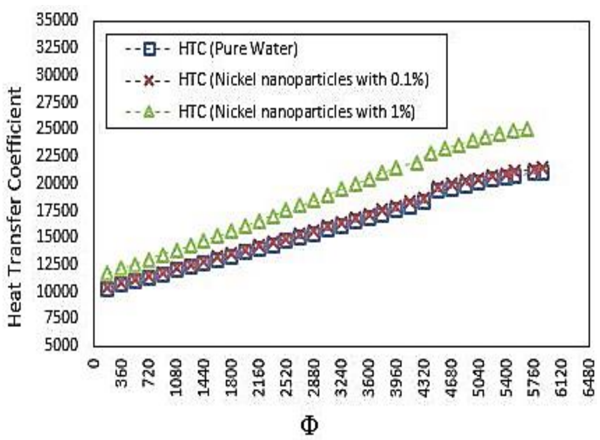

Figure 7. Distribution of heat transfer coefficient for pure water and nanofluids

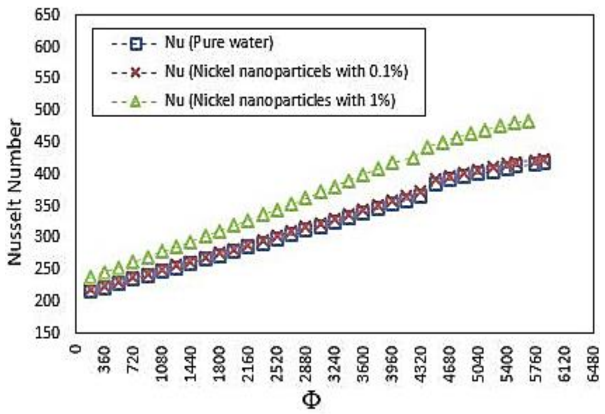

Figure 8. Distribution of Nusselt number for pure water and nanofluids

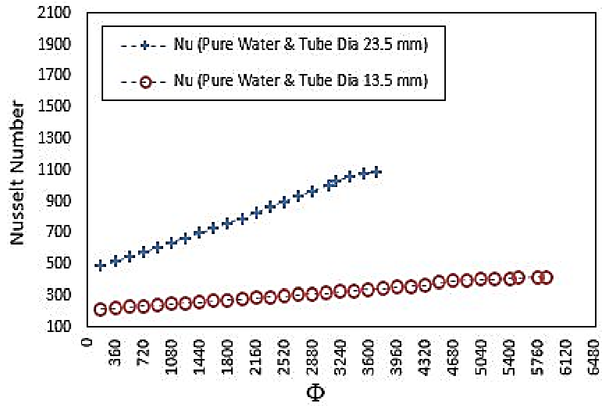

Figure 10. Distribution of Nusselt number for pure water and nanofluids

on distribution of heat transfer coefficient and Nusselt number. While the pure water without nanoparticles has been considered for studying of the effect of inside diameter of tube, it reveals in Figure 9 that heat transfer coefficient and Nusselt number have been enhanced by an increase in the inside diameter of tube.

In fact, two important events have occurred when inside diameter of tube has altered from 0.0135 to 0.0235 meter. At first, the heat transfer coefficient has been improvedequal 49.78% by enhancing of tube diameter and second, length of heat exchanger has been decreased by enhancing of tube diameter so that, the end of sub-cooled boiling section has declined equal 37.12%.

On the other hand, Nusselt number has been increased equal 160.92% by enhancing inside diameter of tube so that, it reveals in Figure 10.

In the current study, the effect of tube diameter and nanofluid have been scrutinized numerically on circumferential heat transfer coefficient so that, according to Figure 11, it has been increased equal 1.73% by volume concentration 0.1% of nanoparticles to heat transfer coefficient with pure water in the whole circumferential elements. Also, it has been obtained an increasing 19.34% for circumferential heat transfer coefficient by adding nanoparticles with volume concentration 1%. A significant enhancement has beenrevealed in circumferential heat transfer coefficient with an increase in of tube diameter so that, it has been increased equal 49.72%. It reveals in Figure 12.

In thermal analysis, thermal parameters alterations have high importance so that, impress on to increasing of thermal performance. In the current study and according to the obtained results, influence of nanoparticles and also tube diameter were revealed on enhancement of heat parameters. In truth, according to application of helically coiled tube heat exchangers in different industries such as nuclear industry and above all in molten salt reactors (MSR), a high heat transfer coefficient makes an acceptable reliability and ultimately that heat exchangers are used in more and sensible temperatures.

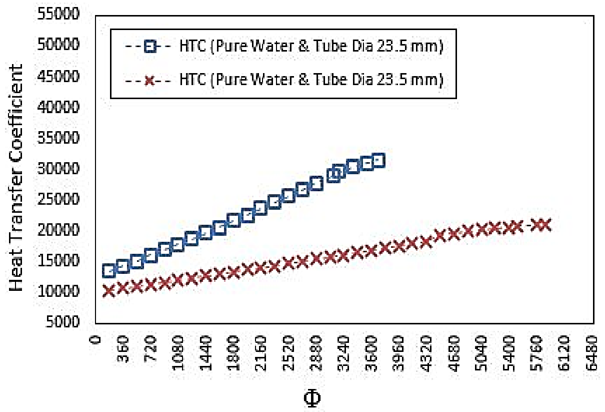

Figure 9. Distribution of heat transfer coefficient for different tube diameter

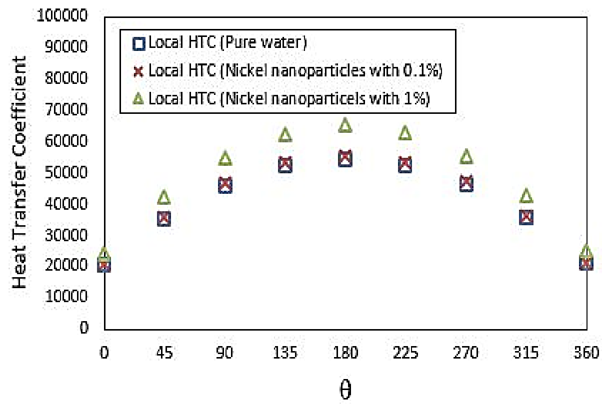

Figure 11. Local heat transfer coefficient for pure water and nanofluids on end of sub-cooled section

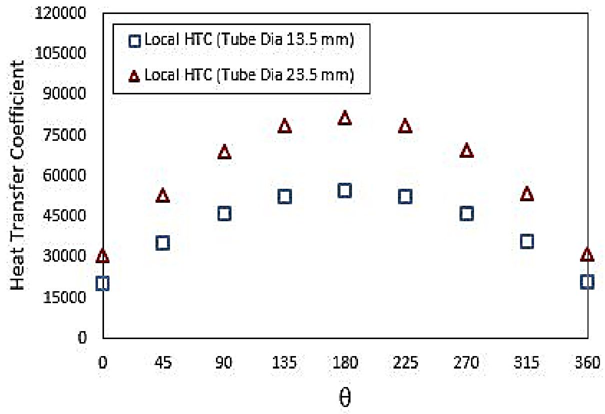

Figure 12. Local heat transfer coefficient for different tube diameter on end of sub-cooled section

CONCLUSION

Helically coiled tube heat exchangers have been widely applied in many power conversion systems for their advantages, involving compactness and high efficiency in heat transfer. This paper presents a scrutiny regarding effects of nanoparticles' scattering into base fluid and different tube diameter on heat transfer coefficient and Nusselt number above all the end of sub-cooled boiling flow section.

The results in the current article have been investigated from two aspect, such as alteration of inside tube diameter from 0.0135 to 0.0235 meter and also adding nanoparticles Nickel to pure water. Eventually, significant results have been obtained in executed analysis, so that it was shown which thermal performance impress on to mentioned changes. As a result, heat transfer coefficient enhanced by 1.77 and 20.90% and Nusselt number increased by 1.47 and 17.47% while volume concentration of nanoparticles were 0.1 and 1%, respectively. When inside diameter of tube has altered from 0.0135 to 0.0235 meter, the heat transfer coefficient has increased by 49.78% and Nusselt number was augmented equal to 160.92%. Also, length of heat exchanger has been decreased by enhancing of tube diameter so that, the end of sub-cooled boiling section has declined equal to 37.12%. In fact, reducing of length of heat exchanger means that amount of loops has decreased and ultimately it can be an economical approach.

The effects of nanoparticles' dispersing and tube diameter is consequential above all in circumferential heat transfer coefficient so that, it has been enhanced by 1.73% and 19.34% for volume concentration of 0.1 and 1% of nanoparticles, respectively to circumferential heat transfer coefficient with pure water. Also, when tube diameter enhanced, it has been increased equal to 49.72%.

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Persian Abstract

چکیده

در پژوهش حاضر، اثرات نانوذرات و تغییر قطر لوله بر روی عملکرد حرارتی در یک مبدل حرارتی لوله مرکزی مارپیچی و پوسته بررسی شده است. مطالعه حاضر یک تحلیل بر مبنای دینامیک سیالات محاسباتی همچنین مدل‌سازی مبدل حرارتی مذکور با نوشتن کد در نرم‌افزار متلب برای دو رژیم شامل انتقال حرارت جابجایی اجباری در جریان سیال تک فاز و جوش زیر سرد انجام شده است. نانو ذرات نیکل با غلظت حجمی ۰/۱ و ۱ درصد در این آنالیز در نظر گرفته شده است. بر مبنای نتایج به دست آمده، هر دو عامل افزایش غلظت حجمی نانو ذرات و افزایش قطر لوله موجب بهبود ضریب رسانندگی حرارتی و عدد نوسلت شده اند. در حقیقت، ضریب انتقال حرارت و عدد ناسلت با غلظت ۰/۱ و ۱ درصد حجمی نانوذرات نیکل افزایش یافته است.