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Heat transfer and friction factor analysis of MWCNT nanofluids in double helically coiled tube heat exchanger

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Abstract

The convective heat transfer rate and friction factor analysis are determined with the help of a double helically coiled tube heat exchanger by handling multiwall carbon nanotube (MWCNT)/water-based nanofluids as a cooling medium. This experiment was conducted with constant heat flux method and a laminar flow regime in the range of 120–180 L h^{-1}. The 0.2–0.6% volume concentration of MWCNT/water-based nanofluids was prepared by using two-step methods. It is conceived that the MWCNT/water-based nanofluids had produced a higher convective heat transfer compared with water. It is also perceived that heat transfer increases with an increasing volume concentration of MWCNT/water-based nanofluids. Finally, the highest convective heat transfer 35% was recorded at a 0.6% volume concentration of MWCNT/water-based nanofluids at 140 L h^{-1} flow rate and at 1400 Dean number. It is drawn that the friction factor using MWCNT nanofluids is 40% greater than water with Dean number range 1400–2400.

Keywords MWCNT/water · Double helically coiled tube heat exchangers · Nusselt number · Thermal conductivity · Secondary flow · Volume concentration · Dean number · Laminar flow

List of symbols

A	Surface area
cp	Specific heat capacity
di	Diameter of inner tube
di	Diameter of outer tube
De	Dean number
H	Convective heat transfer coefficient
K	Thermal conductivity
L	Effective length of tube
m	Mass flow rate
Nu	Nusselt number
Uo	Overall heat transfer coefficient

Abbreviation

DHCTHX	Double helically coiled heat tube exchanger

Subscripts

cr	Critical
i	Inner side
nf	Nanofluid
o	Outer side
nfp	Nanofluid particle size
np	Nanoparticle size
bf	Base fluid

Introduction

In recent trends, the heat exchanger is developed with a new design and replaced the cooling medium as nanofluids to increase the performance of the heat exchanger. In this regard, to achieve heat exchanger efficiency when compared with long-lasting cooling liquids, the newly developed nanofluids are currently being investigated.

It is an experimental investigation of heat transfer characteristics with curly cosine chamfered surface in tube design. Hot water and cold water flow rates in different conditions, as well as wavy wavelength, are utilized in different techniques in surface methodology. The above terms are producing better heat transfer. Exergy efficiency finds out the method of exegetic sustainability. It is concluded that cold water increases the heat transfer, and then wavy

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length improvement and heat transfer reduced. It is found that the grooved tube is better than the plain tube. This study helps to influence the heat exchanger and effectiveness of the wavy surface structures. When the wavy length starts to decrease, the efficiency of the heat exchanger and the coefficient of heat transfer increased. Wavy wavelength played a major key role in the sensitivity and efficiency of the heat exchanger and the heat transfer coefficient with increasing wavy wavelength [1].

The impact of the magnetic field with Nusselt number deviation on water-based ferrofluid with one mass percent Fe_3O_4 nanofluids circulated in helically coiled tubes with a constant heat flux method with different Reynolds numbers. The ferro-fluid is prepared by the two-step method. The heat transfer coefficient of active and passive techniques used is increased with periodic intervals. There are two types of passive techniques used to change the shape of the helical structure form, the addition of magnetic nanoparticles to the active technique used. Two fundamental methods are followed to produce a better heat transfer coefficient and pressure drop. The primary stage is changing the geometric shape of the heat exchanger and torsional ratio. It is found that the impact of fluid flow directions and the formation of strong secondary flow. The steady-state condition represents the average amount of Nusselt and Reynolds numbers, and then the highest magnetic field creates the highest Nusselt number. It is concluded that the presence of the magnetic field has given the greater heat transfer and found the Nusselt number in the range up to 10% [2].

Sheikholeslami et al. [3] numerically investigated the exergy loss in turbulator with a lower volume concentration of nanofluids analyzed. Finite volume method models are used in this numerical work. They suggest that the increasing height of the turbulator produces greater heat transfer. Sheikholeslami et al. [4] in this analysis made by finite volume method (FVM) used the basic equations for nanofluid flow in a pipe and found that the dominant factor is entropy and also thermal management system achieved better results. Sheikholeslami et al. [5] analyzed the new twisted turbulator inserts in the heat exchanger by the finite volume method. They focused on Re, pitch and height ratio of the turbulator inserts. It is concluded that reducing pitch value generates higher nanofluids mixing and increases the thermal performance of the system.

Sheikholeslami et al. [6] analyzed the heat exchanger inserting the innovative helical twisted turbulator by the FVM method. They reported the enhancement of heat transfer using nanofluids with the formation of stronger secondary flow and better mixing of nanofluids with the help of Nu, Re and width ratios of the innovative turbulator. Sheikholeslami et al. [7] carried out the better friction by addition of new nanorefrigerant, namely oils and CuO nanoparticles. They suggested that the increasing fraction of nanofluids produces the higher friction factor. In this investigation, Bejan numbers are additionally included for the level of vapor losses and gain in the greater entropy generation and exergy losses.

Sheikholeslami et al. [8] studied the investigation of increasing the heat transfer and reducing the pressure drops by adding the innovative nanorefrigerant as a cooling medium. With the addition of nanorefrigerant and nanoparticles flow inside the tube surface, some modifications occurred in the nominal level of the surface. It is concluded that new nanorefrigerant mixers produce higher heat transfer and lower pressure drops. Sheikholeslami et al. [9] studied the heat transfer enhancement by introducing the 3D obstacles in Al_2O_3-H_2O-based nanofluids. In this experimental investigation, it is found that the Hartmann number plays the major role for producing increasing energy transforms with the effect of Rayleigh number and Darcy number.

A power transformer is used to improve its effectiveness. This investigation concentrates on the impact on the transformer oil of oxidized multi-walled carbon nanotubes. To ensure the maximum purity of transformer oil, the maximum amount of carbon nanotubes was selected up to 0.01 mass percent. The heat transfer performances of the transformer oil and nanofluids have been studied in free and forced convection. This investigation shows the reduction in breakdown voltage with increased concentration. Electrical conductivity does not change in the transformer oil thermal conductivity with higher temperature and concentration. It is found that the properties of TiO_2 and heat transfer improved with the use of low concentration of nanofluids. The TiO_2-based oxidized MWCNT concentration of 0.001 mass percent of nanofluids is selected [10].

Research work is carried out on the inclined smooth pipe by affecting copper oxide thermal oil during the flow in the pipe on heat transfer and pressure drop. The flow of nanofluids produces a better heat transfer in laminar flow conditions. Nanofluids flow creates some changes like increase and decreases in the Graetz number and Prandtl number heat transfer. It is suggested to find the Nusselt number and friction with the same flow conditions. This investigation concentrates on the difference between 19 and 21% of industrial opted nanofluids. This research contains the percentage of heat transfer and the ratio of pumping power. The paper could not hold CuO thermal oil, adverse inclinations and smooth pipe if the stress dropped above the heat transfer improvement. It is found that heat transfer improvement is more than an increase in pressure drop; it directly represents the results more than the experimental results [11].

Kumar et al. [12] studied the helical coil heat exchanger with Al_2O_3/water nanofluids in laminar flow conditions, and they reported that helical coils create the secondary flow with better heat transfer with nominal friction factor. In this investigation, it is found that the heat transfer and fluid flow characteristics explored with the Reynolds number, and nanoparticles under the Nusselt number concentration are used to turbulent flow condition of MgO–water in a tube. In this experiment, we take the water and nanofluid with various concentrations of nanoparticles with various nanoparticle diameters used. When the volume concentration of nanoparticle increased, the Nusselt number increased as well as the nanoparticle diameter decreased. The Nusselt number indicates an increment. In this experiment, the significant features such as heat transfer, nanofluids stability and pressure drop are calculated, and nanofluids thermophysical properties are measured. It is concluded that when the Nusselt number is higher at that time, nanoparticles are added with increasing volume concentration and reduced nanoparticles diameter [13].

Mukesh Kumar et al. [14] reported that helical coil tube heat exchangers produced better heat transfer and thermal performance. There is no deviation for different flow regimes. The primary concept of this investigation is to deliver zero energy and is achieved with the help of solar collectors and photovoltaic cells to create the effect of the heat exchanger. The impact of nanofluids/Al_2O_3 is studied with swirling flow conditions in the heat exchanger. The outcome represents that thermal systems are additionally installing solar collectors; then the performance of the system achieved greater improvements [15]. Mukesh Kumar et al. [16] concluded that the helical coil tube heat exchangers are designed with Dean number, and they performed with effective heat transfer rate in an increased manner compared to straight tube heat exchangers. Helical coils create the secondary flow formation, but there is no impact in heat exchanger performances.

Dean [17] proposed the Dean number for helical coils. Dean number is a non-dimensionless number that represents the flow configuration of a coiled tube like a Reynolds number in a straight tube. However, the Dean number is directly proportional to the Reynolds number and multiplied by the curvature ratio of the coiled tube. It deals with the formation of secondary flow and compares the thermal performances of the heat exchanger. In specified Dean number, the stronger secondary formation is created in particular pitch coil diameter. Taguchi method is used to optimize the nanofluids flow from Fe_3O_4/water-based nanofluids in heat transfer the helically coiled tube. The input data are assigned to ANSYS Fluent software. Initial testing is performed with different Fe_3O_4/water-based nanofluids with different mass flow rates. Taguchi method is used for this analysis. Some controls and variables allocated the analysis. The impact of various parameters found the heat transfer and fluid flow characteristics. It is concluded that the mass flow rate is efficient with the coil profiles. Under the circumstances, nanofluids are a proportion type of flow and coil cur profiles. It is possible to achieve maximum effectiveness [18].

Mukesh Kumar et al. [19] investigated the helical coil tube heat exchanger using Al_2O_3/water nanofluids with pressure drop. It is noted that increasing nanoparticle volume concentration increased heat transfer with notable pressure drop occurred when compared to the straight tube heat exchangers. Then helical coils are containing with Dean number. Dean numbers increased with increasing the nanofluids volume concentration. Nguyen et al. [20] reported that the new turbulator is fixed in the heat exchanger for the flow is turbulent. Hybrid nanofluids are used in this investigation; they suggested that minimum pitch turbulator provides the higher turbulent flow behaviors and better heat transfer rate also achieved.

Sheikholeslami et al. [21] numerically investigated the inserting helical disturbers in a pipe and analyzed FVM predictions. They observed that the higher width of the disturber produces the increasing Nu and Re. Sheikholeslami et al. [22] studied the innovation of swirl flow turbulator used in this heat exchanger by adding CuO nanoparticles and introduced the Bejan number for heat transfer and friction factor enhancements. They found that reducing Bejan number gives the higher thermal entropy managements. Jafaryar et al. [23] predicted the inserting new twisted turbulator in the heat exchanger with the opposite axis by analyzed FVM. They included that the Darcy factor and Nusselt number achieve better secondary flow formation by changing the angle of the twisted turbulator. Finally, they reported that the Nu increases by increasing the angle of turbulator and enhances the heat transfer with the formation of secondary flow.

Farshad et al. [24] numerically analyzed the Al_2O_3 water nanofluids utilized in the heat exchanger by inserting the multichannel turbulator. In this investigation, they are focused on the Re, different diameter ratios and channels and found that the good mixing of nanofluids enhances the greater heat transfer by varying the different diameter ratios of the turbulators. Sheikholeslami et al. [25] concluded simulation analysis for heat transfer characteristics using Al_2O_3 water nanofluids as a cooling medium. In this research work, the shape factor is included for the better mixing of nanoparticles and to attain better nanofluid properties. Increasing the magnetic force and thermal energy storage system is increasing with increasing Nusselt numbers.

Sheikholeslami et al. [26] reported that utilizing the new phase change material in a thermal storage system besides CuO nanoparticles was analyzed by finite element method (FEM). They reported that the nanoparticle size 40 nm is the better solidification and produces eminent phase change material. Ma et al. [27] revealed that the lower concentration of nanofluids achieved the higher entropy generation and fine amplification of wavy channels are reduced the discharge. They suggest a better heat storage system using renewable energies. This analysis is predicted by using the finite volume method. Finally, their better prediction is the solidification of phase change materials based on the nanoparticle concentrations. Kumar et al. [28] concluded that heat exchanger existing coolants are replaced with Al_2O_3/water nanofluids for producing better heat transfer coefficient with remarkable pressure drop occurred when increasing the nanoparticle volume concentration.

Much research work is carried out for finding the heat exchanger effectiveness, but limited research work only concentrated in a straight tube and single-coil tubes heat exchangers. Therefore, it is reported that our experimental work focused on a double helically coiled tube heat exchanger. The limited number of research work is carried out by using MWCNT nanoparticle as a cooling medium in a double helically coiled tube heat exchanger. MWCNT nanoparticles have more thermal conductivity compared with other nanoparticles. Other nanoparticles widely used are unreported, whereas MWCNT nanoparticle is selected. It is found that the Nusselt number and friction factor utilized in the double helically coiled tube heat exchangers (DHCTHX) are used in MWCNT/water-based nanofluids replaced another cooling medium.

Materials and methods

Details of MWCNT nanoparticles

Details of MWCNT nanoparticle are shown in Table 1. Prasher et al. [29] and Timofeeva et al. [30] experimentally studied and reported that the thermal conductivity and viscosity of MWCNT formula are derived to find the values of '*k*'. Equation (1) is used to calculate the volume fraction of the MWCNT nanofluids.

$$\text{Volume faction of nanofluids } \phi = \frac{\frac{m_{\text{nf}}}{\rho_{\text{nf}}}}{\left[\frac{m_{\text{nf}}}{\rho_{\text{nf}}} + \frac{m_{\text{h}}}{\rho_{\text{h}}}\right]} \quad (1)$$

MWCNT/water-based nanofluids preparation

The dry MWCNT nanoparticles are purchased from Nanostructured and Amorphous Materials, USA. The MWCNT nanoparticles are characterized by SEM and UV methods.

Table 1 Details of MWCNT

S. no	MWCNT volume concentration/%	Thermal conductivity of MWCNT, *K*/W m^{-1} K^{-1}	Viscosity of MWCNT, *μ*/Ns m^{-2}
1	0.2	0.7136	1.5255×10^{-3}
2	0.4	0.8125	2.044×10^{-3}
3	0.6	0.888	2.5652×10^{-3}

The MWCNT size is 50–80 nm (± 5 nm) using Zeta potential method to find the nanoparticle size. Figure 1 shows the UV–visible spectroscopy of MWCNT nanoparticles. In this experimental work, MWCNT/water-based nanofluids are characterized in two-step techniques. Based on the literature, a two-step technique is producing better stability with a nominal amount of agglomeration.

Ghadimi et al. [31] reported that the MWCNT/water nanofluids have been characterized and synthesized with the volume concentration of 0.2%, 0.4%, and 0.6%. SEM images are shown in Fig. 2. SEM analysis reports show the hollow tube formation of MWCNT with layer type similar to the structure of MWCNT. SEM image of MWCNT nanoparticles spreads the entire fluid region with long-term stability (more than 30 days). And there is no sedimentation of nanoparticles after the preparation of 30 days. This research work carried out heat transfer and friction factor for smooth helically coiled tube heat exchangers. This experiment conducted a constant heat flux method for test section wall temperature and flow the TiO_2 nanoparticles and deionized water under turbulent flow conditions. Nusselt number and friction factors are explored. This investigation found that the use of TiO_2/distilled water increases the heat transfer rate. Pitches play the major key roles in this heat transfer analysis for design the geometry. It is concluded that the smallest pitches produce the maximum thermal efficiency by using nanofluids in corrugated tubes [32]. Ruthven et al. [33] compared coil tubes and straight tubes for heat transfer enhancements in parallel flow and counter flow conditions. It is stated that helical coils are better than straight tubes, but helical coils create the secondary flow formation, so some nominal pressure drop occurred. The numerical study initiates the impact of a magnetic field on ferro-fluid's heat

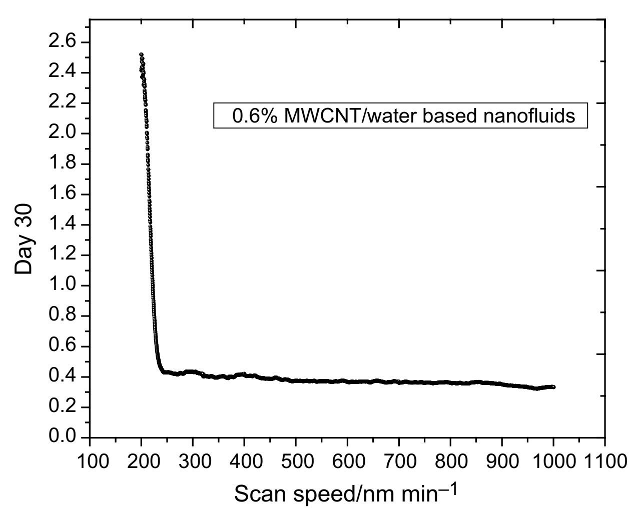


Fig. 1 UV–visible spectroscopy of 0.6% MWCNT/water-based nanofluids

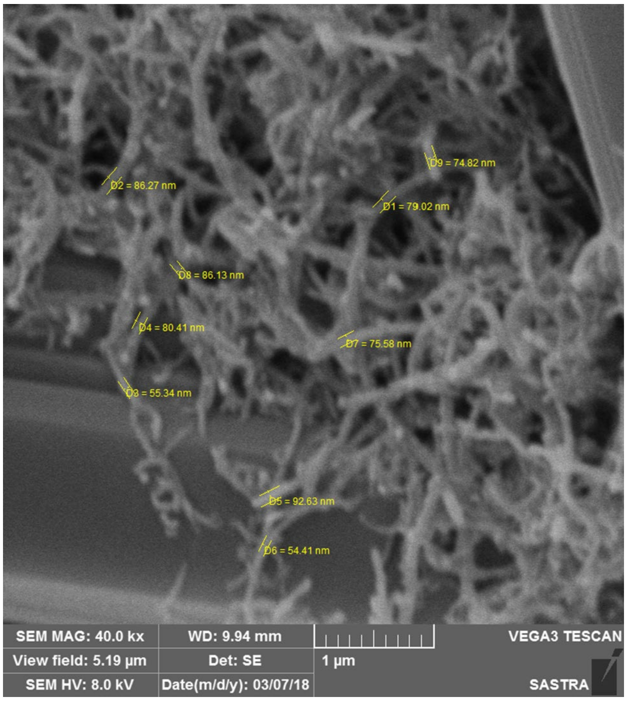


Fig. 2 SEM image of MWCNT/water-based nanofluids

transfer and fluid flow in a helical coil tube. As the magnetic field gradient value and Reynolds number of heat transfer rate and pressure drop are the various parameters investigated in this study, the helical coil tubes are maintained the condition of steady-state flow with constant wall temperature. It is represented that the magnetic field induces the expected Nusselt number. The Nusselt number increases if the magnetic gradient increased, and it is low, if the Nusselt number increase is significantly low. It is concluded that helical coil tubes produced the highest magnetic field efficiency [34].

Jayakumar et al. [35] suggested the geometrical design of helical coil tubes considered for the Nusselt number to evaluate the flow behaviors of the nanofluids. Helical coil pitch values are mainly focused on the design of the helical coil tubes. Two different types of nanofluids are used in this investigation, such as Ag–water and SiO_2, and the convective heat transfer and friction factor are found through helically coiled tubes under constant wall conditions. Different volume fractions and temperatures are adjusted to find the viscosity and thermal conductivity. The range of Reynolds number is 1040–2120. Also, the helical coil parameters are maintained. Using nanofluids in helically coiled tubes is better than straight tubes in increasing the heat transfer efficiency. The friction factor and Nusselt number obtained experimental calculations [36]. Saidur et al. [37] studied the various types of design of heat exchangers. Heavy load heat exchangers worked an effective manner for choosing the coolant in nanofluids. Huminic [38] studied the helical coil heat exchangers and reported that increasing the Dean number is an increased heat transfer rate with varying flow controls. This research work contains two different types of nanofluids (Al_2O_3 and TiO_2), two straight tubes and two microchannel models created. This model is prepared with pitch and curvature ratio maintained for helical coil tubes. Al_2O_3 nanofluids flow inside the coils, and Nusselt number is greater than water. There is nominal friction occurred for flowing the helical coil tubes by adding Al_2O_3 and TiO_2 nanoparticles [39]. Hashemi et al. [40] compared straight tubes and helical coil heat exchangers using CuO/oil nanofluids and get the increased heat transfer in helical coils. It is suggested that helical coil designs majorly focused on performance index to analyze the thermal performance of the heat exchanger.

Nanofluids play the major key role in the heat exchanger for better heat transfer. This study takes the plastic coil for cooling purpose and produces better heat transfer. It is reported that heat transfer flows in counter flow direction hot and cold water circulated in helical coils. It is reported that the heat transfer not correlated with theoretical results based on experimental results [41]. Kumaresan et al. [42] reported that the major problem of using nanofluids in heat exchanger is sedimentation of the nanofluids in coil tubes. They suggested that using a surfactant sodium dodecyl benzene sulfonate stabilizes the nanofluids. Surfactants are maintaining the nanofluids in stable conditions for 30 days. Two different techniques prepare the nanofluids and find the four different methods in heat transfer in nanofluids, and coiled tubes generated and matched. One is a helically coiled tube, and another type is conical coiled tubes with maximum, minimum, and medium diameter pitch diameter size. The velocity of the conical coiled tubes creates the secondary flow. When compared, the helically coiled tube creates better heat transfers, and some deviations occurred in the conical coiled tube. Dean number increased in the helically coiled tube with increasing pitch diameter for the conical tube in secondary flow formation [43].

Jorge et al. [44] reported that it is preparing nanofluids in an ultrasonic bath for 40 min in each liter of nanofluids. High values are compared with scanning electron microscope values to increase heat transfer using MWCNT nanofluids. The MWCNT nanoparticles are mixed with base fluid and submerge with ultrasonic vibrator for 100 watts at 40 min ± 5 kHz, Toshiba, India, with continuous 5 h for each liter of nanofluids. The nanoparticles are dispersed uniformly in the 1 L of base fluid contains 0.2% of surfactant. Surfactants are giving the stability of nanofluids for 30 days. Pak et al. [45] discovered that better mixing of nanoparticles dispersed in base fluids produces greater agglomeration to enhance the overall thermal performances of the heat exchanger.

Double helically coiled tube heat exchanger (DHCTHX)

Rennie et al. [46] represented the double pipe heat exchanger characteristics of the double pipe heat exchanger (DPHE) with turbulent flow conditions. DPHE is based on the performance assessment of the relationship between the heat transfer rate and pressure drop. This method is used to found better heat transfer and pressure drop with the increase in lobes of the tube while the tubes flow in the smooth surface. DPHE produces the better result in three internal and external lobe cross sections. The velocity and temperature distribution of the DPHE are reported.

Xin et al. [47] recommended helical coil heat exchangers used in food processing industries, atomic plants, rescue units, and cooling devices. Vimal et al. [48] compared the single helically coiled heat exchangers to double helically coiled heat exchangers and suggested that the double helically coiled tube heat exchangers are creating the increased thermal performances. Kakac et al. [49] suggested that the selection of a better heat exchanger is a double helically coiled heat exchanger. It is used to give the increased heating or cooling effect. Double helical coils are insulated in cotton materials, and then it is worked in a constant heat flux method. Rennie et al. [50] reported that increasing the mean coil diameter of double helically coiled tube heat exchangers achieves the multiplied overall heat transfer coefficient. Figure 3 shows the test section of the double helically coiled tube.

Experimental setup

Figure 4 represents the schematic diagram of the double helically coiled tube heat exchanger. The experimental setup consists of a double helically coiled tube. Hot water is circulated in the outer coil. MWCNT/water nanofluids circulate the inner loop. In both the coils the flow circulates in laminar flow condition. The external coil connected with the hot water tank (50 L capacity) with a 2KW immersion water heater controlled with a thermostat; a 0.5-hp power hot water pump circulates the hot water. The inner coil tubes are connected with MWCNT nanofluids storage tank and (25 L capacity) with a 0.5-hp power pump fitted with two valves and maintain the flow rates. Straight tubes are winded with wooden pattern and create the double helically coiled tube test section. Both tubes are inserted concentrically and maintained an equal gap between the tubes with filled fine particles of sand. Copper is more thermal conductivity material, so we choose the coil tube in copper for making a double helically coiled tube. A hot water storage vessel fixes the thermostat to control the temperature. Eight (K-type) thermocouples with an accuracy of 0.09 are fitted in the helical tube and found the inlet, middle and outlet temperature. Figure 5 shows the experimental real setup of the double helically coiled tube heat exchanger.

After the fixing thermocouples to avoid the leakage, metal paste is used to arrest the leakage. Two pressure gauges are fitted and measured the pressure of the nanofluids loop. Constant heat flux is maintained for this experimental work, so the test section is insulated with cotton. Rotometer is fixed before the test section of both coil tubes and controls the flow rates in liter per hour (LPH). The inner coil flows the nanofluids, once the nanofluids complete the flow of the test section heat transfer occurred, and nanofluids gain the hot source, so nanofluids are cooled with the help of radiator attachment. Once the experimental setup is ready, initially, water is circulated and checks all the possible sources of fittings and leakages. Then nanofluids are used to find heat transfer performances.

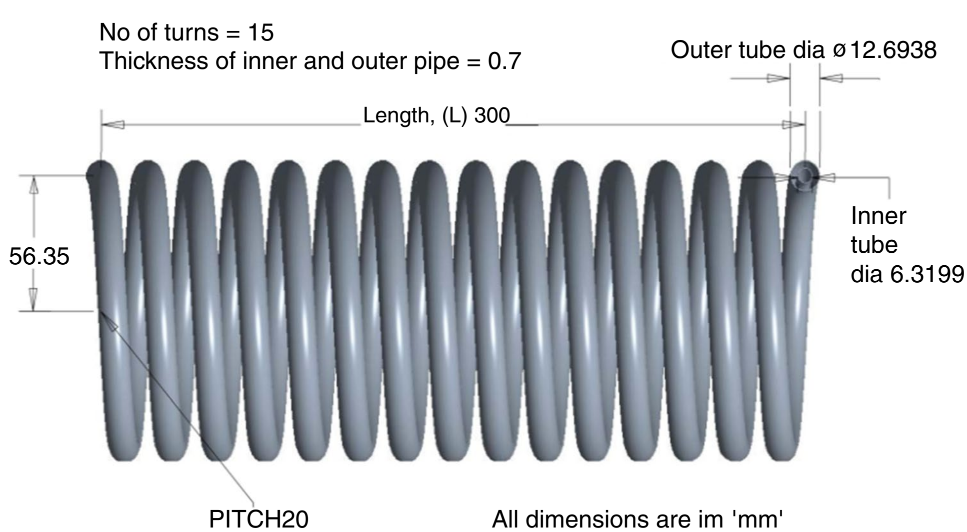


Fig. 3 Test section of double helically coiled tube

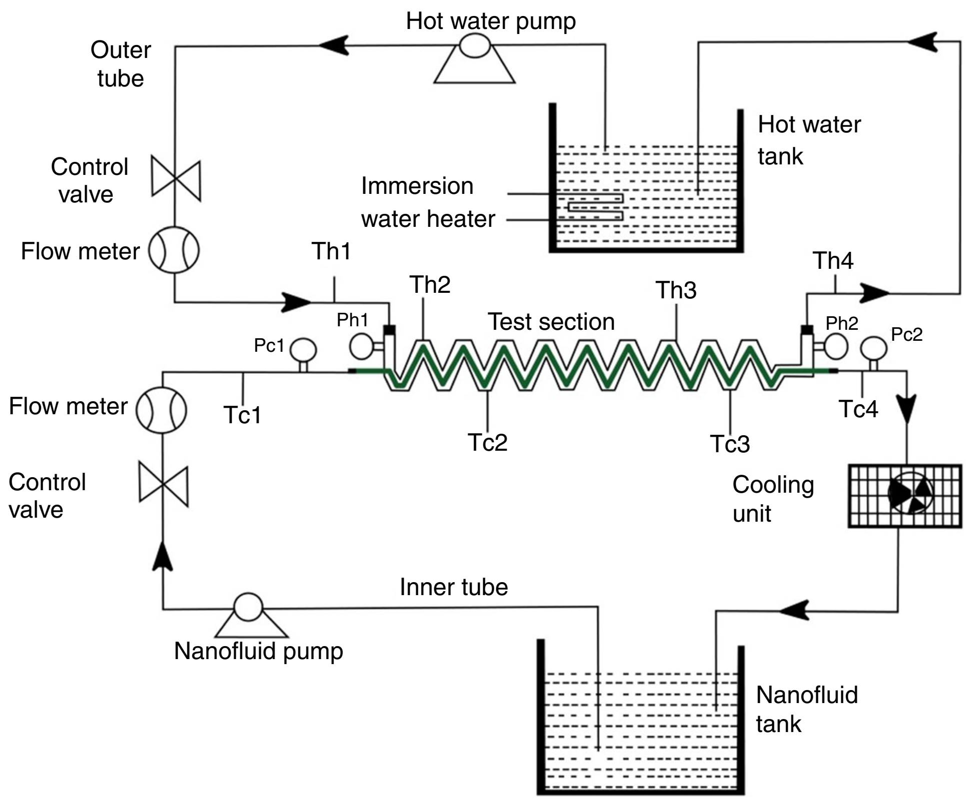


Fig. 4 Layout of double helically coiled tube heat exchanger

Palanisamy et al. [51] studied the cone helical coil heat exchanger using MWCNT nanofluids in various volume concentrations and reported that the better cooling performances give the MWCNT nanofluids and increased thermal behaviors. Mukesh Kumar et al. [52] analyzed the stability of different base fluids and suggested that MWCNT nanofluids are only stable after 30 days of preparation. It is used for heat transfer purposes. Muruganandam et al. [53] studied the internal combustion engines using MWCNT nanofluids as a coolant and reduced the exhaust temperature 10–15% effective manner. Dimensions of the test section are given in Table 2.

Description of experimental facility

The double helically coiled tube test section pitch is maintained in the experimental work entirely. Initially, hot and cold water is circulated in parallel flow conditions. Outer tube circulates the boiling water for 2–3 min to attain a steady-state status. The hot water storage tank maintained the temperature with the thermostat controller provided. Outer coil allows the boiling water, and the inner loop allows the MWCNT nanofluids; the readings are taken and recorded. The inner circle allowed the 0.2% 0.4% and 0.6% volume concentration of MWCNT/water nanofluids and maintained a mass flow rate of 120–180 LPH. Hot water flow rates are kept in constant, and flow rates are various inner coils. K-type thermocouples measure the inlet and outlet temperatures and displayed in the digital display. Measuring jar is used to collect the output fluid using stopwatch; time calculation theoretically calculated the flow rates. This entire experiment is conducted in $1400 < De < 2300$ under the laminar flow condition. The friction factor is calculated for recorded readings. Pressure gauges displayed the pressure drop in each test; the readings are taken and recorded. Due to some uncertainty of the instruments, some of the values slightly varied (Tables 3, 4).

Numerical calculations

Equations (3–6) are used to calculate and find the mass flow rate, heat transfer and velocity of both fluids (hot and nanofluids). Equations (7–10) are used to calculate the overall heat transfer coefficient, Dean number, pressure drop and friction factor for this experimental work. Table 5 represents the data correlations. In this experiment, data correlations utilized Minitab 18 software tool and found the correlation between Dean Number and Nusselt number. Pearson correlation value $r = 0.990$. It is a strong, positive correlation.

Finally, the orthogonal regression Eq. (2) is suggested:

$$\mathrm{Nu} = -0.853 + 0.036 * \mathrm{De} \quad (2)$$

Figure 6 represents the scatter plot comparison between the Dean number and Nusselt number. Figure 7 represents the

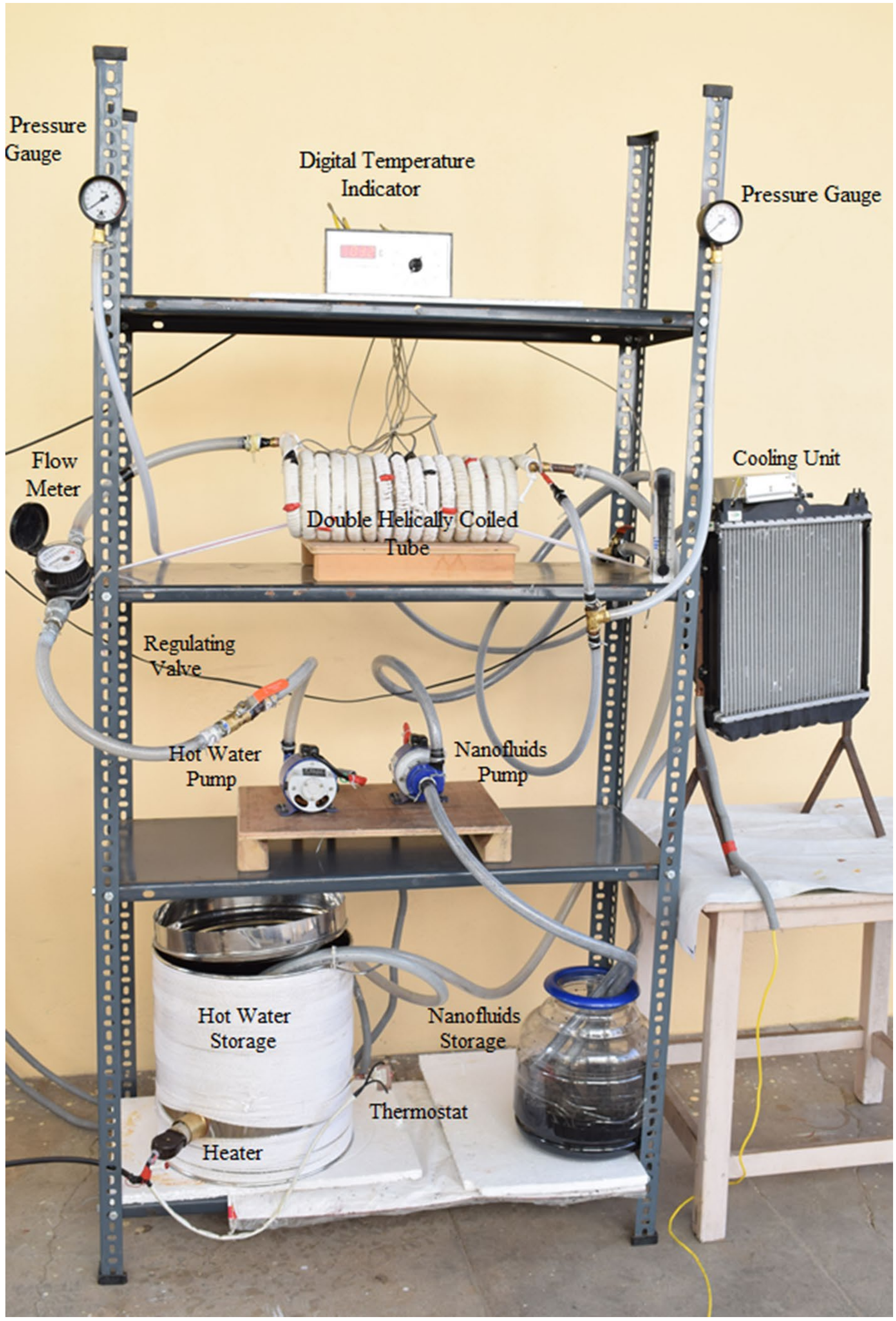


Fig. 5 Experimental real setup (DHCTHX)

Table 2 Dimensional parameters of test section

S. no	Description	Size/units
1	Inner tube diameter	6.3199 mm
2	Outer tube diameter	12.6938 mm
3	Thickness of inner and outer tube	0.7 mm
4	Pitch	20 mm
5	Mean diameter	112.7 mm
6	Effective length of the test section	300 mm
7	Number of turns	15

Table 3 Thermophysical properties of dry MWCNT nanoparticles

Material	True density/cm^3	Bulk density/g cm^3	Length/µm	Outer diameter/nm	Inner diameter/nm
MWCNT	2.1	0.18	10–20	50–80	5–15

Table 4 Thermophysical properties of water and different types of 0.6% volume concentration of nanofluids

S. no	Materials	Density/kg m^{-3}	Specific heat capacity, cp/J kg^{-1} K^{-1}	Thermal conductivity/W m^{-1} K^{-1}
1	Water	997	4187	0.613
2	MWCNT	1660**	2310**	0.888**
3	Al_2O_3	3960	773	0.4
4	Cu O	6006	551	0.33
5	Cu	8940	385	0.40
6	Fe_3O_4	5180	670	0.80
7	TiO_2	4250	692	0.84

Table 5 Experimental data's for Pearson correlation

S. no	Mass flow rate (LPH)	Volume concentration of MWCNT/water-based nanofluids (%)	Dean number (De) X	Nusselt number (Nu) Y
1	120	0.2	1636.66	56.530
2	140		1899.24	68.030
3	160		2182.22	77.798
4	180		2455.50	87.558
5	120	0.4	1437.27	50.935
6	140		1673.00	54.730
7	160		1922.35	67.910
8	180		2163.09	76.400
9	120	0.6	1320.21	47.800
10	140		1536.81	56.070
11	160		1765.78	64.073
12	180		1986.92	72.159

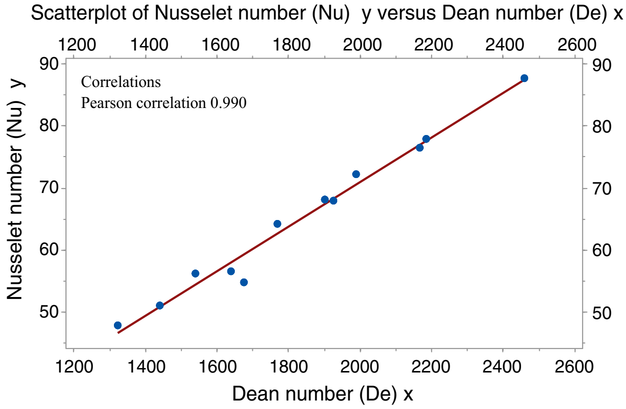
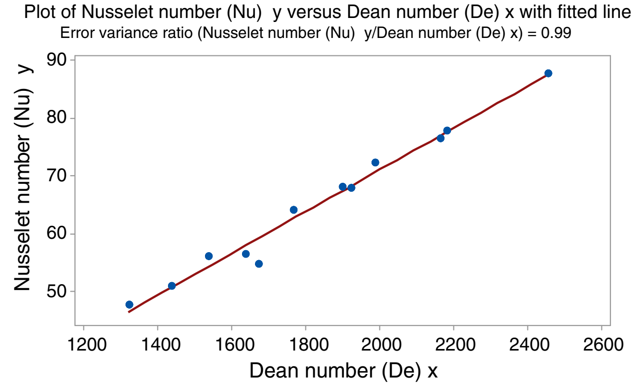


Fig. 6 Scatter plot comparison of De versus Nu



Orthogonal: Nusselet number (Nu) $y = -0.853 + 0.036$ Dean number (De) x

Fig. 7 Orthogonal regression comparison of De versus Nu

orthogonal regression equation for the Dean number and Nusselt number

Heat flow rate of hot fluid $Q_h = M_{\mathrm{h}} * C_{\mathrm{p}}\left(T_3 - T_4\right) * 1000$

$$= 0.05 * 4.186 * (65 - 56) * 1000$$
$$= 1883.7 \left(\mathrm{J\ s^{-1}}\right)$$

Heat flow rate of nanofluids $Q_{\mathrm{nf}} = M_{\mathrm{nf}} * C_{\mathrm{p}}\left(T_2 - T_1\right) * 1000$

$$= .0830 * 2.21(48 - 31) * 1000$$
$$= 3259.41 \left(\mathrm{J\ s^{-1}}\right)$$

$$\text{Overall heat transfer coefficient } U_o = \frac{Q}{A_o lmtd} = 3259.41/(0.1217 * 20.76) = 1291.14\ \left(\text{w m}^{-2}\ \text{k}^{-1}\right)$$

$$\text{Reynolds number } R_e = \frac{\rho v D}{\mu} = 1660 * 1.9264 * .00635/\left(2.5652 * 10^{-3}\right) = 7916.02$$

$$\text{Dean number } D_e = R_e(r/R)^{0.5} = 7916.02 * (0.251) = 1986.921$$

$$\text{Inner heat transfer coefficient } h_i = \frac{Q_c}{A_{io}\left(T_2 - T_1\right)} = 3259.41/(0.0199 * (48 - 31)) = 10091.021\ \left(\text{w m}^{-2}\ \text{k}^{-1}\right)$$

$$\text{Nusselt number for nanofluids } N_{unf} = \frac{h_{nf} * d_{nf}}{K_{nf}} = 10091.021 * .00635/0.888 = 72.159$$

$$\text{Nusselt number for hot fluid } N_{uh} = \frac{h_h * d_h}{K_h} = 5367.52 * 0.0127/0.628 = 108.54$$

$$\text{Friction factor } f = \frac{\Delta p * Di}{2 * \rho * v^2 L} = \left(0.6 * 10^5 * 0.00635\right)/\left(2 * 1660 * 1.9264^2 * 5\right) = 0.030$$

$$\text{Mass flow rate } m = Q * \rho \text{ kg m}^{-3} \tag{3}$$

$$\text{Heat transfer rate } Q_{nf} = m_{nf} Cp_{nf}\left(T_{nf,in} - T_{nf,out}\right) \text{ J s}^{-1} \tag{4}$$

$$\text{Velocity of hot fluid } Vhot = \frac{Qhot}{1000 * \text{Area}} \text{ m s}^{-1} \tag{5}$$

$$\text{Velocity of cold fluid } Vcold = \frac{Qcold}{1000 * \text{Area}} \text{ m s}^{-1} \tag{6}$$

$$\text{Heat transfer coefficient } U_0 = \frac{q}{A * \text{LMTD}} \tag{7}$$

$$\text{Dean number } De_{nf} = \text{Re}\left(\frac{Di}{2R_o}\right)^{0.5} \tag{8}$$

$$\text{Friction factor } fc = \frac{\Delta p * D}{(2\rho v^2 L)} \tag{9}$$

$$\text{Pressure drop } \Delta p = \frac{\rho L v^2}{2g} \tag{10}$$

Uncertainty analysis

Analysis of uncertainty is used to measure the deviation of heat transfer rate and friction factor results. Coleman et al. [54] proposed uncertainty method in this investigation and the results were analyzed. Uncertainty is obtained from errors in the heat transfer rate as well as friction factor measurement. Table 6 mentions the uncertainty analysis of the experiment specifications. Finally, it is found that the heat transfer uncertainty is less than 0.99%.

Results and discussion

Overall heat transfer coefficient of MWCNT/water-based nanofluids

Figure 8 represents the comparison between the overall heat transfer coefficients of MWCNT/water-based nanofluids. It is clearly shown that 0.6% MWCNT/water-based nanofluids give the overall heat transfer coefficient in the laminar flow regime. Dean number range 1400–2200 is maintained.

Figure 9 represents the comparison of the experimental inner heat transfer coefficient with the tube side Dean number. It is shown that increased volume concentration of nanofluids increases the heat transfer. 0.6% of the volume concentration of nanofluids gives significant improvement. Helical coil tubes make the secondary flow formation so that nanoparticles are mixed with low fluid easily and also the stability of nanofluids maintained.

Table 6 Uncertainty analysis of the experiment specifications

S. no	Specifications	Uncertainty level
1	Copper tube diameter	±0.04 mm
2	Copper tube length	±0.6 mm
3	Heat transfer rate	±0.6 °C
4	Friction factor	±0.2
5	Pressure	±0.045 bar

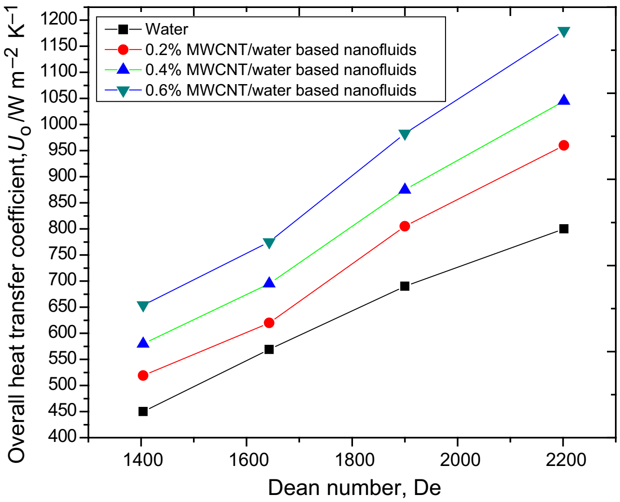


Fig. 8 Experimental overall heat transfer coefficient with tube side Dean number

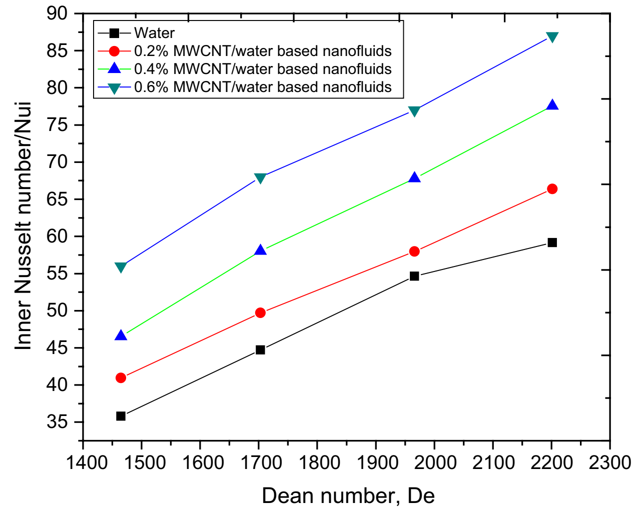


Fig. 10 Experimental inner Nusselt number with tube side Dean number

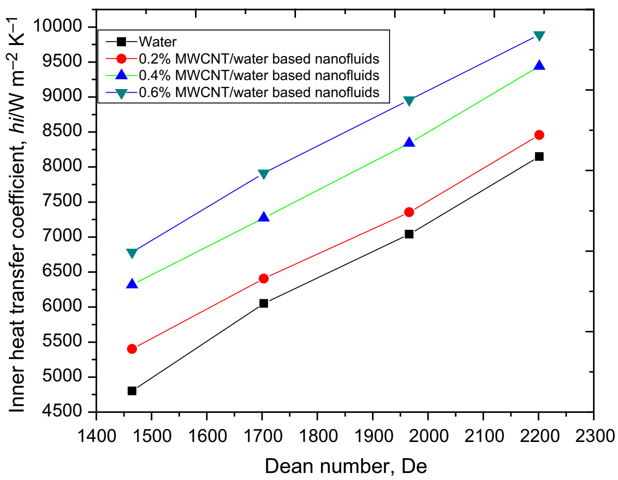


Fig. 9 Experimental inner heat transfer coefficient with tube side Dean number

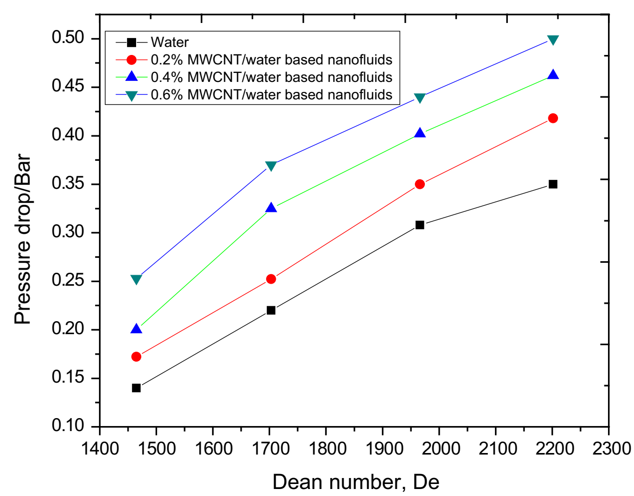


Fig. 11 Experimental pressure drop for the double helically coiled tube

Figure 10 shows the experimental inner Nusselt number with tube side Dean number. Helical coils formed secondary flow, but MWCNT nanofluids do not allow creating the secondary flow formation in the tube side. MWCNT makes the Brownian motion of the fluids flowing in coil tubes.

Effect of pressure drop and friction factor

Figure 11 represents the experimental pressure drop for the double helically coiled tubing. Pressure drop occurred due to the increasing volume concentration of nanofluids. It is reported that 0.6% MWCNT/water-based nanofluids make the pressure drop compared to that of water. The velocity of nanofluids increased and pressure drop increased.

Figure 12 shows that the friction factor decreases with increasing MWCNT/water nanofluids volume concentration and Dean number with an increase in viscosity when increasing the particle volume concentration. It confirms that the significant friction factor occurred at 0.6% MWCNT/water nanofluids in the maximum Dean number.

Conclusions

In this research work, a double helically coiled tube heat exchanger using 0.2%, 0.4% and 0.6% volume concentration of MWCNT water-based nanofluids in laminar flow condition, the convective heat transfer and friction factor

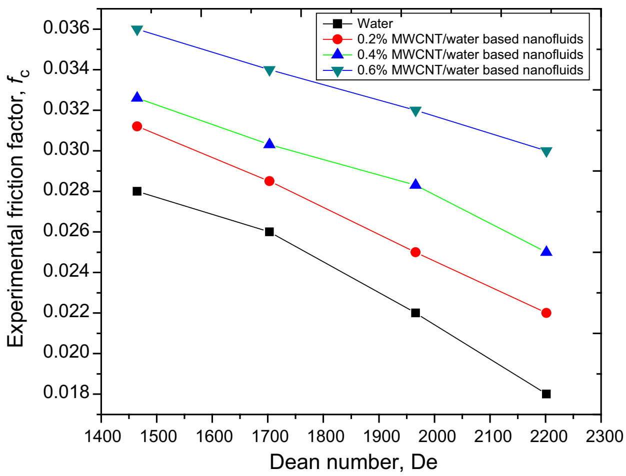


Fig. 12 Experimental friction factor for the double helically coiled tube

analysis is determined. This experiment was conducted with constant heat flux method and a laminar flow regime in the range of 120–180 L h^{-1}. The 0.2–0.6% volume concentration of MWCNT/water-based nanofluids was prepared by using two-step methods. It is conceived that the MWCNT/water-based nanofluids had produced a higher convective heat transfer compared with water. It is also perceived that heat transfer increases with an increasing volume concentration of MWCNT/water-based nanofluids. Finally, the highest convective heat transfer 35% was recorded at a 0.6% volume concentration of MWCNT/water-based nanofluids at 140 L h^{-1} flow rate and at 1400 Dean number. It is drawn that the friction factor using MWCNT nanofluids is 40% greater than Water with Dean number range 1400–2400. Finally, it is concluded that the double helically coiled tube heat exchanger using MWCNT water-based nanofluids is a better replacement for the other cooling mediums with a nominal amount of friction factor. Therefore, the utilization of MWCNT water-based nanofluids has vast possible usage of a DHCTHX.

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