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Experimental Study on the Effect of TiO_2–Water Nanofluid on Heat Transfer and Pressure Drop in Heat Exchanger with Varying Helical Coil Diameter

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ABSTRACT

The growing demand for efficient heat exchangers has promoted extensive research in exploring advanced heat transfer fluids and novel geometries. This paper investigates the heat transfer and pressure drop characteristics in helical coil heat exchanger employing water-based TiO_2 as nanofluid. The utilization of nanofluids offers promising enhancements in thermal conductivity and convective heat transfer in heat exchanger applications. The effect of nanofluid concentration and flow rate on heat transfer and pressure drop with varying helical coil diameter performance is investigated. Experimental tests were conducted using a heat exchanger with different helical coil pipe diameters of 9.53mm, 12.7mm and 15.88mm with constant pitch of 30mm and varying concentrations of TiO_2 nanoparticles in water (ranging from 0.1% to 0.5% by volume). The heat transfer coefficient and pressure drop were measured at different operating conditions. The results shows that the addition of TiO_2 nanoparticles to water significantly enhanced the heat transfer performance in the helical coil heat exchanger. There is an enhancement in heat transfer coefficient with increasing nanofluid concentration and with increase in pipe diameter. The maximum enhancement in heat transfer coefficient is observed at nanofluid concentration of 0.5% and for pipe diameter of 15.88 mm. However, there is increase in pressure drop with increase in nanofluid concentration and with decreasing pipe diameter. The pressure drop found to be higher for nanofluids compared to pure water. The maximum pressure drop is observed at a concentration of 0.5% and for pipe diameter 9.53mm. In conclusion, the use of a water-based TiO_2 nanofluid in a helical coil heat exchanger offers improved heat transfer performance compared to pure water. However, the pressure drop also increases with nanofluid concentration and decreasing pipe diameter. Therefore, a trade-off between heat transfer enhancement and pressure drop should be considered in the design and operation of such heat exchangers.

1. Introduction

Heat exchangers play a crucial role in various industries, including power generation, chemical processing, and refrigeration. Enhancing the heat transfer efficiency of these devices is essential for improving overall system performance and energy utilization. The utilization of nanofluids, which are

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colloidal suspensions of nanoparticles in a base fluid, has emerged as a promising approach to achieve higher heat transfer rates Wagd Ajeeb *et al.,* [1]. Keblinski *et al.,* [2] in this paper contributes to the understanding of heat transfer mechanisms in nanofluids and provides insights into the factors influencing their thermal conductivity. It is a valuable resource for researchers studying nanofluids and their applications in various fields, including heat exchangers, cooling systems, and thermal management. Xuan *et al.,* [3] The study focuses on conducting experimental investigations to explore the convective heat transfer behaviour of nanofluids. The researchers prepared nanofluids by dispersing nanoparticles (such as Cu, Al_2O_3, and SiO_2) in base fluids (such as water and ethylene glycol) and examined their heat transfer performance. The experimental results demonstrate that nanofluids exhibit significantly enhanced convective heat transfer compared to their base fluids. Murshed *et al.,* [4] The study examines the experimental and theoretical investigations conducted to understand the thermal conductivity behaviour of nanofluids. It discusses the factors influencing thermal conductivity enhancement, including the type, size, and concentration of nanoparticles, as well as the base fluid properties. The review emphasizes the challenges associated with accurate measurement techniques and the discrepancies in reported data. Kole *et al.,* [5] The experimental findings demonstrate that the presence of TiO_2 nanoparticles in water enhances the heat transfer coefficient in the double-pipe heat exchanger. The heat transfer enhancement is observed to increase with increasing nanoparticle concentration. The researchers discuss the possible mechanisms responsible for the improved heat transfer, including nanoparticle agglomeration and changes in fluid properties. Timofeeva *et al.,* [6] measure several thermophysical properties of the nanofluids, including thermal conductivity, viscosity, and specific heat capacity. The experimental setup and measurement techniques used for each property are explained in detail. Madhu *et al.,* [7] presents the experimental results obtained for heat transfer and pressure drop in the helical coil heat exchanger using the TiO_2 nanofluid. The researchers analyse the data and discuss the variations in heat transfer coefficient and pressure drop with respect to different parameters, such as nanoparticle concentration and coil pitch. Madhu *et al.,* [8] The study presents the experimental results obtained for heat transfer in the helical coil heat exchanger with varying pitch. The researchers analyse the data and discuss the variations in heat transfer coefficient and Nusselt number with respect to different pitches. Sridharan *et al.,* [9] The paper discusses the pressure drop characteristics observed in the helically coiled heat exchanger. The researchers analyse the effect of coil diameter on pressure drop and investigate the flow patterns and fluid behaviour within the coil. Joshi *et al.*, [10] the paper presents an experimental investigation of heat transfer enhancement in a helical coil heat exchanger with varying coil diameter. The study provides insights into the effects of coil diameter on heat transfer performance and emphasizes the importance of optimizing the coil geometry for efficient heat exchange. These findings contribute to the understanding of helical coil heat exchangers and offer practical implications for their design and application in various industries. Kriksunov *et al.,* [11] The study numerical simulations to complement the experimental investigations. The researchers describe the numerical model used to simulate the heat transfer and fluid flow in the helical coil heat exchanger. They discuss the governing equations, boundary conditions, and numerical methods employed. Buonomo *et al.,* [12] The researchers provide details about the geometry of the helical coil heat exchanger and explain the meshing strategy employed in the numerical analysis. They discuss the importance of capturing the coil geometry accurately for reliable simulations. Yıldırım *et al.,* [13] Based on the experimental results, the authors conclude that coil diameter significantly affects the heat transfer and pressure drop characteristics in helical coil heat exchangers. They emphasize the importance of optimizing the coil diameter to achieve efficient heat transfer while considering the associated pressure drop. The findings provide valuable insights for the design and operation of helical coil heat exchangers. *Jalili et al.,* [14] The study investigates the behaviour of a micro-polar nanofluid under the influence of various factors, including thermophoresis, Hall currents, Brownian motion, and rotation. A nanofluid is a mixture of nanoparticles in a base fluid, and the addition of nanoparticles can significantly alter its thermophysical properties. Payam Jalili *et al.,* [15] The study presents a new analytical approach to analyse the thermal behaviour of micro-polar nanofluids under the influence of thermophoresis, Brownian motion, and Hall currents. Micro-polar nanofluids are complex fluids that contain suspended nanoparticles and exhibit micro-scale rotational effects, making their thermal behaviour different from traditional fluids. Jalili *et al.,* [16] The study presents a new hybrid analytical and numerical technique to analyse heat transfer in a cylindrical polar system subjected to a magnetic field. Cylindrical polar systems are three-dimensional coordinate systems commonly used to describe physical phenomena in cylindrical geometries. The presence of a magnetic field adds complexity to the heat transfer process, making it a subject of interest for various engineering and scientific applications. Payam Jalili *et al.,* [17] The study focuses on investigating the thermal distribution in a hybrid nanofluid flowing through an oblique artery with mild stenosis. An oblique artery refers to a blood vessel with a non-perpendicular angle to the direction of flow, and stenosis is the narrowing of the artery due to the buildup of plaque or other factors. Hybrid nanofluids are composite fluids containing nanoparticles that enhance their thermal properties. P Jalili *et al.,* [18] The study focuses on the heat transfer analysis of ALOOH (Aluminium Oxide Hydroxide) nanofluid and water mixture flowing through a microchannel heat sink. A microchannel heat sink is a device used for cooling electronic components and other small-scale applications where efficient heat dissipation is required. ALOOH is a type of nanofluid, which is a suspension of nanoparticles in a base fluid, known for its enhanced thermal properties. Panel Bahram Jalili *et al.,* [19] The study investigates a novel application of a curved rectangular fin to enhance the heat transfer in a double-pipe heat exchanger when using a nanofluid. Heat exchangers are devices designed to transfer heat between two fluids, and they are widely used in various industries for efficient heat transfer applications. Nanofluids, which are colloidal suspensions of nanoparticles in a base fluid, are known to offer improved thermal properties. Bahram *et al.,* [20] The study focuses on the analysis of a squeezing flow of a Casson fluid between two circular plates. Casson fluid is a type of non-Newtonian fluid characterized by a yield stress and exhibits different flow behaviours compared to traditional Newtonian fluids. The fluid flow between the plates is likely driven by the motion of the plates, which results in the squeezing effect. Ramadhan *et al.,* [21] The study focuses on investigating the heat transfer and friction factor characteristics of a plain tube using hybrid nanofluids. Nanofluids are a combination of nanoparticles and base fluids, known for their enhanced heat transfer properties. The researchers conducted both experimental and numerical analyses to explore the heat transfer and frictional behaviour of the plain tube. Azmi *et al.,* [22] The study focuses on investigating the thermal hydraulic performance of a tube with wire coil inserts using hybrid nanofluids composed of TiO_2 and SiO_2 nanoparticles. Nanofluids are known for their improved heat transfer properties, and the addition of wire coil inserts can further enhance heat transfer in heat exchangers and other thermal systems. Fikri *et al.,* [23] The study examined the effects of varying the concentration of TiO_2 and SiO_2 nanoparticles, as well as the proportion of water and ethylene glycol in the mixture, on the thermal performance of the nanofluid. The researchers aimed to determine the optimal composition that would maximize the heat transfer efficiency for solar applications.

The objective is to determine the impact of TiO2-water nanofluid on heat transfer in a helical coil heat exchanger. The study aims to quantify the enhancement in heat transfer performance compared to traditional working fluids, such as pure water, The study aims to investigate how varying the helical coil diameter affects the heat transfer and pressure drop characteristics when using TiO_2-water nanofluid. By altering the coil diameter, the research aims to identify trends between the coil diameter and the observed heat transfer and pressure drop performance.

2. Methodology

The experimental setup for the study is represented by a line diagram and an image, as depicted in Figure 1 and Figure 2, respectively.

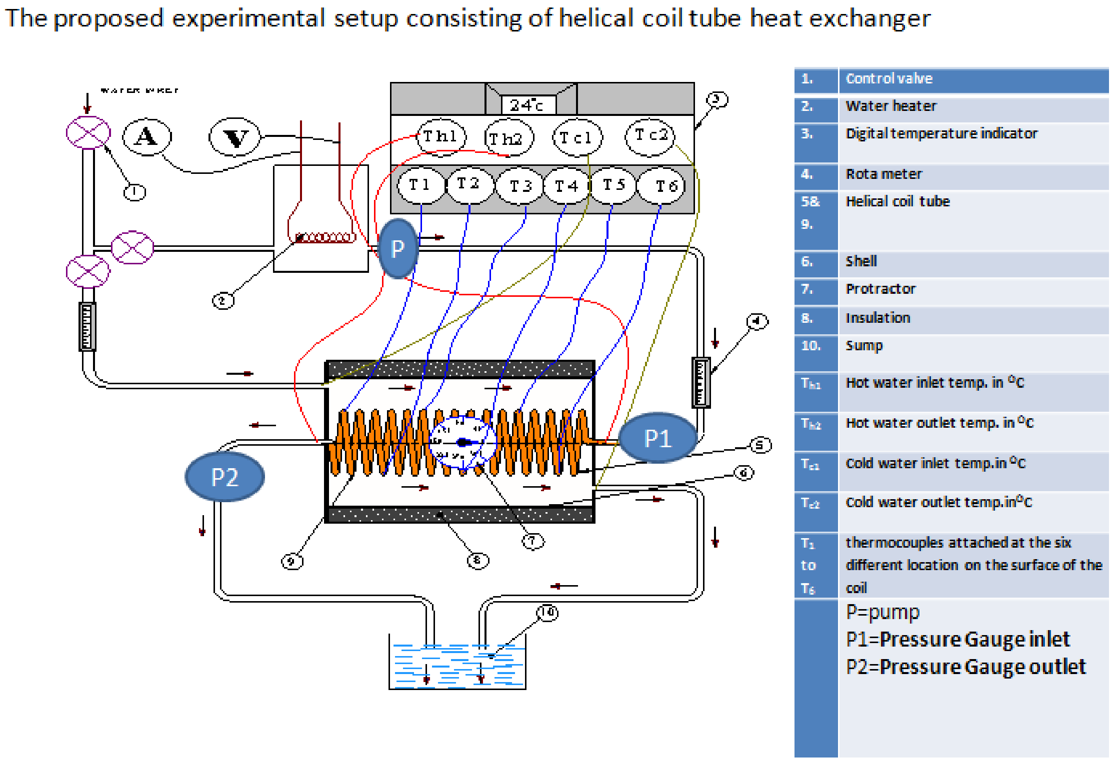
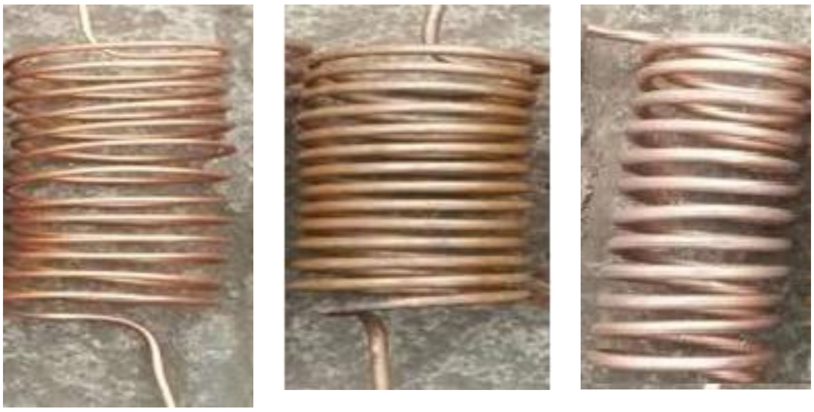


Fig. 1. Line diagram of the Experimental setup

The image of the test section is presented in Figure 3. The experimental setup consists of two loops, each serving a specific purpose. The first loop is responsible for handling the nanofluids and includes a helically coiled tube side. This loop is connected to a storage tank, a 2KW capacity heater, and a pump.

Fig. 1. Pitch-variable helical coils

The nanofluids are circulated within this loop to facilitate the heat transfer process. The second loop is dedicated to the shell side and deals with cold water. It comprises a 0.5 horsepower pump, a valve for flow control on the tube side, and a test section. This loop allows for the circulation of cold water, which acts as the heat sink, in the shell. To minimize heat loss, glass wool is employed to insulate the exterior of the shell. This insulation helps maintain the desired thermal conditions within the system. Table 1 provides the details regarding the geometry of the three helical coiled tubes used in the research work.



(a) d_o = 9.53(3/8”) (b) d_o =12.7(1/2”) (c) d_o =15.88(5/8”)

Fig. 3. Helical Coils with varying diameter and constant pitch = 30m

The helical coil with varying diameter and a constant pitch might be chosen in certain engineering or scientific applications. Heat Transfer Enhancement of Helical coils are often used in heat exchangers to improve heat transfer efficiency. By varying the diameter along the coil, the fluid flow pattern can be manipulated to enhance heat transfer between the fluid and the coil's outer surface. This can be beneficial in applications where efficient heat transfer is crucial, such as in refrigeration systems or industrial heat exchangers. Pressure Drop Control of Varying the coil's diameter can help control the pressure drop across the coil. By carefully designing the coil's geometry, engineers can achieve the desired pressure drop to optimize fluid flow in a system. Compact Design of Helical coils with varying diameter and constant pitch can allow for a more compact design of heat exchangers or other fluid systems. This is especially important in applications where space is limited, and efficient use of available space is essential. Flow Distribution of the variation in diameter can help achieve better flow distribution within the coil. This can prevent flow maldistribution and ensure that all parts of the coil contribute evenly to the heat transfer process. Improved Performance of the combination of varying diameter and constant pitch can lead to better overall performance in certain applications compared to traditional straight tubes or coils. The enhanced heat transfer and pressure drop characteristics can result in improved system efficiency. Turbulence Promotion of the Varying the coil's diameter can induce turbulence in the fluid flow, which can further enhance heat transfer. Turbulence disrupts the boundary layer and promotes better mixing, leading to more effective heat exchange.

Table 1
Geometry of helical coils utilized Madhu *et al.,* [7]

Helical coils	Coil -1	Coil -2	Coil -3
P(mm)	30	30	30
Material Type	Copper		
k_c at atmospheres	386		
N	13.5	13.5	13.5
R_c(mm)	74.9	74.9	74.9
r(mm)	3.952	5.537	7.051
δ	0.0527	0.0739	0.0941
d_o (mm/inch)	9.53(3/8″)	12.7(1/2″)	15.88(5/8″)
d_i (mm)	7.904	11.074	14.102
L (m)	6.706	6.706	6.706
a_o(m^2)	0.2007	0.2675	0.334559
a_i ($m^{2)}$	0.16652	0.2333	0.2971

2.1 Experimentation

In their experimental research, HE conducted a comprehensive analysis of the heat transfer characteristics within helical coil tubes using a water-based nanofluid containing Titanium Dioxide. The study focused on investigating the effects of varying volume concentrations (ranging from 0% to 0.5%) and outer diameters of the helical coil tubes (9.53mm, 12.7mm, and 15.88mm) while maintaining a constant pitch of 30mm. At low concentrations, nanofluids tend to exhibit better stability, reduces issues related to sedimentation and agglomeration of nanoparticles [40]. Proper stability is crucial for the long-term performance and reliability of nanofluids. The research primarily examined the influence of the heat transfer coefficient (Nu), friction factor (ΔP), and Dean Number (De) on heat transfer within the helical coil tube. The flow pattern in the helical coil tube was turbulent, and a counter flow configuration was adopted. During the analysis of the heat transfer characteristics, several assumptions were made. It was assumed that the helical coil tube system was perfectly insulated, resulting in no heat loss to the environment during the experimental flow conditions. The fluid was considered to remain in a single phase throughout the heat transfer process, and the thermal sensitivity and specific heat capacity of the helically coiled tube were assumed to be constant. Negligible changes in potential and kinetic energy were also assumed, and the heat resistance of the liquid film was disregarded. By considering these assumptions, the experimental study aimed to provide valuable insights into the heat transfer behaviour within helical coil tubes and the impact of nanofluid volume concentrations and tube dimensions on the heat transfer performance.

2.1.1 Experimental procedure

To ensure the integrity of the experimental setup and to check for any potential leaks, an initial water supply was utilized. After thorough inspections and verifications, regular water was directed to flow through the shell side, while hot water was circulated through the helical coil tube. The temperature of the water heater was set to approximately 48°C upon activating the control panel because at this hot fluid temperature helical coil tube doesn’t show any thermal deformation, while the cold-water temperature was maintained at 24±1°C. The pitch of the coil was fixed at 30mm once the heat exchanger was activated. Flow regulation of the fluids was achieved using control valves, and the flow rates were measured using rotameters. For the cold water supplied to the shell inlet, a constant flow rate of 4.5 LPM was maintained throughout the evaluations. In each evaluation, the flow rate of the hot water through the coil tube was adjusted to different rates, ranging from 3.6 to 4.2 LPM for Mass flow rate selected to conduct test in corresponding to require range of Reynolds number. Titanium dioxide nanoparticles suspensions with varying volume concentrations (ranging from 0% to 0.5%) were prepared using distilled water. The shell side received cold water, while the helically coiled tube was supplied with nanofluids containing volume concentrations of 0%, 0.1%, 0.2%, 0.3%, 0.4%, and 0.5%. Temperature and mass flow rate readings were recorded for both fluids. Throughout the experiments, helical coil tubes with diameters of 9.53mm, 12.7mm, and 15.88mm were utilized while maintaining a constant pitch of 30mm and a consistent curvature ratio. By following this experimental procedure, the researchers aimed to investigate the effects of volume concentration and tube dimensions on the heat transfer characteristics within the helical coil tubes under study.

2.2.2 Uncertainty of instruments

The uncertainties in the experimental parameters are evaluated with the method suggested by Moffat *et al.,* [40]. Table 2 shows parameters varied in the present study. See nomenclature for definition of the various parameters. The uncertainty in measurement of the average Nusselt number is approximately 2.18 % and Friction factor 1 %.

Table 2
Error in the measured parameters

Parameter	Error in measurement
P, R_c, d_o	±0.1mm
T (hot and Cold fluid)	±0.1°C
P1, P2	±0.01kg/cm^2
$\dot{m}_h$,$\dot{m}_{hc}$	±0.1 kg /sec

2.3 Data Reduction

i. **L**, required to perform N turns as Eq. (1)

$$L = (l + (N\sqrt{(2\pi R_C)^2 + P^2})) \quad (1)$$

l = both sides of an extended straight tube measure 340mm.

ii. Log mean temperature difference, as Eq. (1)

$$\mathrm{LMTD} = \Delta \mathrm{T}_{lm} = \frac{(\Delta T_2 - \Delta T_1)}{(\frac{\Delta T_2}{\Delta T_1})} \quad (2)$$

iii. Thermophysical properties of nanofluids as Eq. (3) to Eq. (5)
The density of TiO_2 nanofluids is found using (Pak and Cho) [27] equation

$$\rho_{nf} = \phi\rho_{p} + (1-\phi)\rho_f \quad (3)$$

Heat capacity, viscosity, and thermal conductivity are the three main factors that go into calculating the nano fluid's rate of heat transfer; these 3 factors may vary significantly from the pure fluid's original.

(Xuan and Roetzel) [26] Eq. (4) is used to calculate the specific heat

$(\rho C_p)_{nf} = (1-\phi)(\rho C_p)_f + \phi\,(\rho C_p)_p$ (4)

The fluid's nanoscale viscosity is measured using this equation.

$\mu_{nf} = \mu_f\,(1+2.5\phi)$ (5)

iv. The rate of heat transfer as Eq. (6) to Eq. (8) and surface area of the helical coil pipe as Eq. (9)

$$Q_h = \dot{m}_h C_h (T_{h1} - T_{h2}) \quad (6)$$

$$Q_c = \dot{m}_c C_c (T_{c2} - T_{c1}) \quad (7)$$

$$Q_{actual} = \frac{Q_h + Q_c}{2} = U_o a_o \Delta T_{lm} = U_i a_i \Delta T_{lm} \quad (8)$$

$a_i = \pi d_i L$ and $a_o = \pi d_o L$ (9)

v. The heat transfer coefficient calculated by using following relationship in Eq. (10) to (13)

$$h_i \frac{Q}{a_i(T_{h(avg)} - T_{is})},\ h_o \frac{Q}{a_o(T_{os} - T_{c(avg)})} \quad (10)$$

$$T_{h(avg)} = \frac{T_{h1} + T_{h2}}{2} \quad (11)$$

$$T_{c(avg)} = \frac{T_{c1} + T_{c2}}{2} \quad (12)$$

T_{os} is the mean temperature of the outside coil surface (calculated as the mean of six thermocouple readings taken at six different coil surface locations), T_{is} the coil's average interior surface temperature can be estimated using the formula below.

$$Q = \frac{2\pi k_c L (T_{is} - T_{os})}{\ln\left(\frac{\frac{d_o}{2}}{\frac{d_i}{2}}\right)} \quad (13)$$

vi. Thermal conductivity of nanofluid is measured by Maxwell equation as Eq. (14)

$$\frac{k_{nf}}{k_f} = \frac{k_p + 2k_f - 2\phi(k_f - k_p)}{k_p + 2k_f + \phi(k_f - k_p)} \quad (14)$$

vii. Nusselt Number: The ratio of temperature gradients by conduction and convection at the surface as Eq. (15) to Eq. (16)

$$\text{Inside Nusselt number} = N_{ui} = \frac{h_i d_i}{k_{nf}} \quad (15)$$

$$\text{Outside Nusselt number} = \mathrm{N_{uo}} = \frac{h_o d_o}{k_{nf}} \quad (16)$$

viii. A stream's flow rate is determined by multiplying its cross-sectional area by its flow velocity (speed). as Eq. (17)

$$V_i = \frac{\dot{\mathrm{m}}_\mathrm{h}}{\rho\mathrm{nf}\times\mathrm{A_i}} \quad (17)$$

ix. Reynolds Number (Re): a dimensionless number used in fluid mechanics to represent the steady or turbulent nature of fluid flow past a body or in a duct as Eq. (18)

$$\mathrm{Re} = \frac{\mathrm{d_i V_i \rho nf}}{\mu\mathrm{nf}} \quad (18)$$

x. The Dean number (De): A dimensionless group in fluid mechanics, which occurs when researching flow in arched pipes and arches.
In order to describe the flow in a helical pipe, one uses the De. as Eq. (19)

$$\mathrm{De} = Re\sqrt{\mathrm{r/R_c}} \quad (19)$$

xi. Friction factor calculations (f): The following relation is used to calculate the friction factor under isothermal conditions from the pressure drop. the Darcy–Weisbach equation as Eq. (20)

$$f = (\Delta P/0.5\rho\mathrm{v}^2)(d/L) \quad (20)$$

xii. In a cylindrical pipe of uniform diameter *D*, flowing full, the pressure loss due to viscous effects Δp is proportional to length *L* and can be characterized by the Darcy–Weisbach equation.

xiii. The Blasius equation for turbulent flow consider is used to validate it as Eq. (21)

$$\frac{0.316}{Re^{0.25}} \quad (21)$$

(3000≤Re≤20000) the flow is turbulent

xiv. The *Nusselt number for inside heat transfer* equation for turbulent flow consider is used to validate it: as Eq. (22)

$$Nu = 0.025De^{0.9112}Pr^{0.4} \quad (22)$$

Which is applicable to 2000<De<12000.

xv. The Prandtl number depends on the nanofluid’s thermal conductivity, specific heat, and viscosity. Equation depicts the formula used by Palesa Helen Mlangeni *et al.,* [42] and other researchers to analyses the nanofluid Prandtl number in scientific literature as Eq. (23)

$$\mathrm{Pr_{nf}} = \frac{\mu_\mathrm{nf}\mathrm{Cp_{nf}}}{\mathrm{k_{nf}}} \quad (23)$$

3. Results and Discussion

Discussion of heat transfer characteristics water-based Nano fluid Titanium Dioxide using different volume concentrations (0-0.5%) of in a Varying diameter of 9.53mm, 12.7mm and 15.88mm with constant pitch 30mm helical coil tube. In order to investigate the heat transfer characteristics in a helical coil tube heat exchanger, experimental investigations were conducted. The study focused on examining the impact of various factors, including the Dean Number, mass flow rate, heat transfer coefficient, pressure drop, friction factor, and Nusselt Number. Both the inner helical coil tube and the shell (annulus) were subject to turbulent flow, and the flow configuration employed was counter flow. During the experimental study, water-based Nano fluid Titanium Dioxide was utilized, with different volume concentrations ranging from 0% to 0.5%. The helical coil tube had a constant pitch of 30 mm, while the diameter varied, with three different sizes investigated: 9.53 mm, 12.7 mm, and 15.88 mm. These variations in diameter allowed for an examination of how the heat transfer characteristics were influenced by the size of the helical coil tube.

3.1 Validation of Experimental Setup
3.1.1 Validation of Nusselt number

The Nusselt number depends on the Dean number and Prandtl number Equation depicts the formula used by J.S. Jayakumar *et al.,* [41]. The Prandtl number depends on the nanofluid's thermal conductivity, specific heat, and viscosity. Equation depicts the formula used by Palesa Helen Mlangeni *et al.,* [42] and other researchers to analyses the nanofluid Prandtl number in scientific literature. **Error! Reference source not found.** shows Comparison of experimental Nusselt Number with J.S. Jayakumar *et al.,* [41] correlation under turbulent flow conditions.

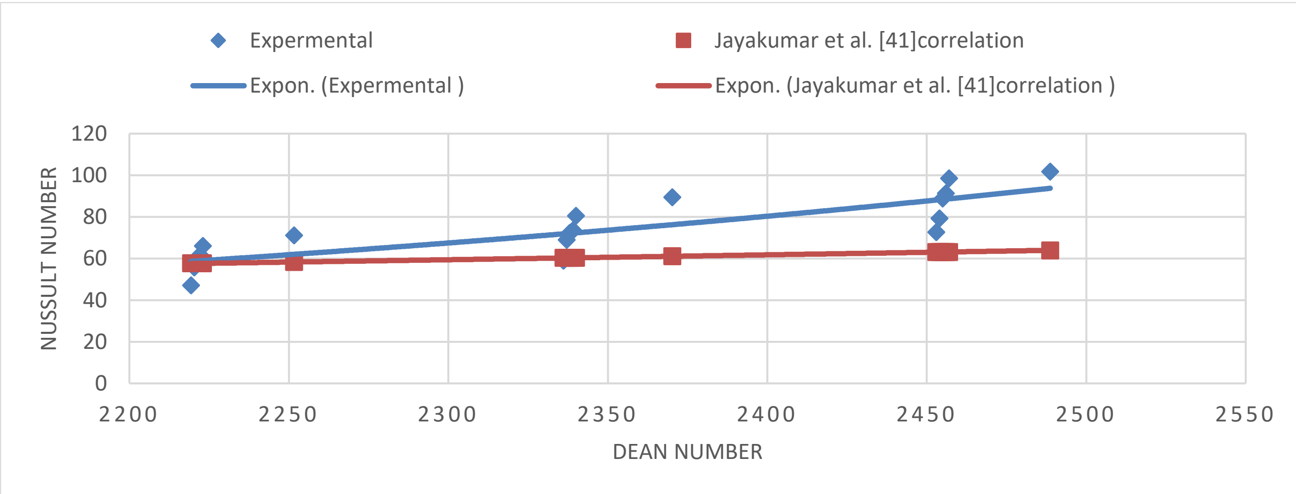


Fig. 4. Comparison of experimental Nusselt Number with J.S. Jayakumar *et al.,* [41] correlation under turbulent flow conditions

The experimental readings of the Nusselt Number have been found to exhibit a high level of agreement with the theoretical values predicted from the J.S. Jayakumar *et al.,* [42] correlation.

3.1.2 Validation of friction factor

For the comparison of the experimental results and validation of the experimental apparatus, experiment is carried water-based Nano fluid Titanium Dioxide using different volume concentrations (0-0.5%) of in a Varying diameter of 9.53mm, 12.7mm and 15.88mm with constant pitch 30mm helical coil tube. **Error! Reference source not found.** shows the comparison between experimental data with Blasius equation under turbulent flow conditions.

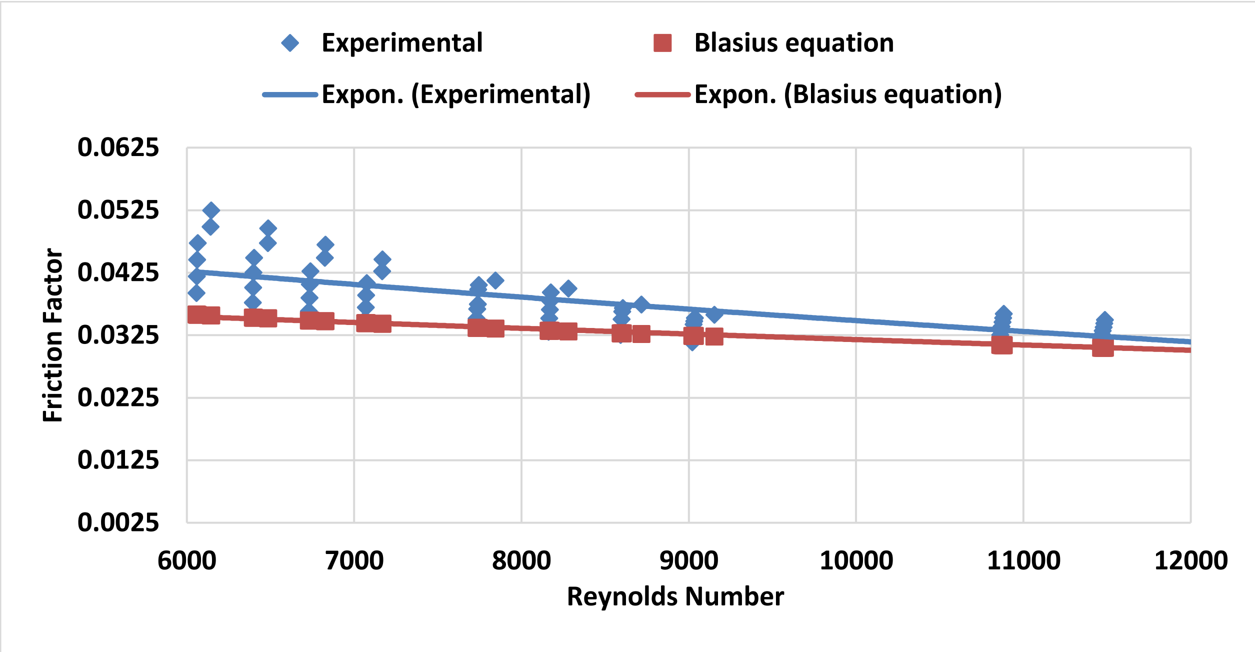


Fig. 5. Comparison of experimental friction factor with Blasius equation under turbulent flow conditions

The experimental readings of the friction factor have been found to exhibit a high level of agreement with the theoretical values predicted from the Blasius equation. The comparison between the experimental and theoretical values indicates a deviation of only ± 10.632%. This demonstrates the reliability and accuracy of the theoretical predictions in estimating the friction factor in the given system.

3.2 Heat Transfer Characteristics

The Figure 6 illustrates the inner heat transfer coefficient of a heat exchanger, which comprises a helical coil tube with a pitch of 30 mm, under steady-state flow conditions. It has been observed that there is a direct relationship between the mass flow rate of the inside hot fluid and the inner heat transfer coefficient. As the mass flow rate of the hot fluid increases, the inner heat transfer coefficient also increases. Additionally, when considering different pipe diameters for the helical coil tube, it has been found that the average value of the heat transfer coefficient is higher by 26% and 60.8% for a helical coil tube outside diameter of 15.88 mm compared to the remaining pipe diameters of 12.7 mm and 9.53 mm, respectively. Moreover, it has been noticed that as the mass flow rate of the inside hot fluid increases, the heat transfer rate of the heat exchanger increases across all pipe diameters studied. Among the various pipe diameters, the heat transfer rate is maximum for a coil tube with an outside diameter of 15.88 mm and minimum for a coil tube with an outside diameter of 9.53 mm, assuming a fixed mass flow rate of the inside hot fluid. Since the mass flow rate is directly proportional to the Reynolds number of the fluid, an increase in Reynolds number leads to an increase in the Nusselt number, indicating improved heat transfer between the hot fluid and the surrounding environment.

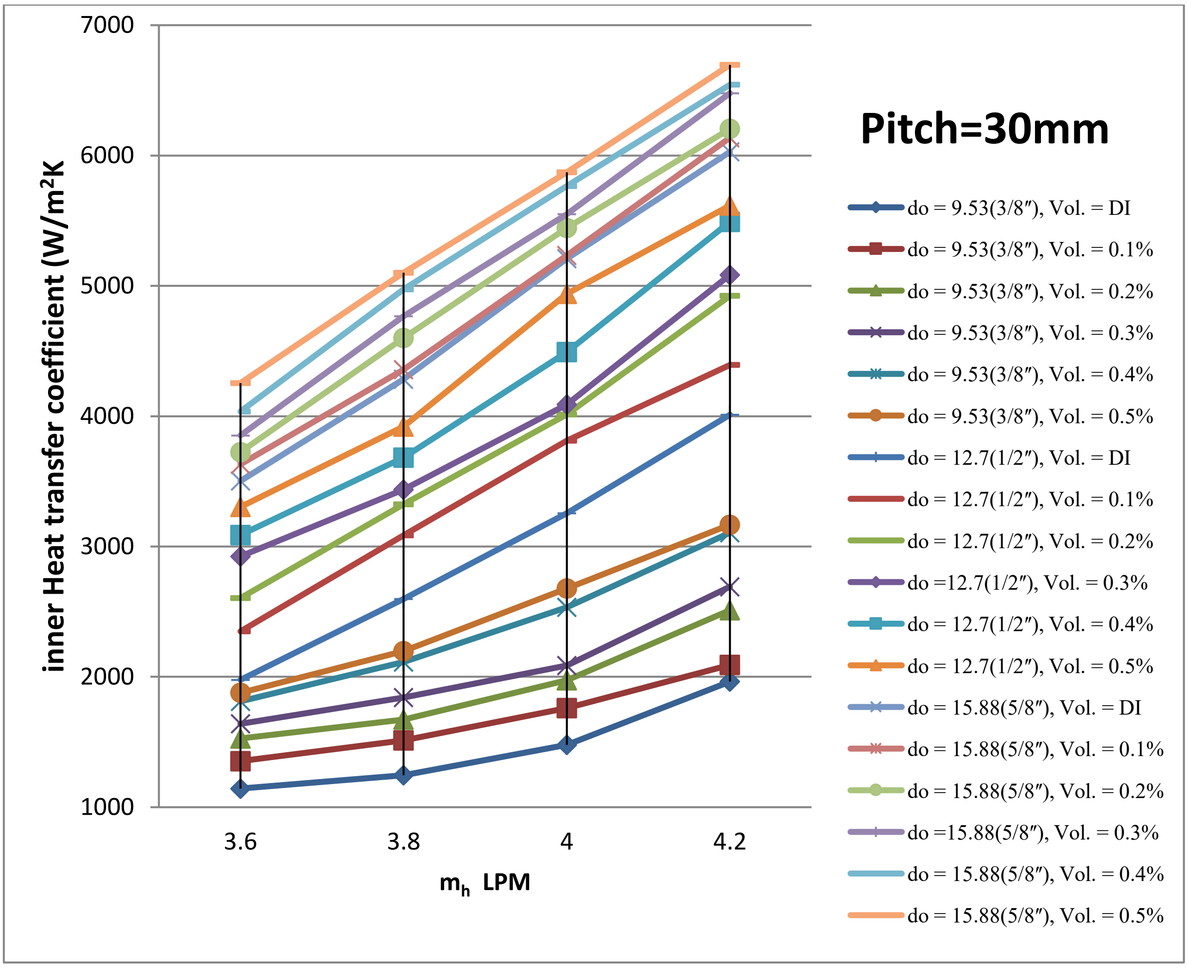


Fig. 6. Inner Heat transfer coefficient versus Dean Number in a nano fluid volume fraction, Pitch= 30mm

The mass flow rate of the hot fluid is directly proportional to the Reynolds number of the fluid. As the Reynolds number increases, the heat transfer rate between the hot fluid and the surrounding environment also increases. This can be attributed to the fact that the higher kinetic energy of the hot fluid particles promotes enhanced heat transfer.

3.3 Experimental Nusselt Number

The inner Nusselt number analysis of a heat exchanger, consisting of a helical coil tube with a pitch of 30 mm under steady-state flow conditions, is depicted in Figure 7. It has been observed that there is a direct relationship between the mass flow rate of the inside hot fluid and the Nusselt number. Specifically, as the mass flow rate of the hot fluid increases, the Nusselt number also exhibits an increase. Furthermore, Figure 6 represents the inner Nusselt number of the heat exchanger for different helical coil tube diameters: 9.53 mm, 12.7 mm, and 15.88 mm, all under steady-state flow conditions. It has been observed that as the mass flow rate of the inside hot fluid increases, the Nusselt number of the heat exchanger also increases for all the pitch values considered in the study. When specifically considering a helical coil tube with a diameter of 15.88 mm, an average inner

Nusselt number is found to be higher by 41.9% and 78% compared to the remaining helical coil tube diameters of 12.7 mm and 9.53 mm, respectively. These results indicate that the Nusselt number, which characterizes the convective heat transfer, is significantly enhanced when using a helical coil tube with a larger diameter, especially with the addition of a 0.5% volume fraction of Nanofluid compared to DI Water.

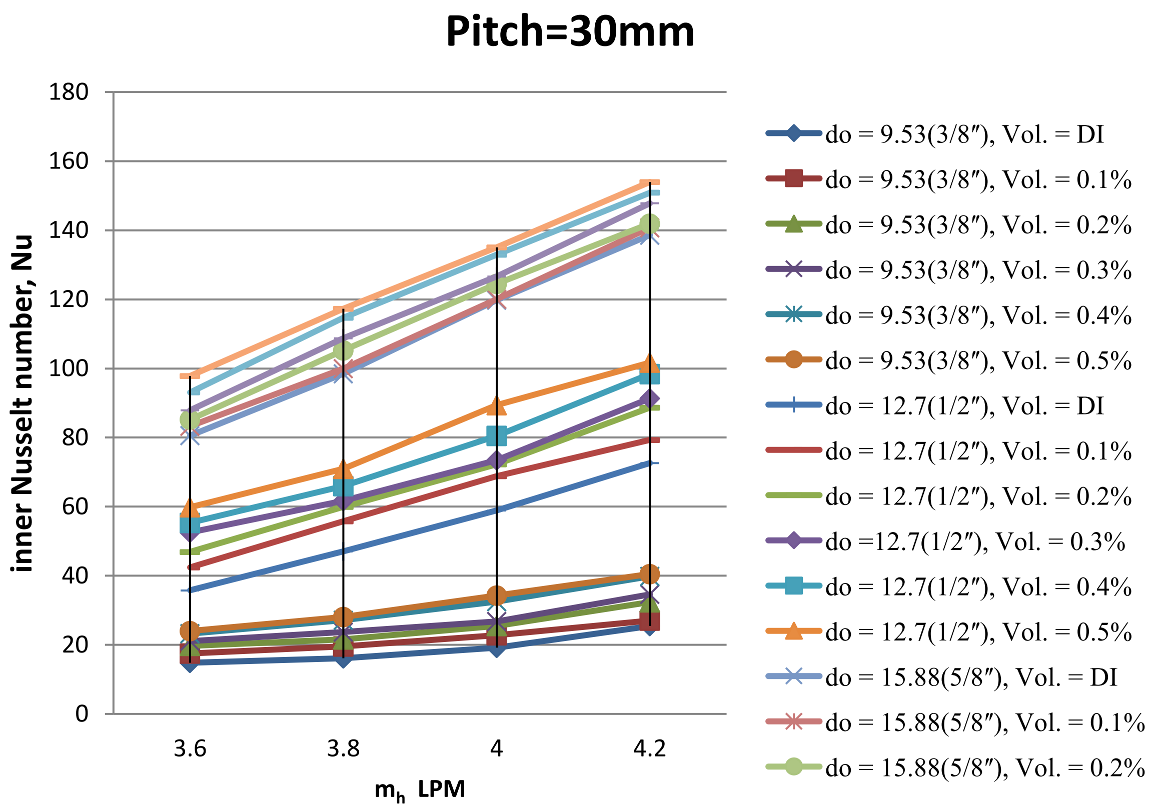


Fig. 7. Inner Nusselt Number versus Dean Number in a nano fluid volume fraction, pitch= 30mm

3.4 Friction Factor Characteristics

The Friction factor analysis of a heat exchanger, comprising a helical coil tube with a pitch of 30 mm under steady-state flow conditions, is presented in Figure 8. It has been observed that there is an inverse relationship between the mass flow rate of the inside hot fluid and the Friction factor. Specifically, as the mass flow rate of the hot fluid increases, the Friction factor decreases. Furthermore, considering a helical coil tube with an outer diameter of 9.53 mm and a volume fraction of 0.5% Nanofluid, the average Friction factor is higher by 1.7%, 3.3%, 5.0%, 6.7%, and 8.4% compared to the remaining volume fractions of 0.4%, 0.3%, 0.2%, 0.1%, and 0% DI Water, respectively. Similarly, for a helical coil tube with an outer diameter of 12.7 mm and a volume fraction of 0.5% Nanofluid, the average Friction factor is higher by 1.6%, 3.6%, 7.2%, 10.9%, and 14.4% compared to the remaining volume fractions of 0.4%, 0.3%, 0.2%, 0.1%, and 0% DI Water, respectively. Moreover, for a helical coil tube with an outer diameter of 15.88 mm and a volume fraction of 0.5% Nanofluid, the average Friction factor is higher by 4.6%, 9.3%, 14.0%, 18.7%, and 23.4% compared to the remaining volume fractions of 0.4%, 0.3%, 0.2%, 0.1%, and 0% DI Water, respectively. Additionally, the Friction factor of the heat exchanger, under steady-state flow conditions and with a pitch of 30 mm, is influenced by the outside pipe diameter. It has been observed that as the outside pipe diameter increases, the Friction factor also increases. Specifically, for a helical coil tube with a diameter of 15.88 mm, the average Friction factor is higher by 15.4% and 24% compared to the remaining helical coil tube diameters of 12.7 mm and 9.53 mm, respectively.

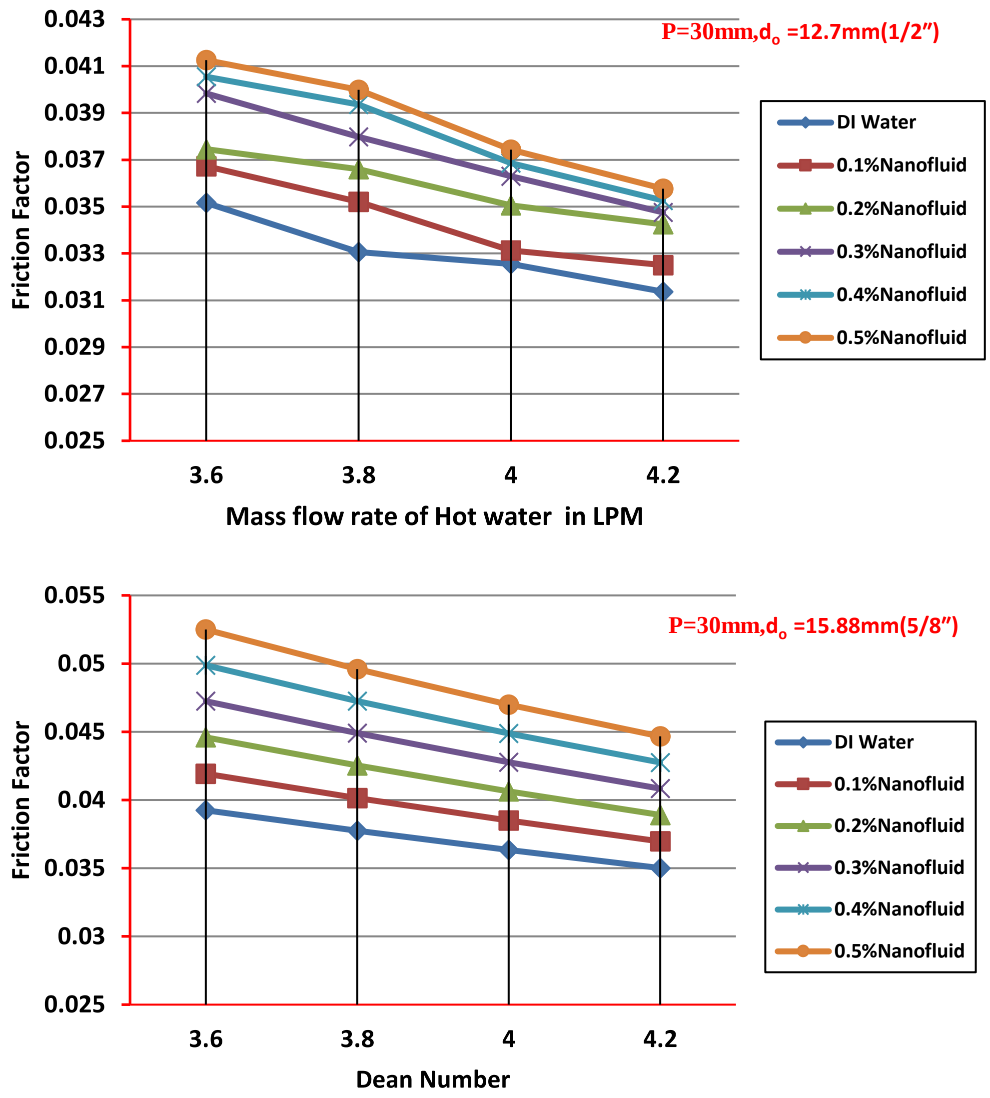


Fig. 8. Friction factor versus mass flow rate in a nano fluid volume fractions, Pitch=30mm

3.5 Pressure Drop Characteristics

The Pressure Drop of a heat exchanger, which comprises a helical coil tube with a pitch of 30 mm under steady-state flow conditions, is depicted in Figure 9. It has been observed that there is a correlation between the mass flow rate of the inside hot fluid and the inner heat transfer coefficient. As the mass flow rate of the hot fluid increases, the inner heat transfer coefficient also increases. Furthermore, when considering different pipe diameters for the helical coil tube, it has been noted that the average value of the Pressure Drop is higher by 79.4% and 92.7% for a helical coil tube with an outside diameter of 9.53 mm compared to the remaining pipe diameters of 12.7 mm and 15.88 mm, respectively. This indicates that the pressure drop experienced in the heat exchanger is significantly greater for the coil tube with a smaller outside diameter.

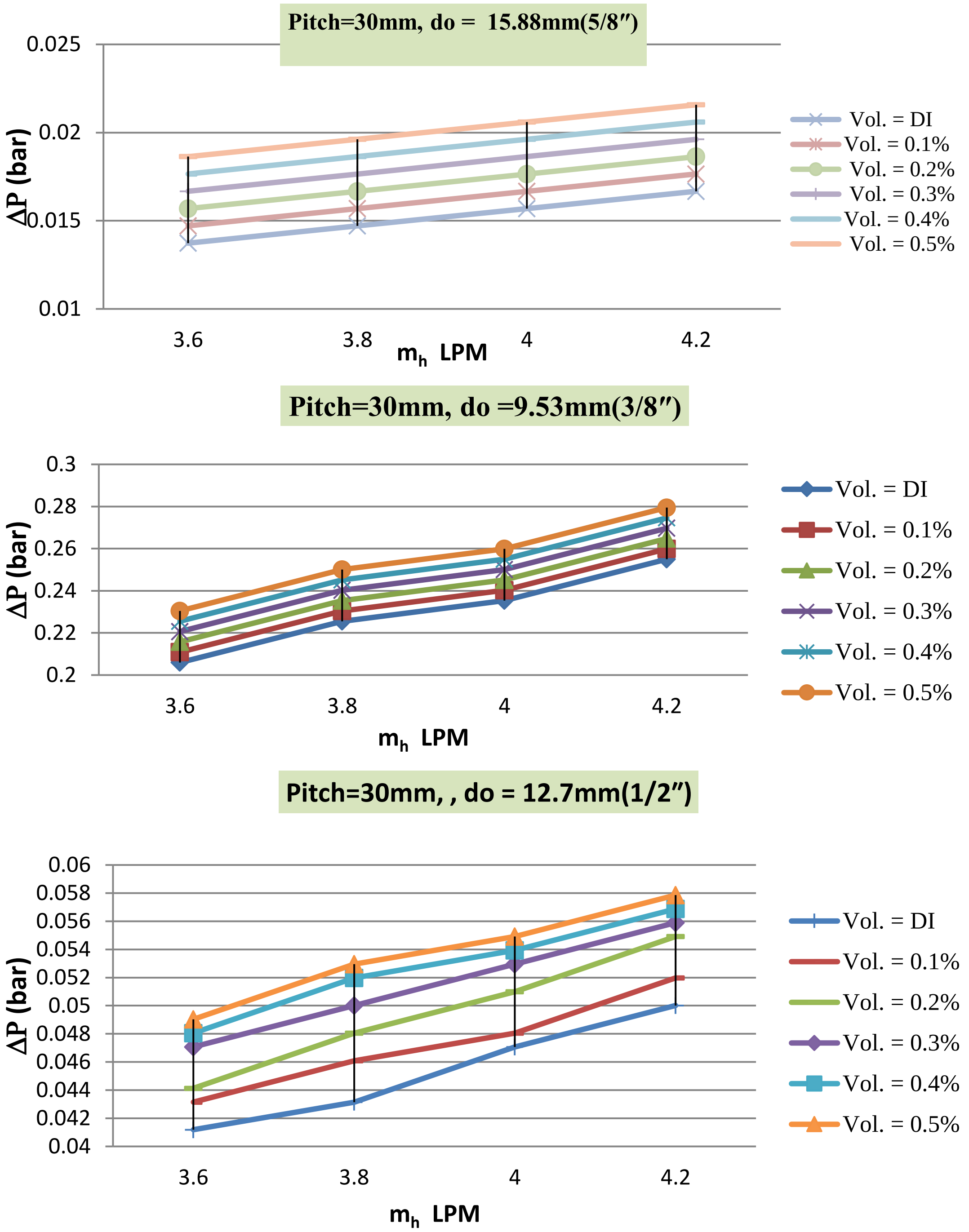


Fig. 9. Pressure Drop versus Dean Number in nano fluid volume fractions

4. Conclusions

The experimental investigation focused on studying the heat transfer properties of Heat Exchangers with helical coil heat exchangers with varying diameters. Water-based TiO2 nanofluid was used as the working fluid, and the effects of different variables, such as nanoparticle concentration, mass flow rate, heat transfer coefficient, pressure drop, friction factor, and Nusselt number, were analysed. Based on the findings of the experimental study, the following conclusions were drawn The Increasing the volume concentration of nanoparticles in the fluid led to greater improvements in the rate of heat transfer when compared to the base fluid. The highest improvement in the Nusselt number (Nu) and friction factor was observed at a volume concentration of 0.5%. the Varying Diameter of Helical Coil Tube of the experimental readings of the friction factor aligned well with the theoretical values predicted by the Blasius equation, with a deviation of ±10.63%. Among the helical coil tube diameters tested (9.53mm, 12.7mm, and 15.88mm), the diameter of 15.88mm exhibited the highest average friction factor, with values 15.4% and 24% higher than those of the 12.7mm and 9.53mm diameters, respectively. For the helical coil tube diameter of 15.88mm, the average inner Nusselt number was found to be 41.9% and 78% higher than those of the 12.7mm and 9.53mm diameters, respectively. The helical coil tube with an outside diameter of 9.53mm exhibited an average pressure drop that was 79.4% and 92.7% higher than those of the 12.7mm and 15.88mm diameters, respectively. The helical coil tube with an outside diameter of 15.88mm demonstrated a higher average heat transfer coefficient, with values 26% and 60.8% higher than those of the 12.7mm and 9.53mm diameters, respectively. These findings indicate that the heat transfer characteristics and pressure drop in helical coil heat exchangers are influenced by nanoparticle concentration and the diameter of the helical coil tube. The results suggest that using a higher nanoparticle concentration and a larger tube diameter can lead to improved heat transfer rates and enhanced overall performance of the heat exchanger.

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References

[1] Ajeeb, Wagd, and SM Sohel Murshed. "Nanofluids in compact heat exchangers for thermal applications: A State-of-the-art review." *Thermal Science and Engineering Progress* 30 (2022): 101276. https://doi.org/10.1016/j.tsep.2022.101276

[2] Keblinski, Phillbot, S. R. Phillpot, S. U. S. Choi, and J. A. Eastman. "Mechanisms of heat flow in suspensions of nano-sized particles (nanofluids)." *International journal of heat and mass transfer* 45, no. 4 (2002): 855-863. https://doi.org/10.1016/S0017-9310(01)00175-2

[3] Xuan, Yimin, and Qiang Li. "Investigation on convective heat transfer and flow features of nanofluids." *J. Heat transfer* 125, no. 1 (2003): 151-155. https://doi.org/10.1115/1.1532008

[4] Murshed, S. M. S., K. C. Leong, and C. Yang. "Thermophysical and electrokinetic properties of nanofluids–a critical review." *Applied thermal engineering* 28, no. 17-18 (2008): 2109-2125. https://doi.org/10.1016/j.applthermaleng.2008.01.005

[5] Kole, M Madhusree and Dey, T. K. “An experimental investigation of TiO2/water nanofluid in a double-pipe heat exchanger.” *Experimental Thermal and Fluid Science*, 63, (2015): 14-21.

[6] Timofeeva, Elena V., Jules L. Routbort, and Dileep Singh. "Particle shape effects on thermophysical properties of alumina nanofluids." *Journal of applied physics* 106, no. 1 (2009). https://doi.org/10.1063/1.3155999

[7] K. S. Madhu, Dr. Shankara Reddy R, Dr. S G Sanga Shetty, Dr Satheesha V. “Heat Transfer and Pressure Drop variation in Helical Coil Heat Exchange with varying pitch using Water-based Tio_2 Nanofluid.” *In International Journal of European Chemical Bulletin* Vol. 12, Issue 7, (2023): 2300-2308.

[8] K. S. Madhu, Dr. R Shankara Reddy., & Dr. S G Sanga Shetty. “Experimental Research on Heat Transfer Characteristics of Helical Coil Heat Exchanger with Varying Pitch for laminar Fluid Flow.” *International Journal of Recent Technology and Engineering (IJRTE)* Vol. 8, Issue 3, (2019): 315–320. https://doi.org/10.35940/ijrte.C4149.098319

[9] Sridharan, V., & Shaji, C. “Pressure drops and heat transfer characteristics of a helically coiled heat exchanger with varied coil diameter.” *International Journal of Heat and Mass Transfer,* 55(23-24), (2012): 7070-7078.

[10] Joshi, S. D., & Mahadik, V. R. “Experimental investigation of heat transfer enhancement in helical coil heat exchanger with varying coil diameter.” *Heat Transfer Engineering,* 36(4), (2015): 392-402.

[11] Kriksunov, L., & Syunev, V. “Experimental and numerical study of the heat transfer and pressure drop in a helical coil heat exchanger.” *Chemical Engineering Transactions,* 52, (2016): 331-336.

[12] Buonomo, B., Iasiello, M., & Pagliarulo, V. “Numerical analysis of heat transfer in a helical coil heat exchanger.” *Chemical Engineering Transactions*, 70, (2018): 67-72.

[13] Yıldırım, G., & Acar, M. "The effect of coil diameter on the heat transfer and pressure drops characteristics in helical coil heat exchangers. (2019). *International Journal of Heat and Mass Transfer*, 134 (2019): 1114-1123.
[14] Jalili, Payam, Hossein Narimisa, Bahram Jalili, and D. D. Ganji. "Micro-polar nanofluid in the presence of thermophoresis, hall currents, and Brownian motion in a rotating system." *Modern Physics Letters B* 37, no. 01 (2023): 2250197. https://doi.org/10.1142/S0217984922501974
[15] Jalili, Payam, Hossein Narimisa, Bahram Jalili, Amirali Shateri, and D. D. Ganji. "A novel analytical approach to micro-polar nanofluid thermal analysis in the presence of thermophoresis, Brownian motion and Hall currents." *Soft Computing* 27, no. 2 (2023): 677-689. https://doi.org/10.1007/s00500-022-07643-2
[16] Jalili, Payam, Ali Ahmadi Azar, Bahram Jalili, Zohreh Asadi, and Davood Domiri Ganji. "Heat transfer analysis in cylindrical polar system with magnetic field: a novel hybrid analytical and numerical technique." *Case Studies in Thermal Engineering* 40 (2022): 102524. https://doi.org/10.1016/j.csite.2022.102524
[17] Jalili, Payam, Ahmad Sadeghi Ghahare, Bahram Jalili, and Davood Domiri Ganji. "Analytical and numerical investigation of thermal distribution for hybrid nanofluid through an oblique artery with mild stenosis." *SN Applied Sciences* 5, no. 4 (2023): 95. https://doi.org/10.1007/s42452-023-05312-z
[18] Jalili, Bahram, P. Jalili, Pooya Pasha, Davood Domiri Ganji, and Hamed Nourouzpour. "Cu: Alooh/Water in a Microchannel Heat Sink Simulation Using a Porous Media Technique and Solved by Numerical Analysis Agm Strategy." *Water in a Microchannel Heat Sink Simulation Using a Porous Media Technique and Solved by Numerical Analysis Agm Strategy*.
[19] Jalili, Bahram, Narges Aghaee, Payam Jalili, and Davood Domiri Ganji. "Novel usage of the curved rectangular fin on the heat transfer of a double-pipe heat exchanger with a nanofluid." *Case Studies in Thermal Engineering* 35 (2022): 102086. https://doi.org/10.1016/j.csite.2022.102086
[20] Jalili, Bahram, Amirhossein Rezaeian, Payam Jalili, Davood Domeri Ganji, and Yasir Khan. "Squeezing flow of Casson fluid between two circular plates under the impact of solar radiation." *ZAMM-Journal of Applied Mathematics and Mechanics/Zeitschrift für Angewandte Mathematik und Mechanik* (2023): e202200455. https://doi.org/10.1002/zamm.202200455
[21] Ramadhan, A. I., W. H. Azmi, R. Mamat, and K. A. Hamid. "Experimental and numerical study of heat transfer and friction factor of plain tube with hybrid nanofluids." *Case Studies in Thermal Engineering* 22 (2020): 100782. https://doi.org/10.1016/j.csite.2020.100782
[22] Azmi, W. H., K. Abdul Hamid, A. I. Ramadhan, and A. I. M. Shaiful. "Thermal hydraulic performance for hybrid composition ratio of TiO2–SiO2 nanofluids in a tube with wire coil inserts." *Case Studies in Thermal Engineering* 25 (2021): 100899. https://doi.org/10.1016/j.csite.2021.100899
[23] Fikri, Mohd Amiruddin, Wan Mohd Faizal, Hasyiya Karimah Adli, Rizalman Mamat, Wan Hamzah Azmi, Zafri Azran Abdul Majid, and Anwar Ilmar Ramadhan. "Characteristic of TiO2-SiO2 Nanofluid With Water/Ethylene Glycol Mixture for Solar Application." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* (2021). https://doi.org/10.37934/arfmts.81.2.113
[24] Frank, M. White. "Fluid mechanics." *McGraw-Hill, capítols* 1, no. 4 (2011): 7.
[25] Kittel, Charles, and Herbert Kroemer. *Thermal Physics*. Macmillan, 1980.
[26] Xuan, Yimin, and Wilfried Roetzel. "Conceptions for heat transfer correlation of nanofluids." *International Journal of heat and Mass transfer* 43, no. 19 (2000): 3701-3707. https://doi.org/10.1016/S0017-9310(99)00369-5
[27] Pak, Bock Choon, and Young I. Cho. "Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles." *Experimental Heat Transfer an International Journal* 11, no. 2 (1998): 151-170. https://doi.org/10.1080/08916159808946559
[28] Blasius, Heinrich. *Grenzschichten in Flüssigkeiten mit kleiner Reibung*. Druck von BG Teubner, 1907.
[29] Bergman, Theodore L. *Fundamentals of heat and mass transfer*. John Wiley & Sons, 2011.
[30] Yunus A.. Çengel, and Afshin Jahanshahi Ghajar. *Heat and Mass Transfer: Fundamentals [and] Applications*. McGraw-Hill Education, 2020.
[31] Suhas V.. Patankar. *Numerical heat transfer and fluid flow*. Hemisphere Publishing Corporation, 1980.
[32] Bejan, Adrian. *Convection heat transfer*. John wiley & sons, 2013. https://doi.org/10.1002/9781118671627
[33] Kern, Donald Quentin, and Donald Q. Kern. *Process heat transfer*. Vol. 871. New York: McGraw-Hill, 1950.
[34] Hewitt, Geoffrey F., George L. Shires, and T. Bott. *Process heat transfer*. Begell House, 1994.
[35] Kakaç, Sadik, Hongtan Liu, and Anchasa Pramuanjaroenkij. "Heat Exchangers." *(No Title)* (2012). https://doi.org/10.1201/b11784
[36] Shah, Ramesh K., and Dusan P. Sekulic. *Fundamentals of heat exchanger design*. John Wiley & Sons, 2003. https://doi.org/10.1002/9780470172605
[37] Kakaç, Sadik, and Yaman Yener. *Convective Heat Transfer*. CRC Press, 1994.
[38] Bergman, Theodore L. *Fundamentals of heat and mass transfer*. John Wiley & Sons, 2011.

[39] Yu, Wei, and Huaqing Xie. "A review on nanofluids: preparation, stability mechanisms, and applications." *Journal of nanomaterials* 2012 (2012): 1-17. https://doi.org/10.1155/2012/435873

[40] Moffat, Robert J. "Describing the uncertainties in experimental results." *Experimental thermal and fluid science* 1, no. 1 (1988): 3-17. https://doi.org/10.1016/0894-1777(88)90043-X

[41] Jayakumar, J. S., S. M. Mahajani, J. C. Mandal, P. K. Vijayan, and Rohidas Bhoi. "Experimental and CFD estimation of heat transfer in helically coiled heat exchangers." *Chemical engineering research and design* 86, no. 3 (2008): 221-232. https://doi.org/10.1016/j.cherd.2007.10.021

[42] Mlangeni, Palesa Helen, Zhongjie Huan, Thembelani Sithebe, and Vasudeva Rao Veeredhi. "Prandtl Number and Viscosity Correlations of Titanium Oxide Nanofluids." *Journal of Engineering* 2023 (2023). https://doi.org/10.1155/2023/4949566