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EXPERIMENTAL STUDY ON THE EFFECT OF HEAT TRANSFER IN HEAT EXCHANGER WITH VARYING HELICAL COIL PITCH AND INCLINATION ANGLE USING TIO_2–WATER NANOFLUID

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Abstract: Heat exchangers are widely used in various industrial processes for efficient heat transfer between fluids. Enhancing the heat transfer performance of heat exchangers has always been a significant area of research. This study presents an experimental investigation on the effect of heat transfer in a heat exchanger using a TiO_2-Water nanofluid. The specific focus is placed on varying the helical coil pitch and inclination angle to explore their impact on heat transfer characteristics. The experimental setup consists of a Counter flow heat exchanger with a helical coil as the heat transfer surface. The nanofluid, prepared by dispersing TiO_2 nanoparticles in water, serves as the working fluid. The helical coil pitch is varied, while the inclination angle is adjusted by tilting the heat exchanger setup. Heat transfer experiments are conducted for different helical coil pitch of 25mm, 30mm and 35mm with inclination angle varying 0°, 15°, 30°, 45°, 60°, 75° and 90° under similar operating conditions. The results reveal that the presence of TiO_2 nanoparticles in the water significantly enhances the heat transfer performance. The maximum heat transfer coefficient 2175.5 W/m^2 K and Nusselt Number 38.9 is observed is $\theta = 75°$ for helical coil tube with pitch 25mm using 0.5% concentration of TiO_2 nanoparticles in the nanofluid and also the Pressure drop increases with increases inclination angle. The highest Pressure drop of 0.049bar is observed for helical coil tube of pitch 25mm and for 0.5 % volume concentration of TiO_2 nanofluid. The findings contribute development of more efficient and compact heat transfer systems in various industrial applications to the optimization of heat exchanger design and operation, enabling the development of more efficient and compact heat transfer systems in various industrial applications.

Index Terms - Helical coil, Nusselt Number, heat transfer, Heat Exchanger, varying pitch, varying inclination angles, Nanofluid.

Nomenclature

a_i	Inside surface area of the helical coil tube in m
A_i	Area of the Cross sectional of inside helical coil tube in m^2
a_o	Outside surface area of the helical coil tube in m^2
C	Capacity ratio
C_c	$\dot{m}_c c_{pc}$ = cold fluid capacity rate in kW /K
C_h	$\dot{m}_h c_{ph}$= hot fluid capacity rate in kW /K
c_{pc}	Specific heat of cold fluid constant pressure in kJ/kg K
c_{ph}	Specific heat of hot fluid constant pressure in kJ/kg K
D_e	Dean number
d_i	Inside diameter of the helical coil tube in mm
d_o	Outside diameter of the helical coil tube in mm
HCHE	Helical Coil heat exchanger
HE	heat exchanger
h_i	Coefficient of heat transfer of inside coil tube W/m^2 °C
h_o	Coefficient of heat transfer of outside coil tube W/m^2 °C
V_i	Inside helical coil tube velocity in m/sec
k_c	Temperature sensitivity of copper coil (W/m K)
k_i	Temperature sensitivity of cold water (W/m K)
k_o	Temperature sensitivity of hot water (W/m K)
L	Overall length of the helical coil tube in mm
l	Extended length of the coil other than coil turns
$\dot{m}_h$	Hot water flow rate in kg /sec
$\dot{m}_c$	Cold water Flow rate in kg /sec
N	Number of turns of coil tube

Nu	Nusselt Number
P	Pitch
Pr	Prandtl number
ΔP	Pressure drops
Q	Rate of Discharge in m^3/sec
r	Inner radius of the helical coil tube in mm
R_c	Mean helical radius of the helical coil in mm
R_e	Reynolds Number
ΔT_{lm}	Log Mean Temperature Difference in °C
U_i	Overall coefficient of heat transfer of inside coil tube W/m^2 °C
U_o	Overall coefficient of heat transfer of outside coil tube W/m^2 °C

Greek letters

δ	Curvature ratio
ρ	Density of water in kg/m^3
μ	Dynamic viscosity of fluid in N-sec/ m^2
ε	Effectiveness
ϕ	volume concentration
f	Friction Factor
θ	Helical coil Heat exchanger inclination angle

Subscripts

h_1	Inlet of hot fluid
h_2	Outlet of hot fluid
c_1	Cold fluid inlet
c_2	Cold fluid outlet
p	Metallic oxide particles

NTU	Number of Transfer units	f	Base fluid density
		nf	Nanofluid

1. INTRODUCTION

Heat exchangers play a crucial role in various industrial processes where efficient heat transfer is essential. Recent advancements have introduced nanofluids, such as TiO_2–water nanofluid, to enhance heat transfer rates due to their improved thermal conductivity. Helical coil heat exchangers have shown promise in achieving better heat transfer characteristics compared to conventional exchangers. However, there is still a need to explore the impact of varying helical coil pitch and inclination angles on heat transfer efficiency when using TiO_2–water nanofluid. [1]The study likely involves experimental investigations to measure the heat transfer rates of both heat exchanger types under controlled conditions. The researchers might have conducted tests with varying operating parameters. [2]The main focus of the investigation is to analyze the heat transfer process when the nanofluid, consisting of TiO_2 nanoparticles dispersed in water, flows through the helically coiled pipes. Forced convection involves the external means, such as a pump, to circulate the fluid through the pipes to enhance heat transfer. [3]The main subject of the research is helically coiled heat exchangers. These types of heat exchangers are known for their compact design and efficient heat transfer capabilities. The study aims to understand the heat transfer mechanisms occurring in such geometries. [4]The paper presents the results and findings from the experimental studies. It likely discusses the heat transfer characteristics, such as heat transfer rates and heat transfer coefficients, in the parallel wavy channel heat exchangers under different channel inclination angles. [5]The primary focus of the research is on vertical helically coiled tube heat exchangers. These heat exchangers consist of helically coiled tubes arranged in a vertical orientation, which can influence the heat transfer characteristics under different flow conditions. [6] The main objective is to analyze the heat transfer characteristics of the nanofluid flowing through the helically coiled tubes. The study likely involves measuring heat transfer rates, heat transfer coefficients, and other relevant parameters to assess the performance of the nanofluid in comparison to conventional fluids. [7] The study's findings may have implications for the design and optimization of heat exchangers and heat transfer systems using nanofluids and helical inserts. Understanding the heat transfer behavior under laminar flow conditions can aid in developing more efficient heat exchange technologies.[8] The findings of the study have implications for understanding the influence of Dean number and pitch size on the flow and heat transfer performance of helically coil-tube heat exchangers. This knowledge can contribute to optimizing the design and operation of such heat exchangers for various industrial applications.[9] The researchers explore the impact of different orientations on the performance of the heat exchanger. The orientations of the heat exchanger can affect the flow patterns and heat transfer rates, and the study likely investigates various configurations.[10] The research involves the evaluation of a shell and helically coiled tube heat exchanger. This type of heat exchanger typically consists of helical coils for fluid flow within a shell, providing a compact and efficient heat transfer design.[11] The research centers on a helical coil heat exchanger, which is a type of heat exchanger with coiled tubes arranged in a helical configuration. [12]Helical coil heat exchangers are known for their compact design and efficient heat transfer performance. The primary objective is to conduct experimental studies to investigate the heat transfer characteristics of the helical coil heat exchanger. [13] The study explores the impact of nanofluids on the heat exchanger's performance. Nanofluids are colloidal suspensions of nanoparticles in base fluids and are known for their enhanced thermal properties, which may improve heat transfer in the heat exchanger. [14]The study utilizes PANI nanofluid, which is a water-based nanofluid containing Polyaniline nanoparticles. Nanofluids are known for their potential to enhance heat transfer due to increased thermal conductivity. The problem addressed by this literature survey is the lack of comprehensive understanding regarding the influence of coil pitch and inclination angle on heat transfer in helical coil heat exchangers with TiO_2–water nanofluid. Although previous studies have investigated the heat transfer enhancement using nanofluids and helical coils, limited research has focused specifically on the combined effect of varying coil pitch and inclination angle. Therefore, this literature survey aims to gather and analyse existing research on similar experimental studies and their findings related to heat transfer in helical coil heat exchangers with TiO_2–water nanofluid. By reviewing the current literature, this study aims to identify research gaps, inconsistencies, and potential areas for further exploration. The survey intends to contribute to the knowledge base on how the manipulation of coil pitch and inclination angle can optimize the heat transfer performance of helical coil heat exchangers when using TiO_2–water nanofluid, thereby facilitating the development of more efficient heat exchange systems in various industrial applications.The objective of this study is to investigate the impact of different helical coil pitch and inclination angles on heat transfer in a heat exchanger using TiO_2–water nanofluid as the working fluid. The researchers aim to explore how variations in coil pitch and inclination angle influence the heat transfer characteristics of the heat exchanger when using the nanofluid.

2. METHODOLOGY FOR EXPERIMENTAL SETUP

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

The proposed experimental setup consisting of helical coil tube heat exchanger

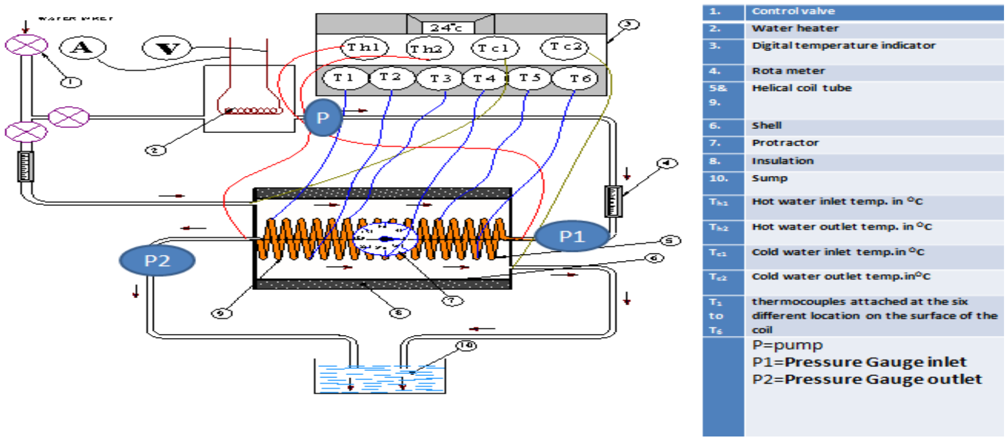


Fig.1. Line diagram of the Experimental setup

Fig. 1 .Pitch-variable helical coils

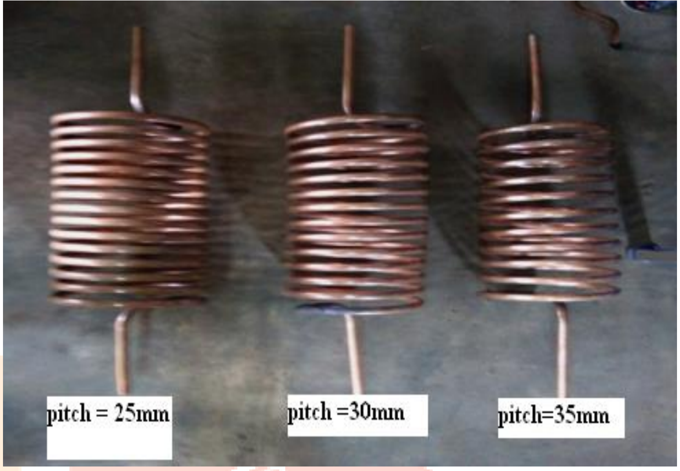


Figure 3 Helical Coils with varying pitch and outer diameter 12.7mm

Table 1 Geometry of helical coils utilized

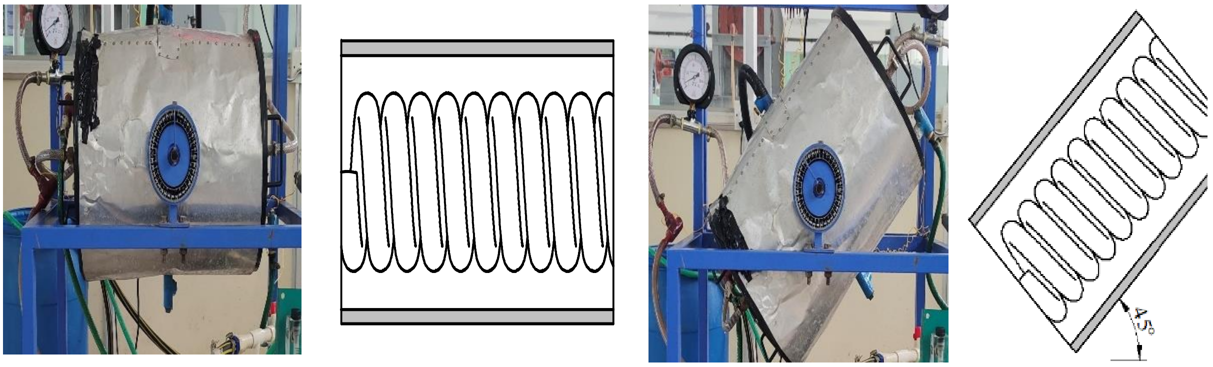
Helical coils	Coil -1	Coil -2	Coil -3
P(mm)	25	30	35
Material Type	Copper		
k_c at atmospheres	386		
N	15	13.5	11
R_c(mm)	74.9	74.9	74.9
r(mm)	5.537	5.537	5.537
δ	0.0739	0.0739	0.0739
d_o (mm/inch)	12.7(1/2″)	12.7(1/2″)	12.7(1/2″)
d_i (mm)	11.074	11.074	11.074
L (m)	7.409	6.706	5.531
$a_o(m^2)$	0.2956	0.2675	0.2206
a_i $(m^{2)}$	0.2577	0.2333	0.1924

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 TiO_2. The study focused on investigating the effects of varying inclination angle (ranging from 0°to 90°), pitch of the helical coil tubes (25mm, 30mm and 35mm) and 0.5% nano fluid volume fraction with constant mass flow rate. The research primarily examined the influence of the heat transfer coefficient (Nu) and friction factor (ΔP) 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.

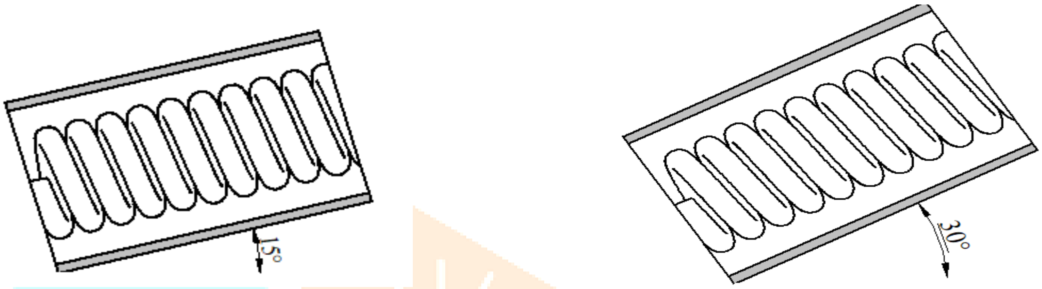
2.2. Experimental procedure

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.



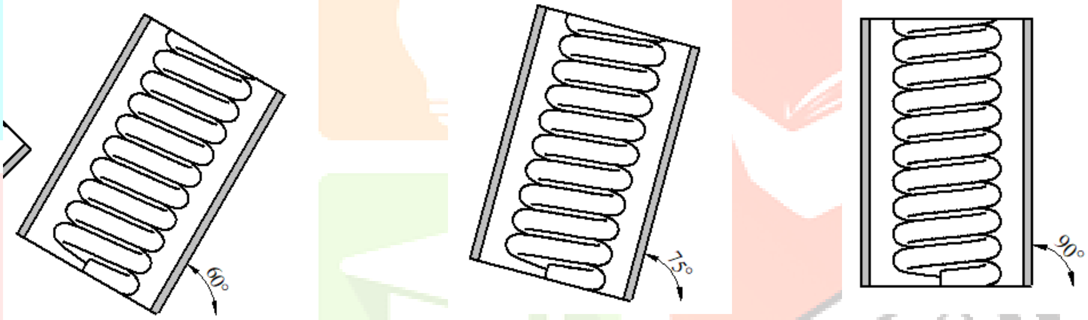
a) Inclination θ = 0°

d) Inclination θ = 45°



b) Inclination θ = 15°

c) Inclination θ = 30°



e) Inclination θ =60°

g) Inclination θ = 90°

f) Inclination θ = 75°

Fig. 4. Helical Coils with varying angle from the horizontal orientation (0°) to the vertical orientation (90°)

The temperature of the water heater was set to approximately 52°C upon activating the control panel, while the cold-water temperature was maintained at 24±1°C. The pitch of the coil was fixed at 25 mm 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 LPM and the flow rate of the hot water through the coil tube was adjusted 3.6 LPM. Titanium dioxide nanoparticles suspensions while the helically coiled tube was supplied with nanofluids containing volume concentrations of 0.5% at helical coil tube inclination 0°. Temperature and mass flow rate readings were recorded for both fluids. Throughout the experiments, helical coil tubes with pitch of 25mm, 30mm, and 35mm were utilized while maintaining a fixed diameter of 12.7mm and a constant curvature ratio. By following this experimental procedure, the researchers aimed to investigate the effects of pitch and tube dimensions on the heat transfer characteristics within the helical coil tubes under study. The orientation of HCHE is changed from the horizontal orientation (0°,15°,30°,45°,60°,75° and 90°) to the vertical orientation manually by the aid of a mechanical holder. For each orientation, the temperatures and pressures at the inlet and outlet of the helically coiled tube and the shell and the surface temperatures of the coil are recorded as shown in figure 5.

2.3 Uncertainty of instrument

The uncertainties in the experimental parameters are evaluated with the method suggested by 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/cm²*
$\dot{m}_h$ $\dot{m}_{hc}$	±0.1 kg /sec

2.4 Data reduction

i. Overall length (**L**) of the helical coil tube required to perform N Number of turns in Eq. (1)

$$L = (l + \left(N\sqrt{(2\pi R_C)^2 + P^2}\right)) \qquad \text{...... (1)}$$

l = 340mm.

ii. Log Mean Temperature Difference in Eq. (2)

$$\mathrm{LMTD} = \Delta T_{lm} = \frac{(\Delta T_2 - \Delta T_1)}{(\frac{\Delta T_2}{\Delta T_1})} \qquad \text{......... (2)}$$

iii. Thermophysical properties of nanofluids in Eq. (3) to (5)

The density of TiO_2 nanofluids is found using (Pak and Cho) in equation

$$\rho_{nf} = \phi\rho_{p} + (1-\phi)\rho_{f} \qquad \text{.... (3)}$$

The rate of heat transfer in nano fluid is calculated by using 3 factors namely Heat capacity, viscosity, and thermal conductivity these factors may vary significantly from the original pure fluids.

(Xuan and Roetzel)[26] Equation no.4 is used to calculate the specific heat

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

The fluid's nanoscale viscosity is measured using in Eq. (5).

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

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

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

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

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

$$a_i = \pi d_i L \text{ and } a_o = \pi d_o L \qquad \text{... (9)}$$

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

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

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

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

T_{os} -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.

$$Q = \frac{2\pi k_c L(T_{is} - T_{os})}{\ln(\frac{\frac{d_o}{2}}{\frac{d_i}{2}})} \qquad \text{... (3)}$$

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

$$\frac{k_{nf}}{k_f} = \frac{k_p + 2k_f - 2\phi(k_f - k_p)}{k_p + 2k_f + \phi(k_f - k_p)} \qquad \text{... (4)}$$

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

$$\textbf{Inside Nusselt number} = N_{ui} = \frac{h_i d_i}{k_{nf}} \qquad \text{... (5)}$$

$$\textbf{Outside Nusselt number} = N_{uo} = \frac{h_o d_o}{k_{nf}} \qquad \text{... (6)}$$

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

$$V_i = \frac{\dot{m}_h}{\rho nf \times A_i} \qquad \text{... (7)}$$

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)

$$\mathrm{Re} = \frac{d_i V_i \rho nf}{\mu nf} \qquad \text{... (8)}$$

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)

$$\mathrm{De} = Re\sqrt{r/R_c} \qquad \text{... (19)}$$

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)

$$f = (\Delta P/0.5\rho v^2)(d/L) \qquad \text{... (20)}$$

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.

3. RESULTS AND DISCUSSION

Discussion of heat transfer characteristics water-based Nano fluid Titanium Dioxide using volume concentrations0.5% of in a Varying pitch of 25mm, 30mm and 35mm, with constant diameter 12.7mm helical coil tube with varying inclination of helical coil tube heat exchanger 0° to 90°. 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.

3.1 Heat Transfer Characteristics

As shown in Figure 5, the inner heat transfer coefficient increases with the increase in helical coil pipe inclination angle from horizontal to vertical, while maintaining a constant pipe diameter of 12.7mm and mass flow rate. Furthermore, Figure 5 illustrates the inner heat transfer coefficient of the heat exchanger for different helical coil pitch 25mm, 30mm and 35mm under steady-state flow conditions. Specifically, when considering a helical coil tube with a pitch of 25 mm, the average inner heat transfer coefficient is found to be higher by 10% and 19% compared to the remaining helical coil pitches of 30 mm and 35 mm, respectively. Additionally, the results reveal that the presence of TiO_2 nanoparticles in the water significantly enhances the heat transfer performance. The maximum heat transfer coefficient observed is 2175.5 W/m²K at an inclination angle of 75° for the helical coil tube with a pitch of 25mm, using a 0.5% concentration of TiO2 nanoparticles in the nanofluid. Furthermore, when comparing with a pitch of 25 mm, the average inner heat transfer coefficient is higher by 53%, 31%, 23%, 18%, 9%, and 5% for helical coil inclinations of 0°, 15°, 30°, 45°, 60°, and 90°, respectively, with a pitch of 25mm. A notable observation is that the maximum value of the heat transfer coefficient is observed at an inclination angle of 75°. The notable observation that the maximum value of the heat transfer coefficient appears at 75 degrees in the helical coil heat exchanger, rather than in the vertical orientation, can be attributed to several factors related to fluid dynamics and heat transfer.

- **Enhanced Mixing:** At an inclination angle of 75 degrees, the flow pattern inside the helical coil is optimized for better mixing of the nanofluid. This improved mixing enhances the contact between the nanofluid and the pipe wall, leading to more effective heat transfer
- **Reduced Plume Effect:** In the vertical orientation (0 degrees inclination), a plume or stratification effect can occur, where hotter fluid tends to rise to the top while cooler fluid sinks to the bottom. This stratification can lead to reduced heat transfer efficiency due to less effective contact between the nanofluid and the pipe wall. However, at 75 degrees inclination, this plume effect is minimized, promoting better heat transfer.
- **Enhanced Turbulence:** The helical flow pattern at 75 degrees can induce turbulence, which increases the convective heat transfer coefficient. Turbulent flow promotes better mixing and improved heat transfer rates compared to laminar flow, which is more likely to occur in vertical configurations.
- **Reduced Nanoparticle Settling**: In the vertical orientation, nanoparticles in the nanofluid may settle at the bottom of the pipe due to gravity, leading to a non-uniform distribution and reduced heat transfer. At 75 degrees inclination, the settling effect is minimized, resulting in a more uniform distribution of nanoparticles and enhanced heat transfer.
- **Increased Surface Area**: The helical coil configuration with an inclination angle of 75 degrees provides a larger effective surface area for heat exchange compared to the vertical orientation. The increased surface area allows for more heat transfer between the nanofluid and the pipe wall.
- Overall, the specific geometry and flow characteristics of the helical coil heat exchanger at 75 degrees inclination create a favourable environment for efficient heat transfer in the presence of TiO_2 nanoparticles. As a result, this configuration exhibits the highest heat transfer coefficient compared to other inclination angles, including the vertical orientation.

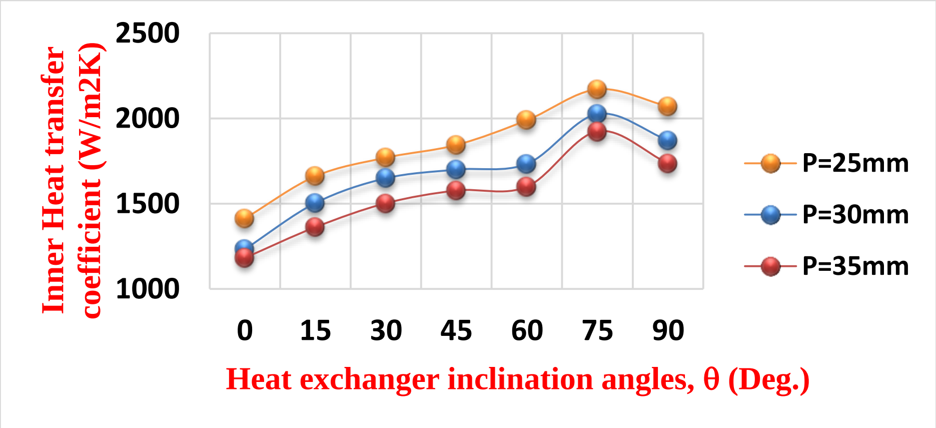


Fig. 5. Inner Heat transfer coefficient versus Heat exchange inclination angles in a nano fluid volume fraction 0.5 %, pipe diameter= 12.7mm

3.2 Experimental Nusselt Number

As shown in Figure 6, the Nusselt Number increases with the increase in helical coil pipe inclination angle from horizontal to vertical, while maintaining a constant pipe diameter of 12.7mm and mass flow rate. Furthermore, Figure 6 illustrates the inner Nusselt Number of the heat exchanger for different helical coil pitch 25mm, 30mm and 35mm under steady-state flow conditions. Specifically, when considering a helical coil tube with a pitch of 25 mm, the average inner Nusselt Number is found to be higher by 10% and 19% compared to the remaining helical coil pitches of 30 mm and 35 mm, respectively. Additionally, the results reveal that the presence of TiO_2 nanoparticles in the water significantly enhances the heat transfer performance. The maximum Nusselt Number observed is 38.9 at an inclination angle of 75° for the helical coil tube with a pitch of 25mm, using a 0.5% concentration of TiO2 nanoparticles in the nanofluid. Furthermore, when comparing with a pitch of 25 mm, the average inner heat transfer coefficient is higher by 53%, 31%, 23%, 18%, 9%, and 5% for helical coil inclinations of 0°, 15°, 30°, 45°, 60°, and 90°, respectively, with a pitch of 25mm

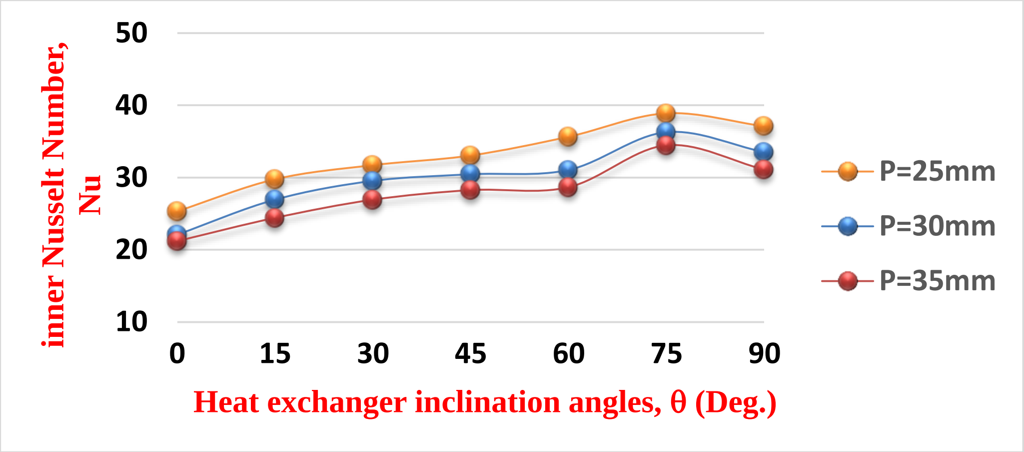


Fig. 6. Inner Nusselt Number versus Heat exchange inclination angles in a nano fluid volume fraction 0.5 %, pipe diameter= 12.7mm

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3.3 Friction factor Characteristics

As shown in Figure 7, the friction factor increases with the increase in helical coil pipe inclination angle from horizontal to vertical, while maintaining a constant pipe diameter of 12.7mm and mass flow rate. Furthermore, Figure 7 illustrates the inner friction factor of the heat exchanger for different helical coil pitch 25mm, 30mm and 35mm under steady-state flow conditions. Specifically, when considering a helical coil tube with a pitch of 25 mm, the average inner friction factor is found to be higher by 2.5% and 1.3 % compared to the remaining helical coil pitches of 30 mm and 35 mm, respectively. Additionally, the results reveal that the presence of TiO_2 nanoparticles in the water significantly enhances the friction factor. The maximum friction factor observed is 38.9 at an inclination angle of 75° for the helical coil tube with a pitch of 25mm, using a 0.5% concentration of TiO2 nanoparticles in the nanofluid. Furthermore, when comparing with a pitch of 25 mm, the average inner friction factor is higher by 1.43 %, 2.7%, 4.65%, 5.77%, 7.61%, and 0.41% for helical coil inclinations of 0°, 15°, 30°, 45°, 60°, and 90°, respectively, with a pitch of 25mm.

The friction factor, also known as the Darcy friction factor or the Fanning friction factor, is a dimensionless quantity that represents the resistance to fluid flow in a pipe or conduit. It is used to calculate pressure drop in the flow of fluids through pipes. The friction factor depends on the flow regime, pipe geometry, and the Reynolds number. In the helical coil heat exchanger at 75 degrees inclination, several factors contribute to the higher friction factor compared to the vertical orientation:

Increased Turbulence: At 75 degrees inclination, the flow inside the helical coil is more turbulent compared to the vertical orientation. Turbulent flow induces more mixing and increases the shear stresses at the pipe wall, resulting in higher frictional losses.

Swirling Flow: The helical coil configuration generates swirling or vortex-like flow patterns, especially at 75 degrees inclination. This swirling motion leads to increased flow resistance and higher friction factors.

Centrifugal Force: The helical flow in the coil induces centrifugal forces on the fluid particles, pushing them outward along the coil's curvature. This force increases the frictional resistance of the fluid as it moves through the coil.

Swirling Flow: The helical coil configuration generates swirling or vortex-like flow patterns, especially at 75 degrees inclination. This swirling motion leads to increased flow resistance and higher friction factors.

Increased Flow Path Length: The helical coil's curved geometry increases the effective flow path length compared to the straight vertical pipe. As a result, the fluid experiences more frictional losses along the coil.

On the other hand, in the vertical orientation, a plume effect or stratification can occur, where hotter fluid tends to rise to the top while cooler fluid sinks to the bottom. This stratification can lead to a more uniform flow profile and, in some cases, a reduced friction factor compared to the helical coil configuration. overall, the complex flow pattern and turbulence in the helical coil heat exchanger at 75 degrees inclination result in higher frictional losses, leading to the observation that the maximum value of the friction factor appears at this inclination angle rather than in the vertical orientation.

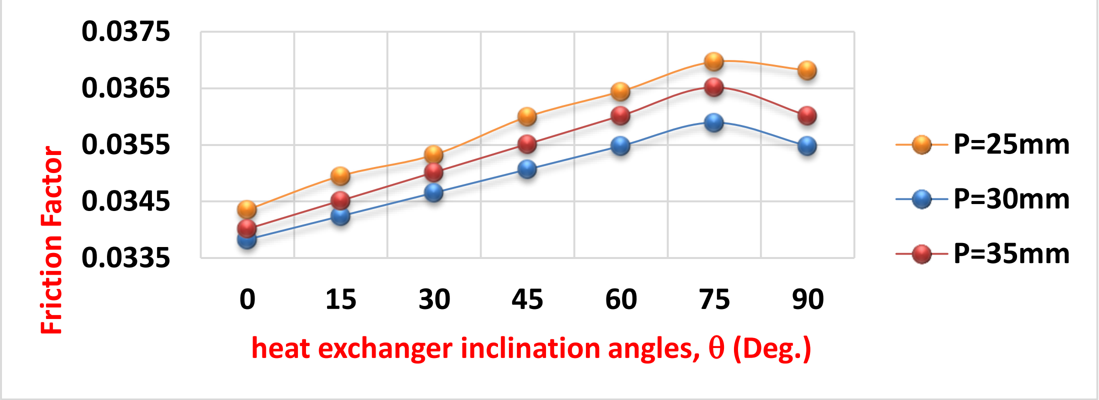

Fig. 7. Friction factor versus Heat exchange inclination angles in a nano fluid volume fraction 0.5 %, pipe diameter = 12.7mm

3.4 Pressure Drop Characteristics

As shown in Figure 8, the Pressure drop increases with the increase in helical coil pipe inclination angle from horizontal to vertical, while maintaining a constant pipe diameter of 12.7mm and mass flow rate. Furthermore, Figure 8 illustrates the inner friction factor of the heat exchanger for different helical coil pitch 25mm, 30mm and 35mm under steady-state flow conditions. Specifically, when considering a helical coil tube with a pitch of 25 mm, the average inner Pressure drop is found to be higher by 13.3 % and 35.7 % compared to the remaining helical coil pitches of 30 mm and 35 mm, respectively. Additionally, the results reveal that the presence of TiO_2 nanoparticles in the water significantly enhances the Pressure drop. The maximum Pressure drop observed is 38.9 at an inclination angle of 75° for the helical coil tube with a pitch of 25mm, using a 0.5% concentration of TiO2 nanoparticles in the nanofluid. Furthermore, when comparing with a pitch of 25 mm, the average inner Pressure drop is higher by 1.43 %, 2.7%, 4.65%, 5.77%, 7.61%, and 0.41% for helical coil inclinations of 0°, 15°, 30°, 45°, 60°, and 90°, respectively, with a pitch of 25mm.

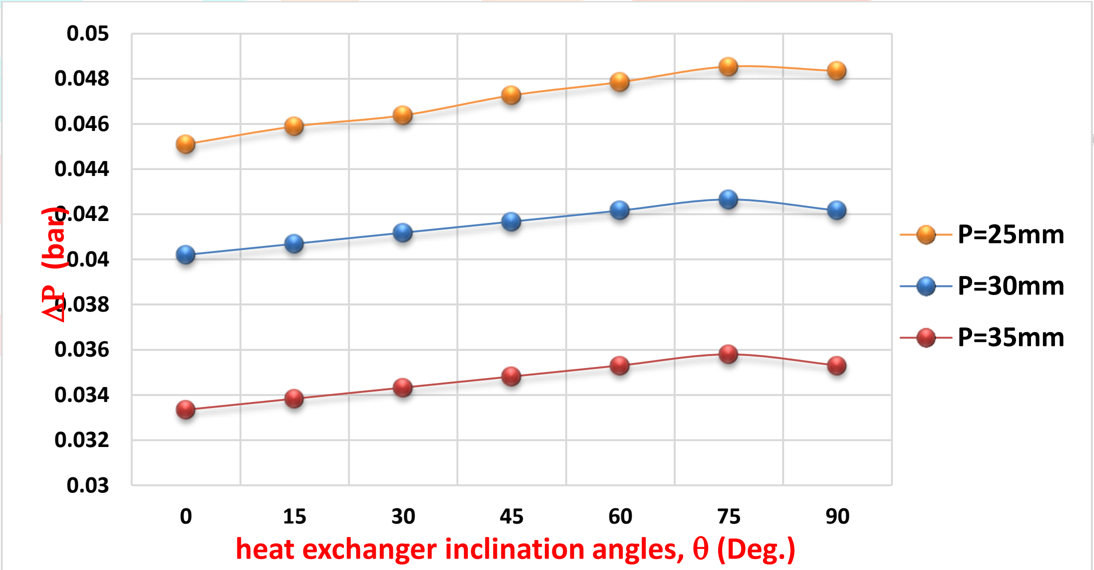

Fig. 8. **Pressure Drop versus Vs Heat exchange inclination angles in a nano fluid volume fraction 0.5 %, pipe Diameter= 12.7mm**

4. CONCLUSIONS

In this study, heat transfer characteristics of a water-based nanofluid containing Titanium Dioxide (TiO2) nanoparticles with a volume concentration of 0.5% were investigated in a helical coil tube heat exchanger. The helical coil tubes had varying pitches of 25mm, 30mm, and 35mm, while maintaining a constant diameter of 12.7mm. The inclination angle of the helical coil tube was varied from 0° to 90° to study its impact on heat transfer. The experimental investigations focused on examining various factors, including the Dean Number, mass flow rate, heat transfer coefficient, pressure drop, friction factor, and Nusselt Number. The flow configuration employed was counter flow, and both the inner helical coil tube and the shell (annulus) experienced turbulent flow. The results revealed several important findings.

Inner Heat Transfer Coefficient: The inner heat transfer coefficient increased with the increase in helical coil pipe inclination angle from horizontal to vertical, while maintaining constant pipe diameter and mass flow rate. When considering a helical coil tube with a pitch of 25 mm, the average inner heat transfer coefficient was higher by 10% and 19% compared to the remaining helical coil pitches of 30 mm and 35 mm, respectively. The presence of TiO_2 nanoparticles significantly enhanced the heat transfer performance, and the maximum heat transfer coefficient was observed at an inclination angle of 75°.

Nusselt Number: The Nusselt Number, representing the convective heat transfer, also increased with the increase in helical coil pipe inclination angle. Similar to the heat transfer coefficient, the Nusselt Number was higher for the pitch of 25 mm compared to the other pitches. The presence of TiO_2 nanoparticles further improved the Nusselt Number, with the maximum value observed at an inclination angle of 75°.

Friction Factor: The friction factor, indicating the resistance to fluid flow, increased with the increase in helical coil pipe inclination angle. When considering a helical coil tube with a pitch of 25 mm, the average friction factor was higher compared to the other pitches. The presence of TiO2 nanoparticles significantly enhanced the friction factor, and the maximum value was observed at an inclination angle of 75°.

Pressure Drop: The pressure drop increased with the increase in helical coil pipe inclination angle. The pitch of 25 mm resulted in higher pressure drop compared to the other pitches. The presence of TiO2 nanoparticles further increased the pressure drop, with the maximum value observed at an inclination angle of 75°.

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