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Hydrothermal Performance Analysis of Double Pipe Heat Exchanger through Insertion of Double Helical Tape

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ABSTRACT

Power plants, nuclear reactors that make electricity, refrigeration and air conditioning (RAC) systems, self-propelled industries, food industries, heat retrieval systems, and chemical handling are just some of the places where heat exchangers are used. You can speed up heat transfer in two ways: by using active methods or passive methods. The active method needs help from outside sources. The passive methods need a surface shape that is different from the others. People have done a lot of work with both methods to improve how heat exchangers work. Many factories use helical tubes because they are small and have a high heat transfer coefficient. They are also known as one of the best ways to make passive heat transfer better. This study examines the hydrothermal performance of horizontal Double Pipe Heat Exchangers (DPHEs) on the external surface of the internal pipe, both with and without continuous Double Helical Tape Inserts (DHTI). We built three DPHEs with counter-flow setups to see how heat moves through them. In two of them, DHTI was made by changing the ratio of the height of HTI to the distance (δ) between the two pipes and the pitch of HTI to the diameter of HTI. We have measured the universal heat transfer coefficient, friction factor, and Nusselt number of a twin pipe heat exchanger that has a double helical tape insert. It was then shown that the experimental data was true for 2300 ≤ Rean ≤ 106 with an error of less than ±10% using the Gnielinski and Filonenko correlations. The outcome indicates that elongating the helical path enhances the centrifugal force, subsequently amplifying the swirl and secondary flows. This breaks the water boundary layer, which makes the turbulence on the outside of the inner tube stronger. This makes the pressure drop a lot and the rate of heat transfer go up too.

Keywords: Heat exchanger, Double Helical tape insert, Hydrothermal performance, Passive technique, Heat transfer enhancement

1. Introduction

1.1 Heat Exchanger

A heat exchanger uses the fact that energy moves from one place to another when the temperature changes. In other words, heat will flow from a heat reservoir that is hotter to one that is cooler. The fluids that are moving around make the temperature difference that lets energy move from one to the other. A heat exchanger can have either latent heat from moving fluids or energy that can be felt. "Hot fluid" is a term for a fluid that gives off energy. The term "cold fluid" refers to the fluid that receives energy. It's clear that the temperature of the hot fluid will go down and the temperature of the cold fluid will go up in a heat exchanger. Heat exchangers can be used to heat or cool the fluid you want. These heat exchangers are also called condensers or evaporators. In many technical settings, heat exchangers are often used to move heat from one fluid to another through tubes.

1.2 Double Pipe Heat Exchanger

Double pipe heat exchangers (DPHEs) are great for situations where the fluid is very thick, very hot, and under a lot of pressure. It is one of the easiest and most helpful ways to exchange heat. A lot of food, oil, gas, and chemical companies use this type of heat exchanger. Many reliable studies have also strongly believed that this kind of heat exchanger is used in high-pressure situations because it is not very wide. They are also very important when you need to keep things at a wide range of temperatures. This type of heat exchanger is also well known to help a lot with reheating, preheating, heating digesters, and heating effluent. A lot of small businesses also use DPHEs because they are cheap to build and keep up. A double pipe heat exchanger is shown in Fig. 1.1.

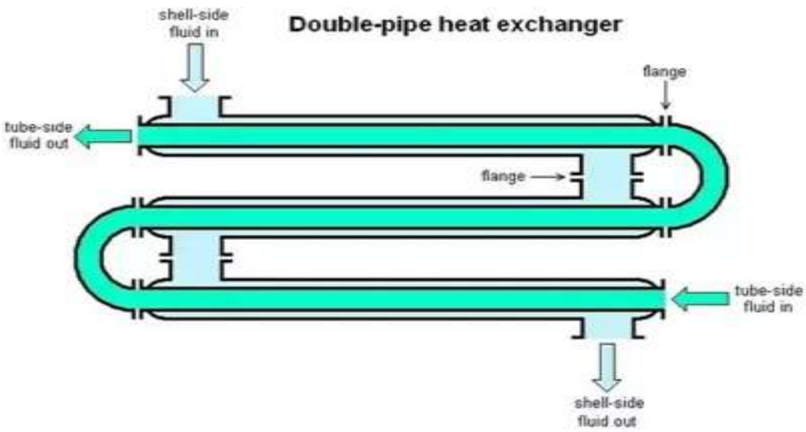

Fig. 1.1: U-type double pipe heat exchanger

1.3 Twisted Tape Inserts

An insert is put into the flow passageways to speed up the transfer of heat and make the passages' hydraulic diameter smaller. Heat travels through a tube faster when there is secondary flow, flow partitioning, or flow blockage. Flow obstructions make the free flow area smaller, which makes the pressure drop bigger and makes the flow more viscous. The best twisted tape is the one that works best and costs the least. When designing a heat exchanger retrofit, it can be helpful to compare how well different tube inserts work. By using techniques that improve heat transfer, you can make heat exchangers work better thermally. One of the passive heat transfer improvement methods is tape inserts. Most heat transfer systems, such as air conditioning and refrigeration systems and food processing, use them. Both active and passive heat transfer enhancement methods are widely used in the chemical industry and in air conditioning systems. These methods make heat exchangers work better while making them smaller and cheaper.

2. literature review

2.1 Introduction

Numerous studies have been conducted to improve the heat transfer rate while simultaneously reducing the size and cost of industrial equipment, motivated by the growing demand to enhance and optimize the performance of heat exchangers. The double pipe heat exchanger is one of many types of devices used in different fields. A lot of people like this kind of heat exchanger because it's easy to use and can be used in a lot of different ways. In certain instances, the focus was solely on the characteristics of the working fluids and their variations [3]. Some looked at compound methodologies [4], changes in geometry [6], active techniques [8, 9], passive strategies [1, 10], and different ways to increase heat [7–5]. The following sections will give a full look at each method, which is still being worked on.

2.2 Review of Past Work

S. No.	Author(s)	Paper Title	Year	Summary
1	Abdalla Gomaa, Yehia Gamal, Mahmoud M. Abdelmagied	Enhancement of thermofluid characteristics via a triple-helical tube heat exchanger	2025	Experimental triple-helical tube HX; ~146% higher Nu vs. double-helical; correlations for Nu, f, and effectiveness.
2	Wahyu D. Prasetyo, Danang Lelono, Ummy Syahida, Bhakti P. Wicaksono, Meutia Hasan	Critical Review of Corrugation in Tubular Heat Exchangers: Focus on Thermal and Economical Aspects	2025	Review of corrugated tubes; trade-off between heat transfer, pressure drop, and cost.
3	J. Wang, Y. Li, J. Lv, J. Zhai, Y. Tu	Thermo-fluid characteristics and exergy analysis of a twisted tube helical coil	2024	CFD + experimental validation; twisted tube + helical coil improves heat transfer and exergy efficiency.
4	Dergi Park	Design and Performance Optimization of Double-Pipe Type Heat Exchangers	2023	Uses response-surface optimization; balances Nu vs. Δp via geometry tuning.

S. No.	Author(s)	Paper Title	Year	Summary
5	A. Mahdi	Heat transfer characteristics of innovative configurations of double-pipe heat exchanger (circular-wavy, oval, oval-wavy)	2020	Wavy and oval geometries show improved thermal performance compared to circular tubes.
6	M.R. Salem, M.B. Eltoukhey, R.K. Ali, K.M. Elshazly	Experimental investigation on the hydrothermal performance of a double-pipe heat exchanger using helical tape insert	2018	Helical tape inserts raise Nusselt number by 69–183% and friction factor by 48–113%.
7	Shailesh Dewangan	A Review of Literature on Experimental Analysis of Overall Heat Transfer Coefficient in Parallel Flow Heat Exchanger using Helical Ribs	2018	Helical ribs enhance heat transfer but increase friction/pressure drop.
8	N. Sreenivasalu Reddy	Experimental Investigation of Heat Transfer Enhancement of a Double Pipe Heat Exchanger with Helical Fins in the Annulus Side	2017	Helical fins in annulus enhance heat transfer compared to plain double-pipe exchangers.
9	Patel Yogeshwari	Numerical and Experimental Investigation of Heat Transfer Augmentation in Double Pipe Heat Exchanger with Helical and Twisted Tape Inserts	2017	Used transformer oil (hot fluid) and water (coolant); CFD + experiment validated results.
10	Pourahmad S., Pesteei S.M.	Effectiveness–NTU analyses in a double tube heat exchanger equipped with inserts	2016	Inserts significantly improve heat transfer effectiveness.

Table 2.1: Summary of literature survey

2.3 Summary of Past Studies

It is evident from the literature review cited above that a wide variety of fin, turbulator, and insert shapes have been employed as passive heat transfer augmentation methods. It was demonstrated that the primary issue with traditional inserts is the significant rise in flow pressure drop. Furthermore, no experimental research has been done to examine how the geometrical parameters of the HTI conducted in the annulus-side affect DPHE performance.

3. Problem Formulation

Aside from insert configurations, the flow conditions (laminar or turbulent) primarily determine an insert's thermohydraulic behaviour. Passive, active, or a combination of passive and active heat transfer augmentation techniques are frequently employed in process industries, evaporator heating and cooling, thermal power plants, air conditioning units, refrigerators, space vehicle radiators, automobiles, etc. Compared to active approaches, passive techniques—which use inserts in the flow path to increase the rate of heat transfer—are more favourable since they can be readily implemented in an existing heat exchanger and the fabrication of the inserts is straightforward. If the right passive insert configuration is chosen based on the heat exchanger's operating characteristics (both flow and heat transfer conditions), passive approaches of heat transfer augmentation might be crucial in the design of compact heat exchangers. Numerous studies on passive methods of heat transfer enhancement have been published in the last ten years. Designers using passive augmentation techniques in heat exchange will find the current study helpful since it deals with recent developments in this field. The passive heat transfer augmentation methods that are most frequently utilised are ribs, fins, dimples, wire coils, twisted tapes, and more.

4. Methodology and Experiment

4.1 Specifications of Heat Exchanger

The experimental study is done in a double pipe heat exchanger having the specifications as listed below:-

Specifications of Heat Exchanger:

Inner pipe ID = 11 mm

Inner pipe OD = 12 mm

Outer pipe ID = 76.2 mm

Outer pipe OD = 81 mm

Material of construction of inner tube= Copper Pipe length= 800 mm

4.2 Experimental Planned

First, the experimental setup's flow diagram is developed. Following extensive study and investigation, the decision was made to use the design of the heat exchanger experimental equipment described in Salem et al.'s 2018 work, which had the same dimensions but different HTI and materials.

Fig. 4.1: Heat exchanger with flange and tape insertion

In this experiment one simple tube and one helical tube was taken then comparing both tube results, according to parameters.

1. Simple tube specification – Material – Copper
2. Length – 800 mm Diameter- 12 mm
3. Helical tube specification - Material – Copper
4. Length – 800 mm Diameter- 12 mm
5. Height of helical tape – 10 mm
6. Number of turn – 16
7. Total diameter of HTI -32 mm Pitch distance – 45 mm

Fig. 4.2: Photograph of the Experimental Setup

4.3 CALCULATION METHODOLOGY

The thermos-physical characteristics of the water in the annulus and the interior tube were computed at mean temperatures Tan, m, and Tt, m, respectively, for all calculations.

Tan, m = (Tan,i + Tan, o)/2

Tt, m = (Tt,i + Tt, o)/2

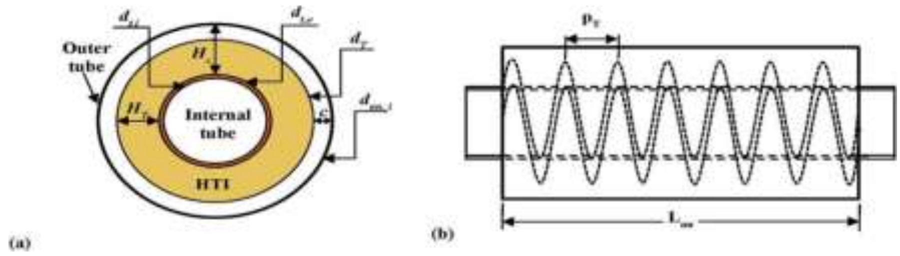

Fig. 4.3: Schematic sketch of the DPHE with HTI; (a) Cross sectional view, (b) Elevation view

Table 4.1: Range of both fluids operating conditions

Parameters/ operating conditions	Range
Annulus- side	4-10 lpm
Inlet temperature	29.2 ºC - 30.9 ºC
Internal tube side	8 lpm
Inlet temperature	50ºC

5. Results and Discussion

5.1 Experimental Results of DPHE with Helical Tape

5.1.1 Variation of Cold and Hot Outlet Temperature

In this work DPHE with helical tape is simulated and results have been presented as shown below. After that comparison will be done between DPHE with or without helical tape.

Table 5.1: Inlet and exit temperature for hot and cold fluid in DPHE with double Helical Tape

(Cold) Water flow rate (lpm)	**Thi (ºC)**	**Tho (ºC)**	**Tci (ºC)**	**Tco (ºC)**
4	50	49.9	29.2	33.7
5	50	49.8	29.6	33.9
6	50	48.7	30.2	33.8
7	50	48.5	30.5	33.6
8	50	49.2	30.6	33.7
9	50	49.3	30.8	33.8
10	50	48.5	30.9	33.9

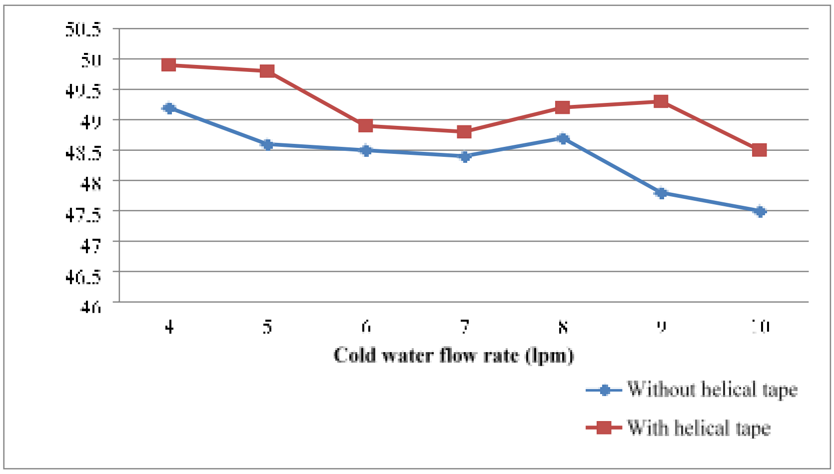

Fig. 5.1: Variation of hot outlet temperature vs cold water flow rate

In the example of DPHE, it illustrates how the Reynolds number affects the water's hot outlet temperature at the exit. Water's ability to carry heat increases as the Reynolds number rises. Heat utilisation rises as a result, but the pace at which heat capacity grows is more important than the rate at which heat utilisation increases. Consequently, a rise in the Reynolds number causes the water's temperature to drop at the exit.

5.1.2 Variation of Heat Transfer Coefficient

Table 5.2: Experimental Results of heat transfer coefficient for DPHE without Helical Tape

(Cold) Water flow rate (lpm)	Thi (ºC)	Tho (ºC)	Tci (ºC)	Tco (ºC)	H (w/m2-k) (Without Helical tape)	h (w/m2-k) (With Helical tape)
4	50	49.9	29.2	33.7	385.22	582.32
5	50	49.8	29.6	33.9	732.12	908.23
6	50	48.7	30.2	33.8	1345.18	1415.68
7	50	48.5	30.5	33.6	1768.24	1896.45
8	50	49.2	30.6	33.7	2057.62	2346.71
9	50	49.3	30.8	33.8	2324.34	2543.20
10	50	48.5	30.9	33.9	2715.11	2907.04

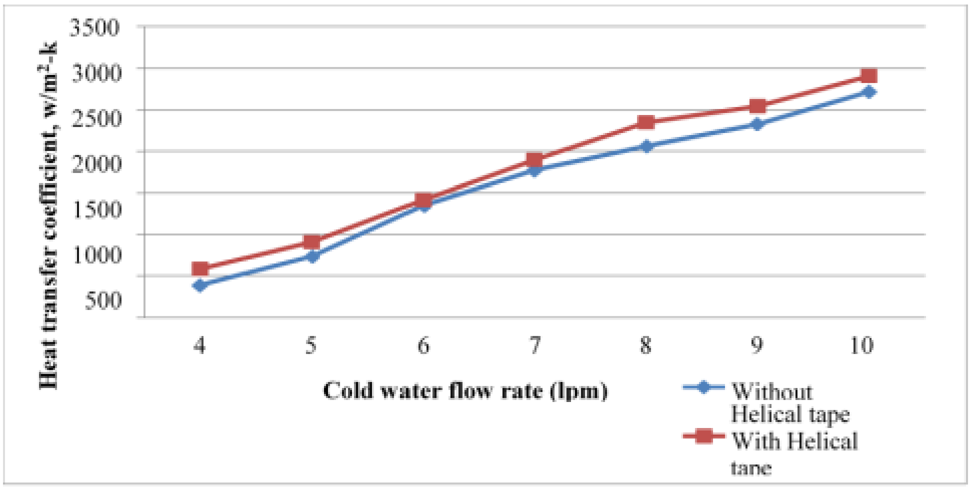

Fig. 5.2: Variation of heat transfer coefficient vs cold water flow rate

5.1.3 Variation of Nusselt Number

A sampling of the results obtained for Nuan at various annulus-side fluid flow rates is shown in Table 5.3.

Table 5.3: Experimental Results of Nusselt number for DPHE without Helical Tape

(Cold) Water flow rate (lpm)	Thi (ºC)	Tho (ºC)	ci (ºC)	Tco (ºC)	Nu (Without Helical tape)	Nu (With Helical tape)
4	50	49.9	29.2	33.7	765.04	1035.62
5	50	49.8	29.6	33.9	782.38	1148.90
6	50	48.7	30.2	33.8	838.24	1343.24
7	50	48.5	30.5	33.6	988.16	1581.36
8	50	49.2	30.6	33.7	1182.32	1871.52
9	50	49.3	30.8	33.8	1224.27	2238.58
10	50	48.5	30.9	33.9	1474.61	2659.14

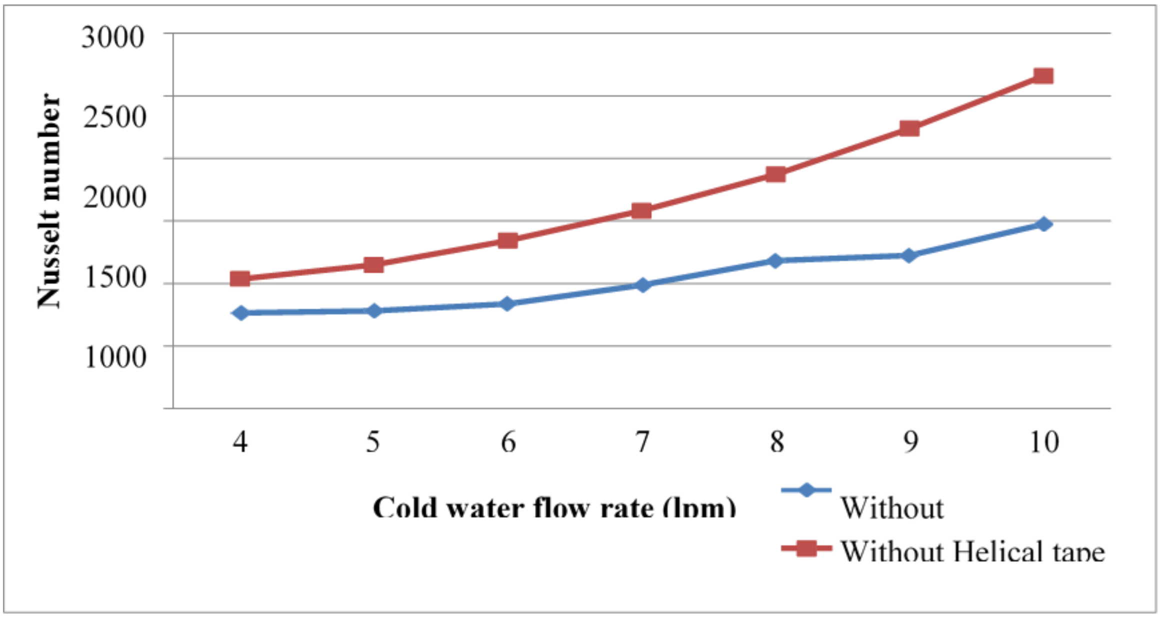

Fig. 5.3: Variation of Nusselt number vs cold water flow rate

5.1.4 Variation of Universal Heat Transfer Coefficient

Table 5.4: Experimental Results of Universal Heat Transfer Coefficient for DPHE without Helical Tape

(Cold) Water flow rate (lpm)	Thi (ºC)	Tho (ºC)	Tci (ºC)	Tco (ºC)	U (w/m2-k) (Without Helical tape)	U (w/m2-k) (With Helical tape)
4	50	49.9	29.2	33.7	432.14	648.24
5	50	49.8	29.6	33.9	612.42	907.56
6	50	48.7	30.2	33.8	808.38	973.58
7	50	48.5	30.5	33.6	862.39	1074.34
8	50	49.2	30.6	33.7	882.76	1134.62

(Cold) Water flow rate (lpm)	Thi (ºC)	Tho (ºC)	Tci (ºC)	Tco (ºC)	U (w/m2-k) (Without Helical tape)	U (w/m2-k) (With Helical tape)
9	50	49.3	30.8	33.8	978.42	1269.23
10	50	48.5	30.9	33.9	1015.66	1388.07

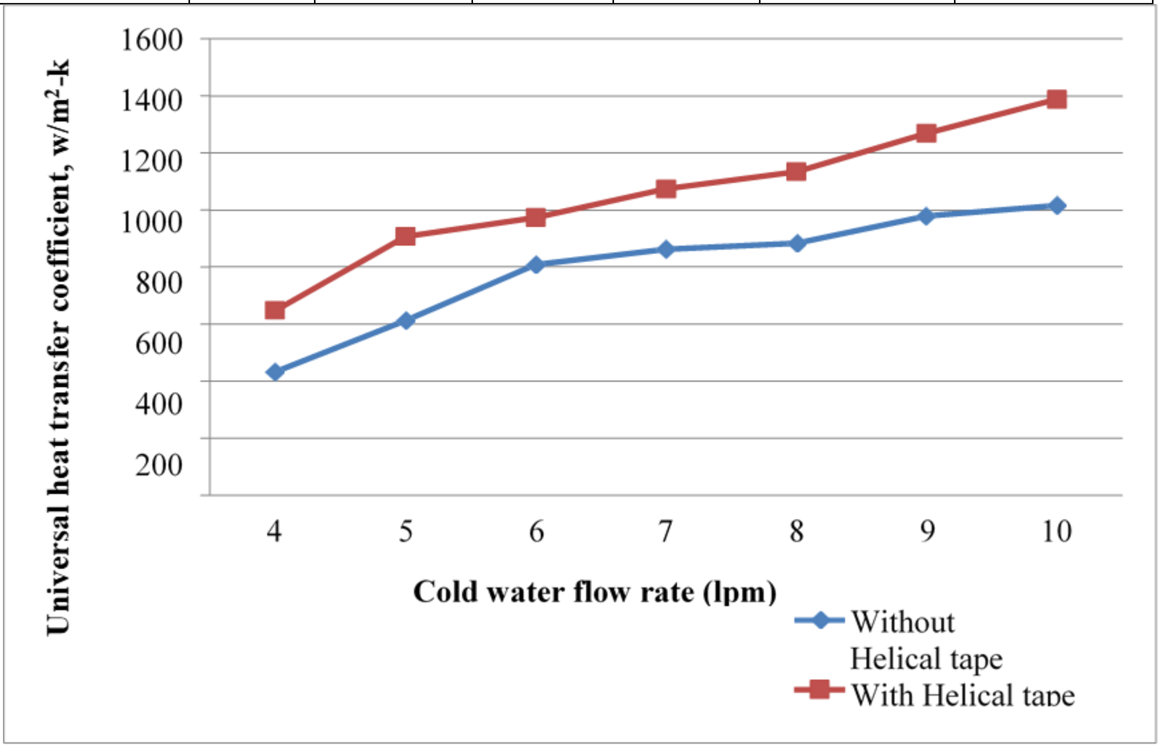

Fig. 5.4: Variation of universal heat transfer coefficient vs cold water flow rate

5.1.5 VARIATION OF FANNING FRICTION FACTOR

Table 5.5: Experimental Results of fanning friction factor for DPHE without Helical Tape

(Cold) Water flow rate (lpm)	Thi (ºC)	Tho (ºC)	Tci (ºC)	Tco (ºC)	fan (Without Helical tape)	fan (With Helical tape)
4	50	49.9	29.2	33.7	0.065	0.088
5	50	49.8	29.6	33.9	0.048	0.074
6	50	48.7	30.2	33.8	0.035	0.062
7	50	48.5	30.5	33.6	0.022	0.047
8	50	49.2	30.6	33.7	0.018	0.038
9	50	49.3	30.8	33.8	0.017	0.028
10	50	48.5	30.9	33.9	0.013	0.022

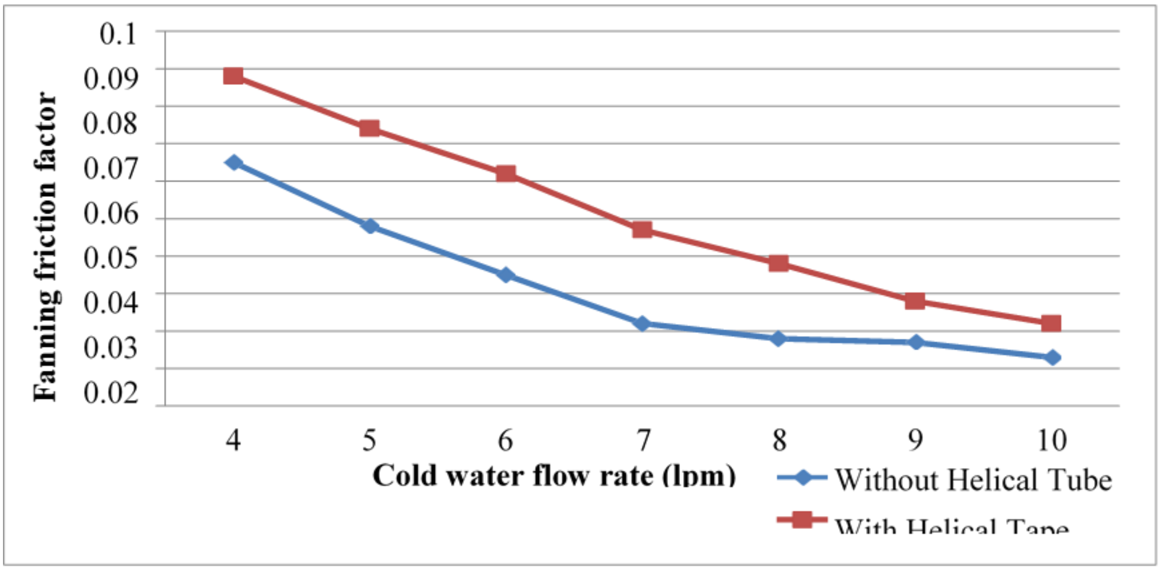

Fig. 5.5: Variation of fanning friction factor vs cold water flow rate

5.2 HYDROTHERMAL PERFORMANCE INDEX

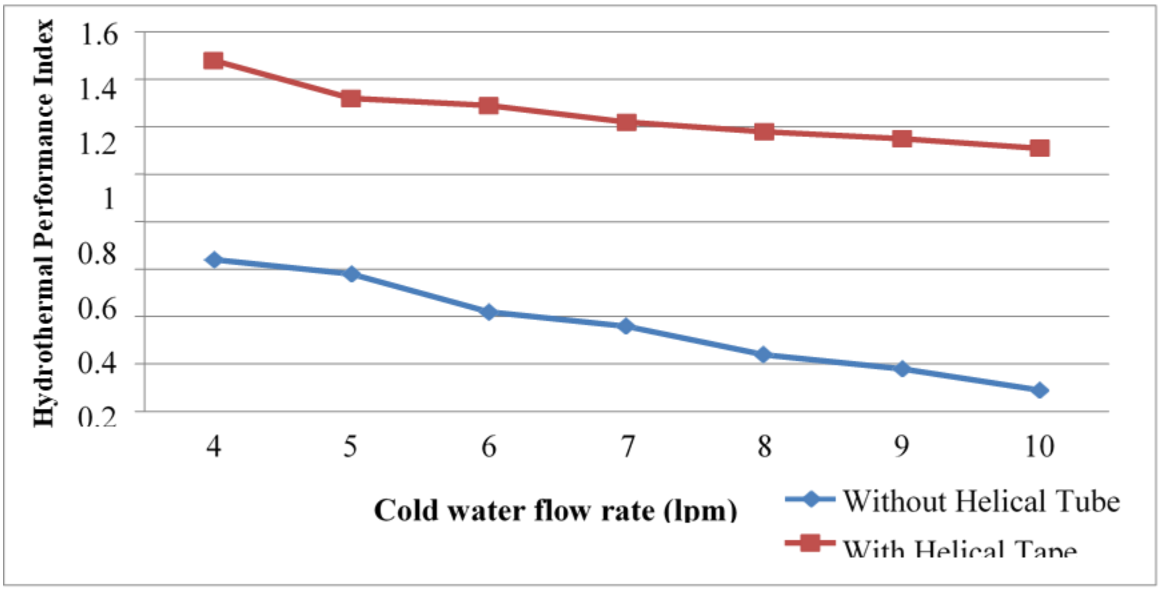

Fig. 5.6: Hydrothermal performance index of DPHE

6. Conclusion and Future Scope

6.1 Conclusion

The objective of this study was to experimentally investigate the hydrothermal performance of horizontal DPHEs on the outer surface of the inner pipe, both with and without a continuous HTI. Throughout this experiment, the primary parameters were the annulus-side operating conditions and the HTI geometrical parameters. One DPHE of counter-flow configurations was built with or without varying HTI height and pitch ratios, and it was tested in the annulus-side at various water flow rates and inlet temperatures. The operational parameters that were examined in the experimental runs were 4 lpm ≤ man ≤ 10 lpm. The results collected allow for the expression of the following conclusions:

When compared to plain annulus heat exchangers, installing a continuous HTI around the outer surface of the inner pipe of DPHEs greatly increases both the annulus-side pressure drop and the heat transfer rate. As the mass flow rate increases, so do the annulus average Nusselt number and friction factor. The HTPI for a tube with helical tape is clearly greater than that of a tube without helical tape, and it remains constant across all mass flow rate ranges. As the Reynolds number rises, the friction factors decrease. It is evident that when the Reynolds number rises, the friction factor value falls. This could be because the friction factor lowers as the Reynold number rises since the boundary layer's thickness decreases as the number rises. It turns out that HTI alone raises the Nuan, Han, and Uan in the heat exchanger. As the mass flow rate increases, these performance metrics rise noticeably. In comparison to the plain scenario, this increase may be the result of both a decrease in the annulus-side hydraulic diameter and an increase in the heat transfer area, which causes a sharp rise in the annulus flow throttling.

Additionally, as the centrifugal force increases, the helical path increases, which in turn causes the swirl and secondary flows to grow. These disrupt the water boundary layer and raise the level of turbulence surrounding the internal tube's exterior. As a result, there is a notable rise in the pressure drop and a notable improvement in heat transmission.

6.2 Future Scope

By creating additional tubes, more research may be done to clarify the impacts of the helical tape's height and HTI pitch. In general, the precision of the various measurement tools and methods determines how accurate the experimental results are.

Together with the HTI's pitch, height, and diameter, the observed annulus diameters and lengths had errors of ± 0.5 mm. The root sum square combination of the impacts of each individual input was also used to compute the parameters' uncertainty.

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