International Journal of Engineering Inventions
e-ISSN: 2278-7461, p-ISSN: 2319-6491
Volume 14, Issue 3 [March. 2025] PP: 137-148

Thermal Performance for Helical Tube with Twisted Tape Inserts for Laminar water flow

Ossama Thamer Hussain[1, *], Prof.Dr.Ahmed F. Khudheyer[2]
[1]*Mechanical engineering department/engineering college/Al-Nahrain university/Baghdad/Iraq)*
(https://orcid.org/0009-0007-6578-6453)
[2]*Mechanical engineering department/engineering college/Al-Nahrain university/Baghdad/Iraq*
(https://orcid.org/0000-0002-5809-4105)

Abstract: *The use of tape insertion to improve the heat transfer for heating and cooling systems is rather widespread. The straight tube has been the subject of the majority of investigations on tape inserts. As opposed to straight tubes, helical coil tubes have been shown to transmit heat more effectively. To get the best heat transfer augmentation, the study goal is to mix the two enhancement techniques and get higher performances. Therefore, the objective is to examine quantitatively the flow characteristics and associated heat transfer in a helical pipe with tape-twisted inserts subjected to a fixed wall temperature.*
A three-dimensional system of computers model is developed using the mass, a momentum, and conservation of energy equations and evaluated against established empirical correlations. Within the Re. Reynolds is between (100–2000) and Dean Numbers De between (25–1200) investigated ranges, the numerical prediction and the experimental correlation analysis indicate fairly well.
In light of the numerical results, the effects of wall temperature T, twist ratio, and inlet Reynolds number Rein have all been assessed and resolved. In contrast to a conventional heat exchanger with a straight tube, Heat transfer efficiency can be increased by up to 4.25 times through the use of the twisting tape insertion to a helical heat exchanger, but the cost of the frictional pressure drop will increase. Since it supports higher secondary flow, a stronger improvement of heat transmission is achieved with a lower twisting ratio. For real-world uses, to predict pressure loss and heat transport, Nu and f correlations are created
Keywords: *Enhancement Techniques, Helical Coil Tubes, Twisted Tape.*

Date of Submission: 15-03-2025 Date of acceptance: 30-03-2025

I. Introduction

Over time, scientists have investigated a number of methods to improve heat transport in thermofluids. This is driven by the growing need for efficient energy utilization and optimization of industrial processes. By reducing energy use and operating expenses, these techniques seek to optimize heat transfer rates. The three primary methods of convective heat transfer intensification are Enhancement strategies including active, passive, and a mix of both. First, where active enhancement occurred this technique boosts heat transfer by using energy inputs or external power sources. Several typical strategies are:

(a) Electro hydro dynamics (EHD) refers to the manipulation of fluid flow using electric fields. Convective heat transmission can be improved by influencing fluid velocity using an electric potential. [1]
(b) Electromagnetic Fields Utilizing magnetic fields can induce Lorentz forces that alter the fluid flow patterns and promote heat transfer. Techniques like magneto hydrodynamics (MHD) and (MHD) pumps fall under this category. [2]
(c) Acoustic Waves, the use of acoustic waves, such as ultrasound, can create oscillations or vibrations in the fluid, enhancing convective heat transfer by disrupting boundary layers and promoting mixing. Examples, use magnetic fields [3-4] and electric in fields [5,6] include the jets [7], also mechanical with mixers or with agitators [8,9].
Second passive Enhancement where this method does not require external power sources and relies on the design or configuration of heat transfer surfaces to improve heat transfer. Some common passive techniques are
(a) Surface modifications, Enhancing heat transfer surfaces through modifications like roughening, ribbing, or using special coatings can disrupt the boundary layer and promote better heat transfer.
(b) Extended Surfaces, adding fins, like pin fins, or other type of extended surfaces to maximize the heat transfer surfaces by increases the effective surface area, leading to improved heat transfer.
(c) Inserts and Enhancers, using inserts such as twisted tapes paper target, or vortex generators, and porous media can create the turbulence, that leads to disrupt the boundary layer, and enhance convective also heat transfer and The effects of fin.

Examples include the following: Nano fluid [10–12], Phase Change Materials (PCM) encapsulation [13–17], insert tape [21–22], and modification surface [23–24].

The final method is a combination of active and passive methods This approach combines both active and passive techniques to achieve optimal heat transfer enhancement. For example, using external power sources in conjunction with specially designed surface modifications or inserts can provide synergistic benefits. Nano fluid and field of magnetism [25], and with surfaces perforated EHD [26].

Understanding the intricate flow patterns, such as vortices, eddies, and recirculation zones, is crucial for predicting and optimizing heat transfer processes. understanding the underlying flow behavior will enable researchers to create creative designs and tactics to improve heat transfer performance, ultimately resulting in more effective and efficient thermal engineering systems which conducted and published research on twisted tape inserts more than a century ago [27], calculating the impact on a (100 horsepower horizontally tube boilers) of tape that is twisted. The boiler's performance is improved by the twisted tape. When the boiler is running slowly, it shouldn't be utilized.

The focus of the resulting research consisted of creating a connection to forecast heat transfer. in a turbulent and laminar flow, either a constant heat flux or a constant wall temperature affects the pressure drop in a pipe with a tape-twisted insert for example [28, 29]. Many studies using different kinds of twisted tape that have various geometries have been conducted and published as a result of the increased interest in modern twisting tape insertion to improve heat transfer throughout the last decade or so. Singh Suri and others [30].

With the help of various square perforated twisted tape inserts, in turbulent flow through heat exchanger tubes, the behavior of friction and heat transmission was examined experimentally. The study used many and variable hole with width ratio of (0.08 to 0.333), Under constant wall of heat flow, the twist ratio (2.0-3.5), and Re. Reynolds number is between (5000 and 27,000). With a significant perforations ratio (0.25) and an acceptable tape ratio of twist (2.54), insert the perforated twisted tape into tubes, the highest Nusselt number was obtained. which showed a significant improvement in thermal performance when compared to plain tubes. *Wongcharee* and *Eiamsa-ard* [31] To enhance laminar convective heat transmission in straight tubes, alternate clockwise and counterclockwise twisted-tape inserts have been proposed. Water was used as the working fluid in the research along with tapes with various twist ratios and Reynolds numbers. Research have better heat transfer performances when compared to those using plain tubes and standard twisted tapes.

For the range in question, enhanced tape that was twisted with an alternate axis significantly outperformed normal twisted tapes in terms of Nusselt number. The twist ratio, however, increased while the Nusselt number decreased. For the turbulent [32] and transitional [33] flow regimes, a similar result was also found. *Rama Kumar* [34] suggested and assessed the effectiveness of twisted tape with a tapered end for improving heat transmission in an elongated round tube. It was found that tape that was twisted and had a tapered edge improves heat transfer more than twisted tape with a constant width. Using a (3D) turbulence model, *Moghadas Zade* [35] examined a unique eccentric helical screw taped insert's capacity to transfer heat in an ordinary circular tube.

This study demonstrated better heat transmission as a result of increased fluid mixing and increased centrifugal force close to the wall brought on by the whirling effects. New coaxial cross-twisted tapes were introduced by *Liu et al*. [36] to enhance the laminar convective heat transfer in spherical straight tubes. The heat transmission of lubricating oil through a tube was numerically analyzed by the authors. The authors performed a numerical investigation Measuring lubricating oil by transferring heat in the small Reynolds number region Re (40-1050) via a tube that has just had twisted tape placed in it. It was found that the spiral cross-twisted tapes offer a smaller boundary layer and a larger temperature graduation near the tube wall. Because of these features, the novel twisted tape transmits heat more effectively than the conventional twisted tape.

Regarding the design of turbulent flow inside a circular tube and the effectiveness of its thermal-hydraulic system, *Esfahani* and *Nakhchi*, [37] studied the effect of the quantity of cuts (single vs double) and the cutting percentage for rectangular-cut twisting tapes. For the Reynolds number range (5000–16,000) that was investigated, The Nusselt number was found to grow as the cut length ratio increased, and double-cut twisted tape has a higher effect on temperature increase than single-cut twisted tape for a given cut ratio. In their article, Man et [38] took into account geometrical features that are commonly assessed when studying twisted tape.

Twisted tapes were discovered to perform better under the square tube and low (Re) conditions. However, using twisted tape can lead to a bigger pressure decrease. Therefore, more research should focus on this topic so that modifications may be made in a way that results in the optimal trade-off between pressure drop and increased heat transmission. Furthermore, *Varun et al*. [39] have written a thorough evaluation of the heat transfer increase using twisted tape inserts. There were several published and studied relationships between the friction factor and the Nusselt number. Along with new twisting tape shapesThere have also been new investigations on the heat transmission of nanofluid technology through tubes. Several nanofluids, such as Fe_3O_4/water [40], and Al_2O_3/water [41], CuO with water [42], also Ag/water [43], and TiO_2/water [44], have been investigated for enhancing heat transmission when mixed with twisting tape inserts.

Curved tape additions have been demonstrated in the previously mentioned research study to enhance the thermal efficiency of straight tubes. We are not aware of any published studies on the application of twisted tape insertion in helix coil tubes. Since helical heat exchangers offer greater heat and mass transfer rates and a lower overall footprint than their straight tube equivalents, they are frequently utilized in industrial applications. It has also been the main topic of engineering study since the helical tube possesses curvature-induced secondary flow, which regulates the transport processes [45]. It is also known that secondary flow causes the heat transfer rate in helical tubes to increase. Therefore, it would be interesting to combine the two processes at the same time and analyze the further improvement that would occur. This improvement would be very significant for many industrial applications, such as electricity production, condensers, refrigeration cycles, exchangers for heat, etc.

II. Methodology

The goal of this study is to determine how twisted tape inserts affect the heat transfer that is connected to flow dynamics in helical tubes. It also aims to look at important variables like twisted ratio and Re_{in} Reynolds No. inlet, and T_w wall temp. that may influence the performance of heat transfer. The temperatures T of (40, 60, and 80 °C) and the Re. Reynolds No. range of (100-2000) were selected using common values seen in real-world applications. In order to compare the outcomes with helical and smooth straight tubes of similar form, the Nusselt, the viscosity factor and Figures of Merit, which are the ratio of the required pumping power to the quantity of heat transfer. Additionally, an investigation of entropy production is performed to determine the root reasons for inefficiency in the investigated geometries. The energy flux vector will be represented by heat lines from every configuration. The purpose of this study is to provide guidelines for using twisted tape inserts in helical tubes for thermal system applications.

Based on the fundamentals of conservation, a 3D software model of Newtonian fluid motion and the corresponding heat transfer has been developed inside a circular tube with a twisting tape insert. The incompressible and laminar flow was assumed to be present. Geometries with straight and helical tubes and twisted tape inserts are being considered, as can be seen in Fig.1.and the Table1 shows the precise geometry and functional features.

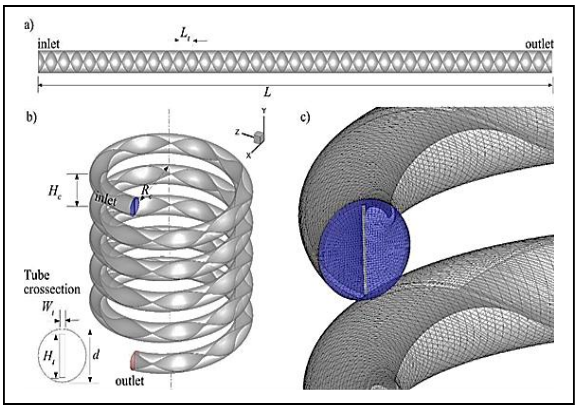

Figure 1. Shows schematic representations of three different tube types, including a) simple tubes, b) and c) helix tubes with tape-twisted inserts, and a representation of computational domain numerical mesh.

Table 1. Operating Parameters

Parameters	Value			Unit
T_{in}	293.15			K
T_{wall}	313.15	333.15	353.15	
D	0.0113			m
H_t	0.01			
H_c	0.02			
L	1.26			
L_t	0.0315	0.0786	0.0157	
W_t	0.0004			
Re	0.04			

L	1.26	
P_{out}	0 Gauge	Pa

2.1 Governing Equations
Motion and energy are transferred at the same moment during the flow through the tube. These flow equations for preservation are provided by [46,47].
$\nabla \bullet \rho\, u = 0$ (1)
$\nabla \bullet (\rho\, u\, u) = -\nabla\, p\, I + \nabla\, \mu\, \nabla u + (\nabla u)\, T + \rho\, g$.(2)
Working fluid density, fluid velocity, pressure, identity tensor, fluid dynamic viscosity, gravity acceleration, specific heat, C_p, are all given in the following table. Thermal conductivity is, and T temperature. However, only conductive heat transmission is taken into account by the twisted tape insert., i.e.
$k_s.\ \nabla.^2 T=0$ (3)
where temperature is T and the twisted tape's conductivity is k_s. The current model applies the concept of entropy equilibrium hypothesis to an open system., which was used in our earlier investigations [48,49].
$-\nabla\sigma + Sg = 0$ (4)
where S_g is the average rate at which entropy is produced per unit capacity and represents the entropy influx. Air, as well as water, are the types of heat transfer fluids taken into account in the present investigation with constant thermos physical properties. Four components make up the entropy production rate for each volume: mass transfer, chemical reaction, viscous dissipation, and heat transfer [50]. Just the first two keywords are used in the current investigation;
$S_g = S_h + S_u$ (5)

$$S_h = \frac{\nabla \cdot (k\nabla T)}{T^2} \quad (6)$$

$$S_\mu = -\frac{1}{T}\boldsymbol{\tau}{:}\nabla\mathbf{u} \quad (7)$$

where the second element in Equation's right-handed side (2) gives the viscous stress tensor, or. A discussion of the Nusselt number and performance index used to measure the investigated coiled tubes' ability to transport heat is included. The definition of the median Nusselt number is

$$Nu_m = \frac{1}{\Delta L}\int_0^L Nu dL \quad (8)$$

Where the equation element is *Nu is* local Nusselt No., which defined as (Nu = h.d/k) And the coefficient h of the heat transfer is {h= $q_{wall}/(T_w - T_m)$},where q_{wall} Is the wall transferring heat, and T_w the temperature of the pipe wall and T_m is average mean temperature which defined as

$$T_m = \frac{1}{VA_c}\int_{A_c} \mathrm{uTdA_c} \quad (9)$$

Where Ac is the cross-sectional area of the tube's, and V is its mixed mean of flow velocity which could be defined as

$$V = \frac{1}{A_c}\int_{A_c} udA_c \quad (10)$$

While the efficiency index is the friction coefficient to the mean Nusselt number ratio, which defines as

$$PI = \frac{Nu_{\mathrm{avg}}}{f} \quad (11)$$

$$f = \frac{\Delta pd}{2pv^2L} \quad (12)$$

Where L is the total length of the tube, d is the diameter, and the fluid pressure that falls over the tube is denoted by p. For entropy generation study, the global creation of entropy rate must be determined, the entropy production rate per unit volume over the full volume (V) is integrated.

$$\dot{S}_g = \int_v S_g dV \quad (13)$$

2.2 Streamline and Heat Line Visualization

$$u = \frac{\partial\psi}{\partial y}.\ v \quad = -\frac{\partial\psi}{\partial x} \quad (14)$$

in which ψ the stream function of (x,y). This function also satisfies the conservation of mass. A streamline is a line with a constant stream function that is the same as the velocity field. Using a similar idea, the definition of the heating line function is [54]

$$J_x = \frac{\partial H}{\partial y} = \rho u c_p T - k\frac{\partial T}{\partial x} \quad (15)$$

$$J_y = \frac{\partial H}{\partial y} = \rho u c_p T - k\frac{\partial T}{\partial y} \quad (16)$$

J_x and J_y are, respectively, total (convection and conduction) heat flux's x- and y-components.

2.3 Boundary Conditions

- Inlet: u_{in}=1.013 m/sec , T_{in}= 300K.
- the constant solar intensity (850 W/m$^{2)}$.
- Inlet, the constant velocity at the inlet corresponds to Re (100 to 2000). With constant temperature with $T=T_{in}$, $u = U_{in}$
- Table 1 displays the results of the assessed inlet velocity.
- outflow: We defined nil-gauge pressure and nil stream at the outflow, where the gradient of temperature was present $P=P_{out}$, $\nabla T=0$
- Wall: no-slip conditions at the surface wall and constant wall temperature were could set as. $T=T_w$, and u=0

Table 2. Independent Test for Mesh

Mesh independent		Straight tube		Helical Tube	
		temp	Δp	**temp**	Δp
1	142,000	347.75	72.12	350.91	88.03
2	492,500	348.16	88.42	350.80	102.20
3	968,240	348.76	97.52	350.39	107.33
4	1,603,800	348.11	99.25	350.35	109.65
5	2,398,220	349.00	99.47	350.23	110.07
6	3,356,340	348.79	99.19	350.24	110.05
7	4,115,160	348.46	98.23	350.23	109.60

2.4 Numerical Methodology

The generated model was integrated with the required boundary conditions and mechanical relations, using the computational domain, while ANSYS Fluent was used to solve it. The generated model included mass, momentum, and energy conservation. In advance of being meshed and labeled in ANSYS meshing, ANSYS Design Modeler was used to establish the model's computational domain. The six dependent variables that comprise the complete model are (u, v, w, p, T, and S_g). Second-order upwind division and the algebraic multi-grid (AMG) technique were utilized to solve the problem using the (Semi-Implicit-Pressure-Linked) Equation, or SIMPLE. For all equations to converge, a residual criterion of 106 was established by gradually increasing the number of meshes used in the test until no discernible changes in the numerical result were seen, and results independent of the mesh were guaranteed. Table 2 shows the final outcomes of the mesh-independent test.

III. Results and Discussion

The twisted tape has received a lot of attention and has proven to be an efficient method for improving passive heat transmission. The utilization of longer flow paths in heat transfer systems provides several advantages for enhancing heat transfer. When the fluid is made to travel through an extended path, it experiences a larger contact area with the heat transfer surfaces, promoting more efficient heat exchange. This increased contact area allows for greater heat rate transfer Q and improved U overall thermal performance.

Introducing a swirl enhanced in the flow is another technique employed to augment heat transfer. The fluid moves in a swirling or circular shape as a result of the rotational momentum that swirl motion gives it. The fluid's heat exchange with the surrounding surfaces is improved, boundary layers are broken up, and better mixing is encouraged by this swirling movement. Better mixing characteristics and more intense turbulence result in higher convective heat transfer coefficients.

Moreover, extending the residence time of the fluid within the heat transfer system contributes to higher heat transfer efficiency. By prolonging the time, the fluid spends in contact with the heat transfer surfaces, there is more opportunity for heat exchange to occur. This extended residence time allows for a more thorough thermal interaction, optimizing the fluid's and the surface's available temperature differential. Consequently, heat transmission is increased, which boosts system performance.

Numerical simulations of straight and helix pipes with identical designs were conducted in order to examine the laminar convective exchange of heat of the helix pipes with a twist tape insert. Research on the effects of the wall's temperature, twist ratio, and inlet Reynolds number is carried out.

3.1 Model Validation

In order to verify the correctness and validity of the validated model, validation of the model must be carried out prior to the numerical investigation. The model's predictions for helix pipes without tape with twists inserts were contrasted with the outcomes of correlations proposed in the scientific literature for linear tubes, and regular tubes with twisted tape inserts. Using the model and correlations proposed by *Edwards et al*. [27], Without a twisted tape insert, the linear tube's Nusselt number coefficients were found. The figures in Fig. 2a from Baehr and Stephan [28]. The mean inaccuracy was 0.12%, The reported data and the predicted Nusselt Number showed good agreement. The graph indicates that with lower Graetz values, the model makes more accurate predictions, where an equilibrium point is reached by the Nusselt number. The predicted Nusselt values and information by Manlapaz as well as Churchill [29] were compared with regard to the helical pipe without the tape's twisted insertion, and Fig. 2b illustrates how closely the findings match.

The generated Nusselt number values for helix tubes have an average accuracy of 2%. The model yields acceptable outcomes for both straight and helix tubes, as may be inferred from the two figures. In order to compare the Nusselt number, Manglik and Bergles' correlations [28] and the experimental information from Manglik's study [55] also support the findings of the straight pipe with a twisting tape insert model. additional friction as illustrated in Figs. (3a and 3b), respectively.

Manglik and Bergles' connection and the simulated outcomes are strongly correlated, according to the graphs. Heat transfer effectiveness deviates a little (7%) at higher S_w values compared to the empirical correlation. A relative deviation of less than 3% indicates great agreement in the comparison of pressure decrease. Manglik discovers that there is a rise in deviation with increasing dimensionless swirl value S_w, reaching up to 10% error when comparing the simulated results to the data from experiments. These confirm the validity and correctness of the proposed model.

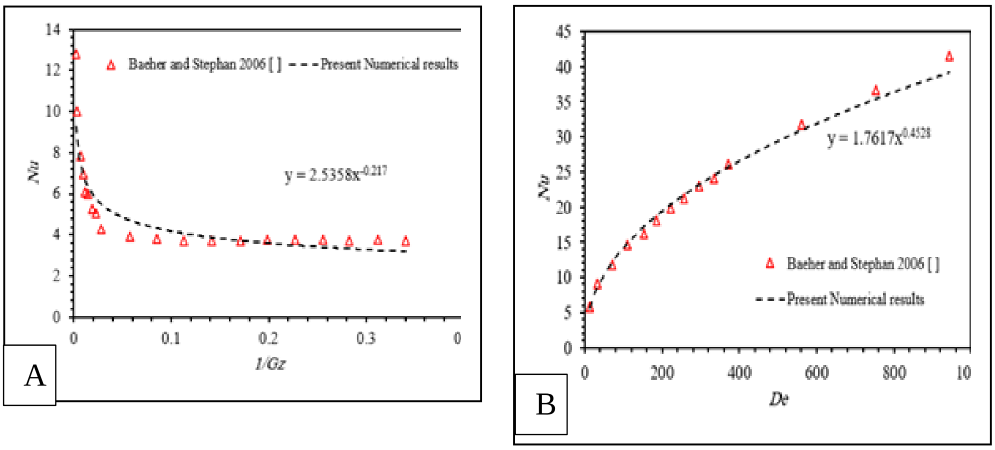

Figure 2. Relation between Nusslt No. with. **A)** liner tube **B)** helical tube both are without twisted tape

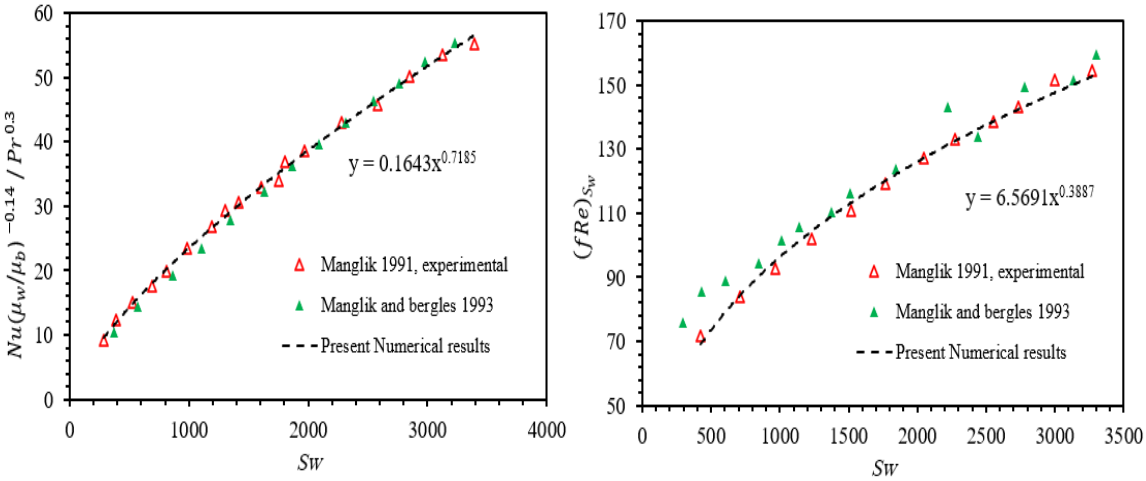

Fig.3. Numerical result for liner tube with twisted tap

3.2 Spin Ratio Effect ion

When assessing the effectiveness of twisted tapes, two important factors are the pitch as well as twist ratio. The distance between two locations orthogonal towards the tape axis on a single plane is known as the pitch. The twist ratio is the tube's internal diameter divided by its pitch. It is important to look at the flow behavior inside the tube under consideration before moving on to the heat transfer performance. The study looks at eight distinct situations using straight and helix tubes having twist ratios of 3.15, 7.86, as well as 15.73 with no twisted tape.
The longitudinally velocity and streamline of the water at pipe cross sections are shown in Fig. 4. The linear pipe at L = 25.16 cm, Re 1000, and T_{wall} 333.15 K without the twisted tape insert lacks the secondary flow, although it is clearly visible in the helix pipe partner. It is evident that the tape facilitates radial secondary flow. greater secondary flow intensity is correlated with more twists in both straight as well as helical tubes, and this is matched by a greater secondary velocity. Additionally, For straight pipes with tape inserts as well as twist ratios of a score of 3. it's crucial to keep in mind that the tape produces two vortices rather than simply one, as in previous straight tube cases.

As seen in Fig. 5, this flow profile is anticipated to directly affect heat transmission and the distribution of temperatures inside the tube. A more even distribution of temperatures is an indication that secondary flow is present, which raises the mixing temperature and boosts heat transmission. It is evident that the tube with the 3.15 tape twist ratio surpasses the other two configurations in terms of homogeneity. With an increase in twist ratio, the temperature gradient becomes less uniform. contrasting tubes with and without helices

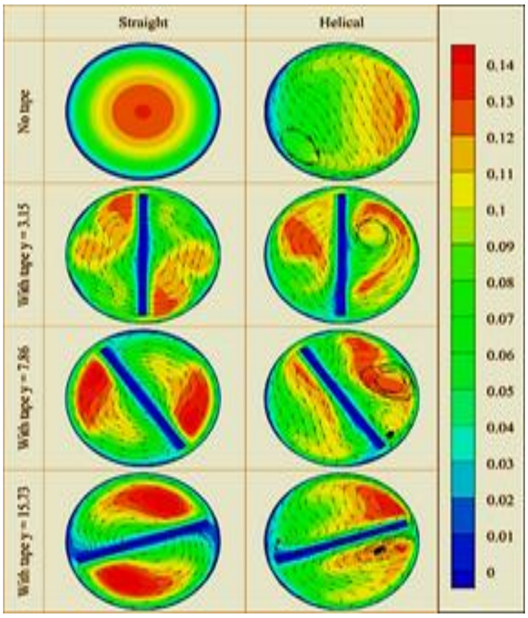

Figure4. shows the streamline of the water and axial velocity (m/s) flow in a tube for different configurations of twisted tape.

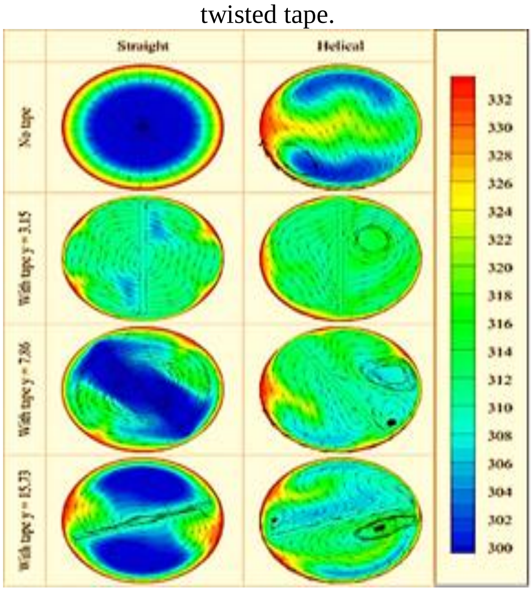

Figure 5. demonstrates the temperature variation (K) and heating stream of water flowing in a tube for different twisted tape

Because the temperature is closer to the wall temperature in helix tubes with twisted tape inserts, a larger temperature profile is seen. When the twisting ratio of their twisted tape is higher, both helical and straight tubes generate more thermal entropy. It is also clear that, as expected, helical pipes generate greater frictional entropy compared to straight tubes due to the greater secondary flow produced. However, unlike thermal entropy, frictional entropy creation diminishes as the twisted ratio increases. These patterns are shown in Fig. 6, which depicts the shape of the overall entropy produced from the water flow in the pipe at Re = 1000. Furthermore, thermal entropy formation appears to be the key component in entropy production. This is clear from the enormous gap. The magnitude of entropy formation owing to heat transfer as well as viscous dissipation are 10^{-2} and 10^{-7}, respectively.

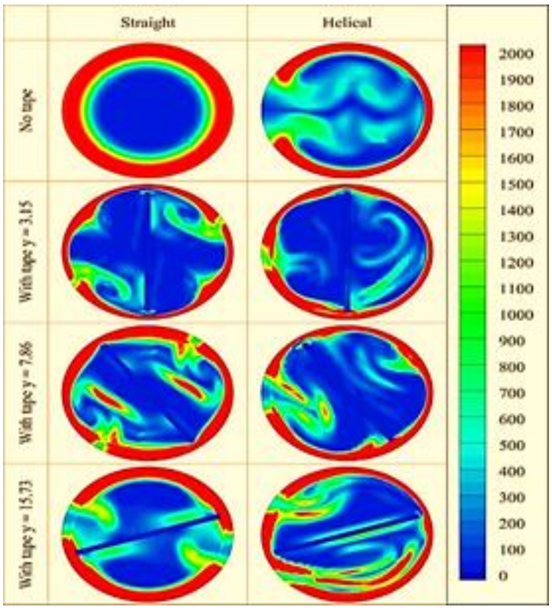

Figure 6. entropy produced for various twisted tape

A performance index has been created to allow for a fair comparison, and Table 3 summarizes the values for all studied settings. Overall, helical tubes provide better performance than straight tubes, as seen by an increased performance index. At higher Reynolds numbers, however, with no a tape insert, the helix tube's effectiveness index is somewhat lower than the one of the straight the pipe. This is most likely owing to the large spike in pressure drop, rather than the better heat transmission afforded by the helical pipe. When the tubes are fitted with the twisted tape insert, in comparison to the flat tube with the identical configuration, the helical tube regularly performs better. It's interesting to note that for various Re and wall temperatures, the influence of the twisting ratio changes for both tubes. The highest twisting ratio yields the worst performance for straight pipes with high Re, while a twisting ratio of 7.86 yields the best results. Additionally, Low-temperature helical tubes are included in the tendency, which is valid for all Reynolds values. However, when the twisting ratio rises at higher temperatures, Helical tubes' performance rating goes up. For airflow, a straight pipe is preferred at smaller Reynolds numbers. This might happen due to the Ra has become low at low Re as well as Pr.

Table 3. Performance measurements for different configurations

T_{wall}(K)	Re	Tape y=7.86		Tape y=15.73	
		Straight	Helical	Straight	Helical
313.15 (Water)	100	21.75	28.48	21.75	28.48
	500	121.43	189.67	121.43	189.67
	1000	315.97	401.86	315.97	401.86
	1500	568.80	635.97	568.80	635.97
	2000	783.66	859.39	783.66	859.39
333.15 (Water)	100	29.66	40.86	29.66	40.86
	500	144.70	236.86	144.70	236.86
	1000	421.02	491.25	421.02	491.25
	1500	679.77	745.68	679.77	745.68
	2000	927.95	966.08	927.95	966.08
353.15 (Water)	100	37.71	49.38	37.71	49.38
	500	165.52	289.02	165.52	289.02
	1000	445.54	579.02	445.54	579.02
	1500	733.42	874.72	733.42	874.72
	2000	994.02	112131	994.02	112131
333.15 (Air)	100	3.92	3.12	3.92	3.12
	500	53.58	52.34	53.58	52.34
	1000	100.71	122.82	100.71	122.82
	1500	173.08	198.69	173.08	198.69
	2000	255.80	269.22	255.80	269.22

T_{wall}(K)	Re	No Tape		Tape y=3.15	
		Straight	Helical	Straight	Helical
313.15 (Water)	100	35.56	54.18	35.56	54.18
	500	261.23	315.29	261.23	315.29
	1000	664.66	671.78	664.66	671.78
	1500	1146.09	1053.83	1146.09	1053.83
	2000	1673.08	1459.14	1673.08	1459.14
333.15 (Water)	100	48.17	72.88	48.17	72.88
	500	330.94	417.16	330.94	417.16
	1000	814.03	865.25	814.03	865.25
	1500	1377.61	1340.03	1377.61	1340.03
	2000	1986.81	1839.59	1986.81	1839.59
353.15 (Water)	100	61.24	93.26	61.24	93.26
	500	401.87	525.54	401.87	525.54
	1000	964.17	1071.34	964.17	1071.34
	1500	1608.58	1643.37	1608.58	1643.37
	2000	2298.26	2239.11	2298.26	2239.11
333.15 (Air)	100	9.38	7.97	9.38	7.97
	500	96.75	124.30	96.75	124.30
	1000	199.83	317.21	199.83	317.21
	1500	309.99	497.04	309.99	497.04
	2000	426.69	676.14	426.69	676.14

3.3 Relationships between Heat transfer and Flow

Later, The study was expanded to include the establishment of flow and heat transfer characteristics for straight and helix pipes having tape-twisted inserts for practical applications. Like *Manglik* and *Bergles* [28] For a straight pipe, the functions Nusslat Nu = f (Sw, Pr, w, b), and friction factor f = f (R_{esw}, y) were used to approximate the results, and Nu is a function of f (D_{esw}, Pr, w, b), where f = f (D_{esw}, y) for the helical tube. In the most extreme situation, there is a thermal entry and buoyant force. Following are suggested relationships between heat transfer and friction factor based on our findings, with a valid range of Reynold No {Re (100-2000), with Pr(0.7-7), also S_w(25-1700),where y(1-15.73),and D_{esw}(25-1200)}. The exponent constants are computed using the multi-regression approach to suit the simulation data.

Straight Pipe:

$$f = 42.48 Re_{sw}^{-0.86} y^{-0.21} \qquad (17)$$

$$Nu = 0.3 Sw^{0.62}\,\mathrm{Pr}^{-0.1}\left(\frac{\mu_w}{\mu_b}\right)^{1.39} \qquad (18)$$

Both correlations have coefficients of determination r2 of 0.9344 and 0.9440, respectively, and their relative error is under 10% when compared to the correlation provided for a straight tube by Manglik and Bergles.Helical tube:

$$f = 13.49 De_{sw}^{-0.77} y^{-0.15} \qquad (19)$$

$$Nu = 1.14 De_{sw}^{0.45}\,\mathrm{Pr}^{-0.1}\left(\frac{\mu_w}{\mu_b}\right)^{1.84} \qquad (20)$$

The friction coefficient correlation and the Nusselt number correlation both have coefficients of determination r^2 of 0.9451 and 0.9895, respectively.

IV. Conclusion

The flow pattern and heat transfer efficiency in a helix pipe with a twisted tape insert exposed to a steady wall temperature were analyzed and evaluated using a computational fluid dynamics approach. The impact of variables like twisted ratio, Re_{in} input Reynolds number, as well as wall temperature were studied to identify the ideal operating conditions.

The results show that applying twisted tape inside a helical pipe enhances the creation of secondary flow when compared to a straight pipe, which is reflected in an increased heat transfer rate (Nu). A lower twisting ratio results in a larger increase in heat transfer at the expense of a higher frictional pressure drop. At low Pr (air), a higher Reynolds number results in a greater Nu Nusselt number and Q heat transfer enhancement, the ratio of the increase of q heat transmission is larger at Re (500–1000), also at higher Pr (water).

As a result, the cutting-edge helix pipe using a twisted tape insert performs best with water with larger Reynolds numbers along with lower twisting ratios. To assist engineers in designing outstanding performance. heat exchangers, both Nu and f correlation are used to forecast pressure loss and thermal transfer. These connections can be employed in practical situations.

Conflict of interest
"The authors declare that there are no conflicts of interest regarding the publication of this manuscript"

Author Contribution Statement
Authors O.T. and A.F: proposed the research problem.
Author O.T.: developed the theory and performed the computations.
Author A.F.: verified the analytical methods and investigated [a specific aspect] and supervised the findings of this work.
Both authors discussed the results and contributed to the final manuscript.

References

[1]. Sheikholeslami, M., Hayat, T. and Alsaedi, A.J.I.J.O.H., (2017). Numerical study for external magnetic source influence on water based nanofluid convective heat transfer. International Journal of Heat and Mass Transfer.Vol. 106,pp.745-755. 10.1016/j.ijheatmasstransfer.2016.09.077.

[2]. Sheikholeslami, M., Hayat, T. and Alsaedi, A., (2017). RETRACTED: Numerical simulation of nanofluid forced convection heat transfer improvement in existence of magnetic field using lattice Boltzmann method.pp. 1870-1883.10.1016/j.ijheatmasstransfer.2017.01.044.

[3]. Noreen, S., Hayat, T., Alsaedi, A. and Qasim, M., (2013). Mixed convection heat and mass transfer in peristaltic flow with chemical reaction and inclined magnetic field. Indian Journal of Physics, 87,pp.889-896.10.1007/s12648-013-0316-2.

[4]. Noreen, S., (2014). Mixed convection peristaltic flow with slip condition and induced magnetic field. The European Physical Journal Plus, 129, pp.1-16. https://doi.org/10.1140/epjp/i2014-14033-3\

[5]. Sheikholeslami, M., Soleimani, S. and Ganji, D.D., (2016). Effect of electric field on hydrothermal behavior of nanofluid in a complex geometry. Journal of Molecular Liquids, 213, pp.153-161.10.1016/j.molliq.2015.11.015.

[6]. Sheikholeslami, M., Soleimani, S. and Ganji, D.D., (2016). Effect of electric field on hydrothermal behavior of nanofluid in a complex geometry. Journal of Molecular Liquids, 213,pp.153161.https://doi.org/10.3390/app9102164

[7]. Xu, P., Yu, B., Qiu, S., Poh, H.J. and Mujumdar, A.S., (2010). Turbulent impinging jet heat transfer enhancement due to intermittent pulsation. International Journal of Thermal Sciences,49(7),pp.1247-1252.https://doi.org/10.1016/j.ijthermalsci.2010.01.020

[8]. Li, Z., Xu, X., Li, K., Chen, Y., Huang, G., Chen, C.L. and Chen, C.H., (2018). Airfoil-shaped self-agitator for convective heat transfer enhancement. International Journal of Thermal Sciences,133,pp.284-298.https://doi.org/10.1016/j.ijthermalsci.2018.07.038

[9]. Agrawal, S., Simon, T., North, M. and Cui, T., (2015). An experimental study on the effects of agitation on convective heat transfer. International Journal of Heat and Mass Transfer, 90, pp.302-313.https://doi.org/10.1016/j.ijheatmasstransfer.2015.05.105

[10]. Elatar, A., Teamah, M.A. and Hassab, M.A., (2016). Numerical study of laminar natural convection inside square enclosure with single horizontal fin. International Journal of Thermal Sciences,99,pp.41-51. https://doi.org/10.1016/j.ijthermalsci.2015.08.003

[11]. Liu, Y., Zhang, S., Huang, H., Suo, Q., Bian, Y. and Zhao, Y., (2019). Enhancing the flow and heat transfer in a convective cavity using symmetrical and adiabatic twin fins. International Journal of Heat and Mass Transfer, 142, p.118447.https://doi.org/10.1016/j.ijheatmasstransfer.2019.118447

[12]. Dou, R., Li, Q., Zhu, C., Zhang, R., Wen, Z. and Liu, X., (2019). Experimental study on the enhancement of contact heat transfer by micro fin. International Journal of Heat and Mass Transfer, 134, pp.482-488.https://doi.org/10.1016/j.ijheatmasstransfer.2019.01.058

[13]. Hayat, T., Khan, M.I., Farooq, M., Alsaedi, A. and Yasmeen, T., (2017). Impact of Marangoni convection in the flow of carbon–water nanofluid with thermal radiation. International Journal of Heat and Mass Transfer, 106, pp.810-815. https://doi.org/10.1016/j.ijheatmasstransfer.2016.08.115

[14]. Hayat, T., Khan, M.I., Qayyum, S. and Alsaedi, A., (2018). Entropy generation in flow with silver and copper nanoparticles. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 539, pp.335-346.https://doi.org/10.1016/j.colsurfa.2017.12.021

[15]. Gómez-Villarejo, R., Estellé, P. and Navas, J., (2020). Boron nitride nanotubes-based nanofluids with enhanced thermal properties for use as heat transfer fluids in solar thermal applications. Solar Energy Materials and Solar Cells, 205, p.110266.https://doi.org/10.1016/j.solmat.2019.110266

[16]. Gao, Y., Xi, Y., Zhenzhong, Y., Sasmito, A.P., Mujumdar, A.S. and Wang, L., (2021). Experimental investigation of specific heat of aqueous graphene oxide Al2O3 hybrid nanofluid. Thermal Science, 25(1 Part B),pp.515-525. https://doi.org/10.2298/TSCI190404381

[17]. Hayat, T., Khan, M.I., Waqas, M., Alsaedi, A. and Khan, M.I., (2017). Radiative flow of micropolar nanofluid accounting thermophoresis and Brownian moment. International Journal of Hydrogen Energy, 42(26), pp.16821-16833. https://doi.org/10.1016/j.ijhydene.2017.05.006

[18]. Zhong, Y., Zhao, B., Lin, J., Zhang, F., Wang, H., Zhu, Z. and Dai, Z., (2019). Encapsulation of high-temperature inorganic phase change materials using graphite as heat transfer enhancer. Renewable Energy, 133, pp.240-247. https://doi.org/10.1016/j.renene.2018.09.107

[19]. Aziz, S., Amin, N.A.M., Majid, M.A., Belusko, M. and Bruno, F., (2018). CFD simulation of a TES tank comprising a PCM encapsulated in sphere with heat transfer enhancement. Applied Thermal Engineering, 143, pp.1085-1092. https://doi.org/10.1016/j.applthermaleng.2018.08.013

[20]. Hawlader, M.N.A., Uddin, M.S. and Khin, M.M., (2003). Microencapsulated PCM thermal-energy storage system. Applied energy, 74(1-2), pp.195-202..https://doi.org/10.1016/S0306-2619(02)00146-0

[21]. Wijayanta, A.T., Yaningsih, I., Aziz, M., Miyazaki, T. and Koyama, S., (2018). Double-sided delta-wing tape inserts to enhance convective heat transfer and fluid flow characteristics of a double-pipe heat exchanger. Applied Thermal Engineering, 145, pp.27-37.https://doi.org/10.1016/j.applthermaleng.2018.09.009

[22]. Tusar, M., Noman, A., Islam, M., Yarlagadda, P. and Salam, B., (2019). CFD study of heat transfer enhancement and fluid flow characteristics of turbulent flow through tube with twisted tape inserts. Energy Procedia, 160, pp.715-722.https://doi.org/10.1016/j.egypro.2019.02.188

[23]. Chakraborty, P., Ma, T., Cao, L. and Wang, Y., (2019). Significantly enhanced convective heat transfer through surface modification in nanochannels. International Journal of Heat and Mass Transfer,136,pp.702-708. https://doi.org/10.1016/j.ijheatmasstransfer.2019.03.053

[24]. Zhou, Z.F., Lin, Y.K., Tang, H.L., Fang, Y., Chen, B. and Wang, Y.C., (2019). Heat transfer enhancement due to surface modification in the close-loop R410A flash evaporation spray cooling. International Journal of Heat and Mass Transfer, 139, pp.1047-1055. https://doi.org/10.1016/j.ijheatmasstransfer.2019.05.063.
[25]. Khan, M.I., Waqas, M., Hayat, T., Khan, M.I. and Alsaedi, A., (2017). Behavior of stratification phenomenon in flow of Maxwell nanomaterial with motile gyrotactic microorganisms in the presence of magnetic field. International Journal of Mechanical Sciences, 131, pp.426-434..https://doi.org/10.1016/j.ijmecsci.2017.07.009
[26]. Alamgholilou, A., and E. Esmaeilzadeh., (2012). "Experimental investigation on hydrodynamics and heat transfer of fluid flow into channel for cooling of rectangular ribs by passive and EHD active enhancement methods." Experimental Thermal and Fluid Science 38: 61-73. https://doi.org/10.1016/j.expthermflusci.2011.11.008.
[27]. Whitham, J. M., (1896). "The effect of retarders in fire tubes of steam boilers." Street railway journal 12, no. 6: 374. https://doi.org/10.1111/j.1559-3584. 1896.tb00751
[28]. Manglik, R. M., and A. E. Bergles., (1993)."Heat transfer and pressure drop correlations for twisted-tape inserts in isothermal tubes: part I—laminarflows."881-889. https://doi.org/10.1115/1.2911383
[29]. Manglik, Raj M., and Arthur E. Bergles., (1993). "Heat transfer and pressure drop correlations for twisted-tape inserts in isothermal tubes: Part II—Transition and turbulent flows." 890-896. https://doi.org/10.1115/1.2911384
[30]. Suri, Amar Raj Singh, Anil Kumar, and Rajesh Maithani., (2017)."Heat transfer enhancement of heat exchanger tube with multiple square perforated twisted tape inserts: experimental investigation and correlation development." Chemical Engineering and Processing: Process Intensification 116:76-96. https://doi.org/10.1016/j.cep.2017.02.014
[31]. Wongcharee, K., and S. Eiamsa-Ard., (2011). "Friction and heat transfer characteristics of laminar swirl flow through the round tubes inserted with alternate clockwise and counter-clockwise twisted-tapes." International Communications in Heat and Mass Transfer 38, no. 3: 348-352. https://doi.org/10.1016/j.icheatmasstransfer.2010.12.007
[32]. Eiamsa-Ard, Smith, and Pongjet Promvonge., (2010). "Performance assessment in a heat exchanger tube with alternate clockwise and counter-clockwise twisted-tape inserts." International Journal of Heat and Mass Transfer 53, no. 7-8: 1364-1372. https://doi.org/10.1016/j.ijheatmasstransfer.2009.12.023
[33]. Abolarin, S. M., Marilize Everts, and Josua P. Meyer., (2019). "Heat transfer and pressure drop characteristics of alternating clockwise and counter clockwise twisted tape inserts in the transitional flow regime." International Journal of Heat and Mass Transfer 133: 203-217. https://doi.org/10.1016/j.ijheatmasstransfer.2018.12.107
[34]. Ramakumar, B. V. N., J. D. Arsha, and Praveen Tayal.,(2016)."Tapered twisted tape inserts for enhanced heat transfer." Journal of Heat Transfer 138, no. 1 011901. https://doi.org/10.1115/1.4031207
[35]. Zade, Navid Moghadas, Shima Akar, Saman Rashidi, and Javad Abolfazli Esfahani.,(2017). "Thermo-hydraulic analysis for a novel eccentric helical screw tape insert in a three dimensional tube."Applied Thermal Engineering124:413-421. https://doi.org/10.1016/j.applthermaleng.2017.06.036
[36]. Liu, Xiaoya, Chun Li, Xiaxin Cao, Changqi Yan, and Ming Ding., (2018). "Numerical analysis on enhanced performance of new coaxial cross twisted tapes for laminar convective heat transfer." International Journal of Heat and Mass Transfer 121: 1125-1136. https://doi.org/10.1016/j.ijheatmasstransfer.2018.01.052
[37]. Nakhchi, M. E., and J. A. Esfahani.. (2019)"Numerical investigation of rectangular-cut twisted tape insert on performance improvement of heat exchangers." International Journal of Thermal Sciences 138: 75-83. https://doi.org/10.1016/j.ijthermalsci.2018.12.039
[38]. Man, Changzhong, Chong Wang, and Jinyu Yao., (2014)."The current situation of the study on twisted tape inserts in pipe exchangers." Journal of marine science and application 13: 477-483.https://doi.org/10.1007/s11804-014-1273-7
[39]. Garg, M. O., Himanshu Nautiyal, Sourabh Khurana, and M. K. Shukla., (2016)."Heat transfer augmentation using twisted tape inserts: a review." Renewable and Sustainable Energy Reviews 63: 193-225. https://doi.org/10.1016/j.rser.2016.04.051
[40]. Kumar, NT Ravi, P. Bhramara, A. Kirubeil, L. Syam Sundar, Manoj K. Singh, and Antonio CM Sousa., (2018) "Effect of twisted tape inserts on heat transfer, friction factor of Fe3O4 nanofluids flow in a double pipe U-bend heat exchanger." International Communications in Heat and Mass Transfer 95: 53-62. https://doi.org/10.1016/j.icheatmasstransfer.2018.03.020
[41]. Hosseinnezhad, Rahim, Omid Ali Akbari, Hamid Hassanzadeh Afrouzi, Mohit Biglarian, Ali Koveiti, and Davood Toghraie., (2018) "Numerical study of turbulent nanofluid heat transfer in a tubular heat exchanger with twin twisted-tape inserts." Journal of Thermal Analysis and Calorimetry 132:741-759. https://doi.org/10.1007/s10973-017-6900-5
[42]. Jafaryar, M., M. Sheikholeslami, and Zhixiong Li., (2018) "CuO-water nanofluid flow and heat transfer in a heat exchanger tube with twisted tape turbulator." Powder technology 336: 131-143. https://doi.org/10.1016/j.powtec.2018.05.057
[43]. Eiamsa-ard, Smith, and Khwanchit Wongcharee., (2018). "Convective heat transfer enhancement using Ag-water nanofluid in a micro-fin tube combined with non-uniform twisted tape." International Journal of Mechanical Sciences146:337-354. https://doi.org/10.1016/j.ijmecsci.2018.07.040
[44]. Eiamsa-ard, S., R. Ketrain, and V. Chuwattanakul.,2018."TiO2/water nanofluid heat transfer in heat exchanger equipped with double twisted-tape inserts." In IOP Conference Series: Materials Science and Engineering, vol. 350, no. 1, p. 012015. IOP Publishing. https://doi:10.1088/1757899X/350/1/012015
[45]. Kurnia, Jundika C., Agus P. Sasmito, Tariq Shamim, and Arun S. Mujumdar., (2016). "Numerical investigation of heat transfer and entropy generation of laminar flow in helical tubes with various cross sections." Applied Thermal Engineering 102: 849-860. https://doi.org/10.1016/j.applthermaleng.2016.04.037
[46]. Bird,R.,B.,(2007).Transport Phenomena, J. Wiley, New York.
[47]. F.P. Incropera, D.P. DeWitt, T.L. Bergman, A.S. Lavine., (2007).sixth ed., Fundamentals of Heat and Mass Transfer, John Wiley, Hoboken, NJ,
[48]. Kurnia, Jundika C., Desmond C. Lim, Lianjun Chen, Lishuai Jiang, and Agus P. Sasmito.m (2019). "Entropy generation and heat transfer performance in microchannel cooling." Entropy 21, no. 2: 191. https://doi.org/10.3390/e21020191
[49]. Kurnia, Jundika C., Agus P. Sasmito, Tariq Shamim, and Arun S. Mujumdar., (2016)."Numerical investigation of heat transfer and entropy generation of laminar flow in helical tubes with various cross sections." Applied Thermal Engineering 102:849-860. https://doi.org/10.1016/j.applthermaleng.2016.04.037
[50]. Sciacovelli, Adriano, Vittorio Verda, and E. Sciubba., (2015). "Entropy generation analysis as a design tool—A review." Renewable and Sustainable Energy Reviews 43: 1167-1181.https://doi.org/10.1016/j.rser.2014.11.104
[51]. Kurnia, Jundika C.,Agus P.Sasmito, and Arun S.Mujumdar., (2011). "Evaluation of the heat transfer performance of helical coils non-circular tubes." Journal of Zhejiang University-SCIENCE A 12: 63-70 https://doi.org/10.1631/jzus.A1000296
[52]. Kurnia, Jundika C., Agus P. Sasmito, Sachin V. Jangam, and Arun S. Mujumdar., (2013). "Improved design for heat transfer performance of a novel phase change material (PCM) thermal energy storage (TES)." Applied Thermal Engineering 50, no. 1: 896-907. https://doi.org/10.1016/j.applthermaleng.2012.08.015

[53]. Kimura, Shigeo, and Adrian Bejan., (1983). "The “heatline” visualization of convective heat transfer." 916-919. https://doi.org/10.1115/1.3245684

[54]. Tao, Wen-Quan, Ya-Ling He, and Lei Chen., (2019): "A comprehensive review and comparison on heatline concept and field synergy principle." International Journal of Heat and Mass Transfer135:436-459. https://doi.org/10.1016/j.ijheatmasstransfer.2019.01.143

[55]. Manglik, Raj Mitra., (1991). Heat transfer enhancement of intube flows in process heat exchangers by means of twisted-tape inserts. Rensselaer Polytechnic Institute..

[56]. D.K. Edwards, V.E. Denny, A.F. Mills., (1979).Transfer Processes: An Introd. to Diffusion, Convection, and Radiation, Hemisphere Publishing Corporation (u.a.).

[57]. Baehr, H.,D.,Stephan, K.,(2013).Heat and Mass Transfer, Springer Science & Business Media,

[58]. Manlapaz, Romeo L., and Stuart W. Churchill., (1980). "Fully developed laminar flow in a helically coiled tube of finite pitch." Chemical Engineering Communications 7, no. 1-3: 57-78. https://doi.org/10.1080/00986448008912549