Comparative Study on Straight Helical and Twisted Helical Tube Heat Exchanger

Maddu Sireesha[1] and Vurity Sridhar Patnaik[2]
[1]Assistant professor, [2]professor
[1,2]Department of mechanical engineering, vitam engineering college, Visakhapatnam, Andhra Pradesh, India
[1]maddu.sireesha@gmail.com
[2]srisaipatnaik@gmail.com

ABSTRACT— Heat recovery is the capture of energy contained in the fluid which would otherwise be lost to the surroundings. This heat recovery is generally obtained from heat exchanger in most of the engineering systems and has a wide variety of applications like in power plants, nuclear reactors, heat recovery systems, processing industries, refrigeration and air conditioning systems etc. In the present study, a twisted helical tube heat exchanger is used as a heat recovery system. The fluid dynamics in twisted helical tube has advantages over straight helical tubes. The twisted helical tube heat exchanger, through which hot water flows, is enclosed in a shell through which cold water flows. The centrifugal force developed inside the twisted helical tube results in the development of a secondary flow which is the key factor for enhancing the rate of heat transfer. In the present study effect of the pitch and curvature ratio of the twisted helical tube counter flow heat exchanger on the enhancement of heat transfer under defined boundary conditions is carried out. The effect of flow rates and direction of both hot and cold fluids on the enhancement of heat transfer was also studied. Experimental results showed that the overall heat transfer coefficient for twisted helical tube heat exchanger is always more than that of a straight helical tube heat exchanger, and increases with the increase in Reynolds number of hot fluid.

Keywords—straight helical tube heat exchanger, twisted helical tube heat exchanger, effectiveness, overall heat transfer coefficient.

1.INTRODUCTION

Now a day's mechanical engineers deal with the heat transfer problems which are observed in the design of I.C engines, refrigeration, air conditioning plants and steam generation systems etc. Heat transfer is the transmission of heat energy from one region to another as a result of temperature gradient. Typically, heat recovery system is obtained from heat exchanger and it is exercised in industries, nuclear power plants, refrigeration systems etc. Heat exchanger is a device used to transfer heat between one or more fluids. The purpose of constructing a heat exchanger is to get better performance of heat transfer from one fluid to another, by direct contact or by indirect contact. Conduction, convection and radiation are three modes of heat transfer. Heat exchange in a heat exchanger takes place through convection.

Swapnil Ahire in [1] worked on the fabrication and analysis of counter flow heat exchanger and then showed the variations of various dimensionless numbers i.e. Reynolds Number, Nusselt's Number and Dean's number. It presents a comparative analysis of the different correlations given by the different researchers for helical coil heat exchanger. The various equations use different parameters for the analysis. It was found that the centrifugal force due to the curvature of the tube results in the secondary flow development which enhances the heat transfer rate.

Mrunal P.Kshirsagarin in [2] worked on Fabrication and Analysis of Tube-In-Tube Helical Coil Heat Exchanger and then showed the experimental study of a wire wound tube-in-tube helical coiled heat exchanger was performed considering hot water in the inner tube at various flow rate conditions and with cooling water in the outer tube. The mass flow rates in the inner tube and in the annulus were both varied and the counter-current flow configurations were tested. The experimentally obtained overall heat transfer coefficient (Uo) for different values of flow rate in the inner-coiled tube and in the annulus region were reported. It was observed that the overall heat transfer coefficient increases with increase in the inner-coiled tube flow rate, for a constant flow rate in the annulus region. Similar trends in the variation of overall heat transfer coefficient were observed for different flow rates in the annulus region for a constant flow rate in the inner-coiled tube. It was also observed that when wire coils are compared with a smooth tube, it was also observed that overall heat transfer coefficient is increases with minimum pitch distance of wire coils. The efficiency of the tube-in-tube helical coil heat exchanger is 15-20% more as compared to the convention heat exchanger and the experimentally calculated efficiency is 93.33%.

As per Mostafa, Nawras h in [3] on the elliptical tubes for polymer heat exchangers, the streamlined shape of outer tube has an optimal thermal recital. A set of design curves were generated from which a number of geometries of the tube and different materials can be easily selected in order to meet the deformation constraints. A finite element solution was determined for strain as a function of the material of the tube. Twisted helical tube heat exchangers provide a higher heat transfer coefficient than any other type of tubular heat exchanger as the fluid dynamics inside the pipes of a twisted helical tube heat exchanger offers certain advantages over the straight helical tube heat exchanger. Twisted helical tube heat exchangers are a comparatively new technology, designed to guide the shell side flow in to a swirl pattern in order to increase the heat transfer rate. Generally the twisted helical tube heat exchanger is used in I.C engines, Boilers, Gas cooling systems etc. It offers some advantages over the straight helical tube heat exchanger in the following ways.

i) Twisted helical tube heat exchanger typically have 40% higher heat transfer coefficient for same pressure drop than conventional shell and tube heat exchanger.

ii) Twisted helical tubes are self supporting and so baffles are not required.

D_i(m)	D_o(m)	P(m)	D_{mean} (m)	D_{shell}(m)
0.008	0.009	0.02	0.035	0.075

Table 1: Dimensions of Coil

TABLE 2: MANUFACTURING OF SHELL

Component	Material
Helical coil	Copper
Shell	Poly vinyl chloride
Insulation	Asbestos
End caps	Poly vinyl chloride

QUANTITY	SPECIFICATIONS
Shell	1 No.
Diameter of shell	0.075m
Length of shell	0.53m
End cap	2 No’s
Diameter of end cap	0.08 m
Thickness of shell	0.002 m

Table 3: Quantity and Specifications

2. Fabrication of Twisted Helical Tube Heat Exchanger

Initially copper tube of length 4m is filled with sand and ends of the tube is closed with caps. This is done to prevent crimpling of tube while bending the tube in making process of helical form. The tube with sand is now heated to make it soft and malleable to bend the tube.

Now the tube is twisted for each twist of 180^0 with an equal interval of over a tube length of 4m. The twisted tube is helically wound for a core diameter of 0.035m by maintaining a pitch of 0.02m for a total number of turns.

The twisted helical tube is concentrically inserted in PVC shell of 0.075m diameter and 0.53 m length by providing shell end caps. The twisted helical tube heat exchanger is provided with hot water and cold water entrance and exit at shell and tube. It is also arranged for measuring for inlet and outlet temperatures of hot and cold water by using digital probes. The hot water pump (0.5hp) is arranged for the supply of hot water through copper tube from hot water tank. The water tank is provided with immersion heaters for a total heat load of 3000watts.

3. EXPERIMENTAL SETUP AND WORKING

3.1. Setup of the system

The experimental setup shown in figure1 represents the experimental setup layout. It is a twisted helical tube heat exchanger consisting of a test section, a constant temperature bath (nearly 180 litres capacity) for supplying hot water, heaters, pump, control systems & temperature indicators. The twisted helical tube is having dimensions of 4m length of copper tube, internal diameter of 0.008m and outer diameter of 0.009m. Shell pipe is having an internal diameter of 0.075m and outer diameter of 0.078m.

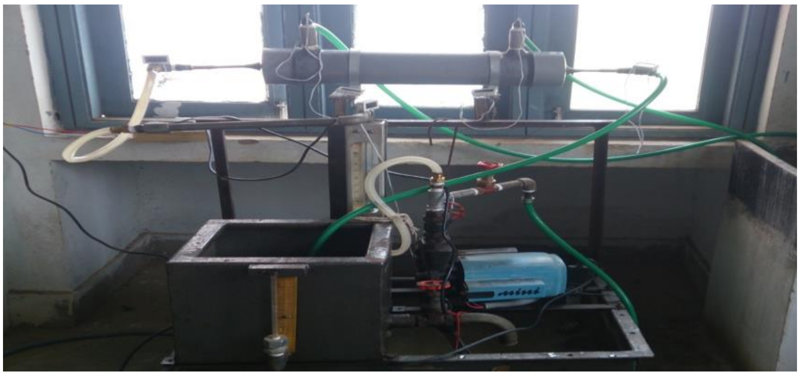


Fig. 1 Experimental setup of twisted cum helical tube heat exchanger

The outer surface of pipe is well insulated by using 0.015m diameter asbestos rope to reduce heat losses to the atmosphere. The flow rates are regulated by using measuring jar of 1 litre capacity and the time taken by using a stop watch

The immersion heaters are placed in lower tank filled with water. The outlet of twisted helical tube heat exchanger is directed to small tank so that the lower tank is maintained at constant temperature. The inlet of shell is connected to ambient water supply and outlet is left to sink after measuring its temperature.

3.2 .Experimental working

i) The tube side fluid is heated to a temperature of 60^0C and above, with the aid of immersion heaters and is stirred to maintain a uniform heat distribution.

ii) In this heating time, the shell side flow rate (litre/sec) is set to desired value.

iii) Once the lower tank containing water reached required temperature, the hot water is pumped into the twisted helical tube and the flow rates (litre/sec) are adjusted to desired values.

iv) Once the system is reached to the steady state temperatures then the readings are noted by using digital temperature indicators.

v) The readings of temperatures obtained for different flow rates are tabulated and required parameters such as Nusselt number, Reynolds number, Dean Number, effectiveness, overall heat transfer coefficient and heat capacity ratio were calculated.

4. NOMENCLATURE

TABLE 4: SHOWS ABOUT THE SYMBOLS REPRESENTATION AND UNITS

Symbol	Representation	Units
C_p	Specific heat of fluid	J/kg-K
H	Heat transfer coefficient	W/m^2K
h_i(exp)	Experimental heat transfer coefficient	W/m^2K
h_i (theo)	Theoretical heat transfer coefficient	W/m^2K
P	Pitch of the coil	m
L	Heat exchanger length	m
LMTD	Log mean temperature difference	K
m	Mass flow rate	kg/s
Nu	Nusselt number	-
Pr	Prandtl number	-
Q	Heat transfer rate	W
Re	Reynolds number	-
U_o	Overall heat transfer coefficient area,	W/m^2K
V	Velocity	m/s

g	Acceleration due to gravity	m/s^2
D_i	ID of inside tube	m
D_o	OD of inside tube	m
μ	Viscosity of the fluid	$N\ s/m^2$
ρ	Density of the fluid	kg/m^3
V_t	Volume flow rate for tube water	m^3/s
V_{sh}	Volume flow rate for shell water	m^3/s
T_{hi}	Tube water inlet temperature	K
T_{ho}	Tube water outlet temperature	K
T_{ci}	Shell water inlet temperature	K
m_c	Mass flow rate for shell water	kg/s
Q_h	Amount of heat transfer rate for tube side water	W
Q_c	Amount of heat transfer rate for shell side water	W
Q_{avg}	Average heat transfer rate	W
De	Dean number	-
He	Helix number	-
T_{co}	Shell water outlet temp.	K
m_h	Mass flow rate for tube water	kg/s
R	Heat transfer ratio	-
γ	Pitch ratio	-
NTU	Number of transfer units	-
ε	Effectiveness	-
k	Thermal conductivity	W/m-k

5. Calculations

5.1. Twisted helical tube heat exchanger

$V_t = 6.67\text{x}10^{-5}\ m^3/s$

$V_{sh} = 2.5\text{x}10^{-5}\ m^3/s$

$T_{hi} = 332.8\ K$

$T_{ho} = 318.6\ K$

$T_{ci} = 302.7\ K$

$T_{co} = 312.5\ K$

$m_h = \rho_h \times V_t = 985 \times 6.67\text{x}10^{-5} = 0.06569\ kg/s$

$mc = \rho_c \times V_{sh} = 985 \times 2.5\text{x}10^{-5} = 0.0246\ kg/s$

$Q_h = m_h c_h (T_{hi} - T_{ho}) = 0.06569\text{x}4183(332.8-318.6) = 3901.89\ W$

$Q_c = m_c\ c_c (T_{co} - T_{ci}) = 0.0246\text{x}4178(312.5-302.7) = 1137.415\ W$

$Q_{avg} = (Q_h + Q_c)/2 = (3901.89+1137.415)/2 = 2519.6525\ W$

$$LMTD = \frac{\Delta T_I - \Delta T_O}{\ln\left(\frac{\Delta T_I}{\Delta T_O}\right)} = \frac{20.3-15.9}{\ln\left(\frac{20.3}{15.9}\right)} = 18.01K$$

Cross-sectional area of tube, $A_o = \pi dL = \pi \times 0.0083 \times 1.885 = 0.06362\ m^2$

Overall heat transfer coefficient,

$$U_o = \frac{Q_{avg}}{A_o\ LMTD} = \frac{2519.652}{0.06362\text{x}18.01} = 2199.040\ W/m^2\ K$$

$V_t = AxV$

$$V = \frac{6.67X10-5}{0.06362} = 1.04\text{x}10^{-3}\ m/s$$

$$Re = \frac{\rho vd}{\mu} = \frac{985X1.04X10^{-3}X0.0083}{0.478\times10^{-6}} = 17787.69$$

$$Pr = \frac{C_{P\mu}}{K} = \frac{4183\times985\times0.478}{0.6513} = 3.02$$

$$De = Re\left(\frac{D}{d}\right)^{0.5} = 17787.69\left(\frac{0.0083}{0.496}\right)^{0.5} = 2301.006$$

$$\gamma = \frac{P}{2\pi Rc} = \frac{0.02}{2\pi X0.035} = 0.09094$$

$Nu = 0.152\ De^{0.431} Pr^{1.06}\ \gamma^{-0.277} = 0.152(2301.006)^{0.431}(3.02)^{1.06}(0.09094)^{-0.277} = 26.79$

We know that,

$Nu=\frac{h_i D}{K}$

$h_i=\frac{Nu.k}{D}=\frac{26.79\times 0.65138}{0.0083}$= 2102.46 W/m^{2}K

He = $\frac{De}{(1+\gamma^2)^{0.5}}=\frac{2301.006}{(1+0.09094^2)^{0.5}}$= 2291.54

$R=\frac{C_{min}}{C_{max}}=\frac{T_{co}-T_{ci}}{T_{hi}-T_{ho}}=\frac{312.5-302.7}{332.8-318.6}$= 0.6901

$NTU=\frac{U_o A_o}{C_{min}}=\frac{2199.040\times 0.06362}{9.8}$= 14.27

Effectiveness, $\varepsilon=\frac{1-\exp[-NTU(1-R)]}{1-R\exp[-NTU(1-R)]}=\frac{1-\exp[-14.27(1-0.6901)]}{1-0.6901\exp[-14.27(1-0.6901)]}$= 0.9994

5.2. Helical tube heat exchanger

V_t= 5x10^{-5} m^3/s

V_{sh}= 1.9x10^{-5} m^3/s

T_{hi}= 335.8 k

T_{ho}= 323.1 k

T_{ci}= 306.3 k

T_{co}= 312.3 k

$m_h=\rho_h\times V_t$ = 985×5x10^{-5}=0.04925 kg/s

$m_c=\rho_c\times V_{sh}$=985×1.9x10^{-5} =0.0187kg/s

$Q_h=m_h c_h(T_{hi}-T_{ho})$ =0.04925x4183(335.8-323.1) =2616.36 W

$Q_c=m_c\, c_c(T_{co}-T_{ci})$ = 0.0187x4178(312.3-306.3) = 468.7716 W

$Q_{avg}=(Q_h+Q_c)/2$ = (2616.36 +468.7716)/2= 1542.56 W

$LMTD=\frac{\Delta T_I-\Delta T_O}{\ln\left(\frac{\Delta T_I}{\Delta T_O}\right)}=\frac{23.5-16.8}{Ln\left(\frac{23.5}{16.8}\right)}$= 19.9K

Cross-sectional area of tube, $A_o=\pi dL=\pi\times 0.0083\times 1.885$= 0.06362 m^2

Overall heat transfer coefficient,

$U_o=\frac{Q_{avg}}{A_o\,LMTD}=\frac{1542.56}{0.06362x19.9}$ = 1218.415 W/m^2 K

V_t = AxV

$V=\frac{5X10-5}{0.06362}$=7.85x10^{-4} m/s

$Re=\frac{\rho vd}{\mu}=\frac{985X7.85X10^{-4}X0.0083}{0.478\times 10^{-6}}$= 13426.29

$Pr=\frac{C_{P\mu}}{K}=\frac{4183\times 985\times 0.478}{0.6513}$= 3.02

$De=Re\left(\frac{D}{d}\right)^{0.5}=13426.29\left(\frac{0.0083}{0.496}\right)^{0.5}$ = 1736.817

$\gamma=\frac{P}{2\pi Rc}=\frac{0.02}{2\pi X0.035}$=0.09094

$Nu=0.152\,De^{0.431}Pr^{1.06}\,\gamma^{-0.277}=0.152(1736.817)^{0.431}(3.02)^{1.06}(0.09094)^{-0.277}$ = 23.78

We know that,

$Nu=\frac{h_i D}{K}$

$h_i=\frac{Nu.k}{D}=\frac{23.78\times 0.65138}{0.0083}$ = 1866.2429 W/m^{2}k

He= $\frac{De}{(1+\gamma^2)^{0.5}}=\frac{1736.817}{(1+0.09094^2)^{0.5}}$= 1729.67

$R=\frac{C_{min}}{C_{max}}=\frac{T_{co}-T_{ci}}{T_{hi}-T_{ho}}=\frac{312.3-306.3}{335.8-323.1}$= 0.472

$NTU=\frac{U_o A_o}{C_{min}}=\frac{1218.415\times 0.06362}{6}$= 12.91

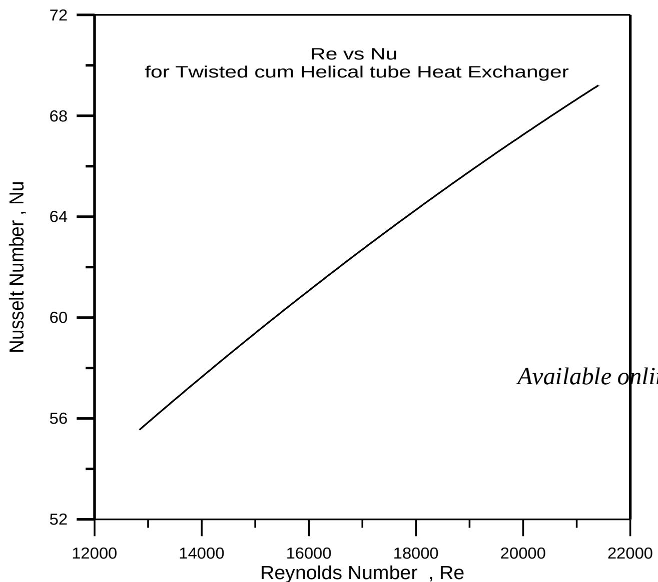
Effectiveness, $\varepsilon=\frac{1-\exp[-NTU(1-R)]}{1-R\exp[-NTU(1-R)]}=\frac{1-\exp[-12.91(1-0.472)]}{1-0.472\exp[-12.91(1-0.472)]}$= 0.9962

Table 5: Shows the Comparison of Twisted Helical and Straight Helical Tube Heat exchanger

Parameters	Twisted helical coil	Helical coil
Tube water inlet temp.	332.8 K	335.8 K
Shell water inlet temp.	302.7 K	306.3 K
Tube water outlet temp.	318.6 K	323.1 K
Shell water outlet temp.	312.5 K	312.3 K
LMTD	18.01K	19.9K
Overall heat transfer coefficient	2199.040 W/m^2 K	1218.415 W/m^2 K
Heat transfer ratio	0.6901	0.472
NTU	14.27	12.91
Effectiveness	0.9994	0.9962
Reynolds number	17787.69	13426.29
Prandtl number	3.02	3.02
Dean number	2301.006	1736.817
Nusselt number	26.79	23.78
Helix number	2291.54	1729.67

6. Result And Discussion

The fig 2 shows the graph between Nusslet number and Reynolds number shows heat transfer rate for different flow rates of cold water in shell & hot water in tube. The graph shows the increase of Nusselt number with increase of flow rate of hot water. The twisted configuration of tube generates more turbulence as compared to the straight helical tube configuration. The rapid propagation of heat in the fluid layers becomes an attribute to the higher overall heat transfer coefficient. The fig 3 shows the graph between Nusselt number and Reynolds number. It is observed that the straight helical tube heat exchanger has lower overall heat transfer coefficient when it is compared with twisted helical tube heat exchanger. This is only due to its centrifugal force developed by the turbulence of the fluid in tube. The fig.4 shows that the increase of overall heat transfer coefficient in general increase with the Reynolds number. The reason for decreasing overall heat transfer coefficient with Re could not be established due to some experimental measures. The greater diffusion rates of heat transfer among hot and cold fluids are due to the existing higher temperature differences. The fig.5 shows that the decrease of overall heat transfer coefficient in general decrease with the Reynolds number. It is due to diffusion rates are very low in straight helical tube heat exchanger.



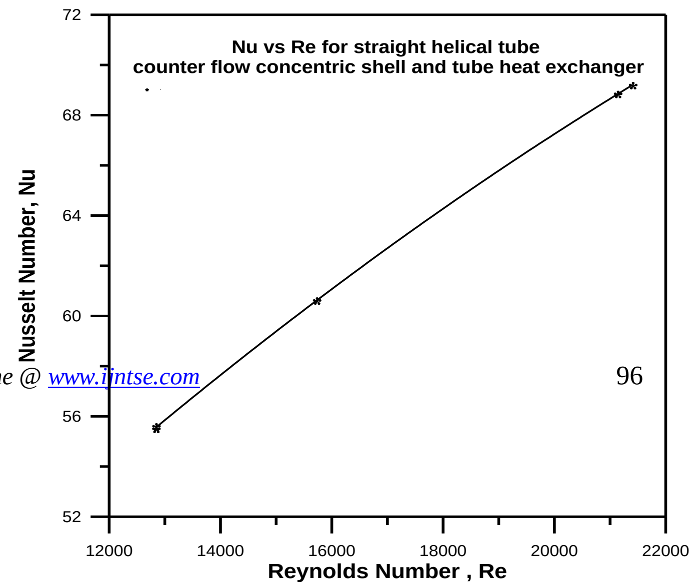


Fig.2 Re Vs Nu for twisted helical tube heat exchanger

Fig.3 Re Vs Nu for straight helical tube heat exchanger

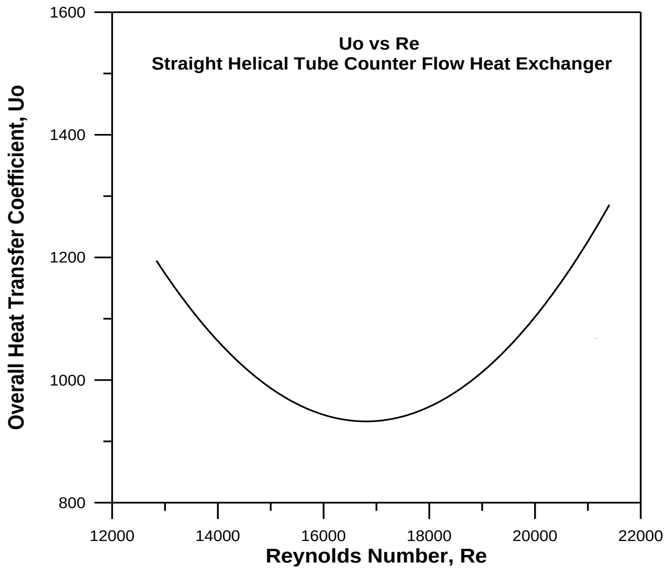


Fig.4 Re Vs Uo for twisted helical tube heat exchanger

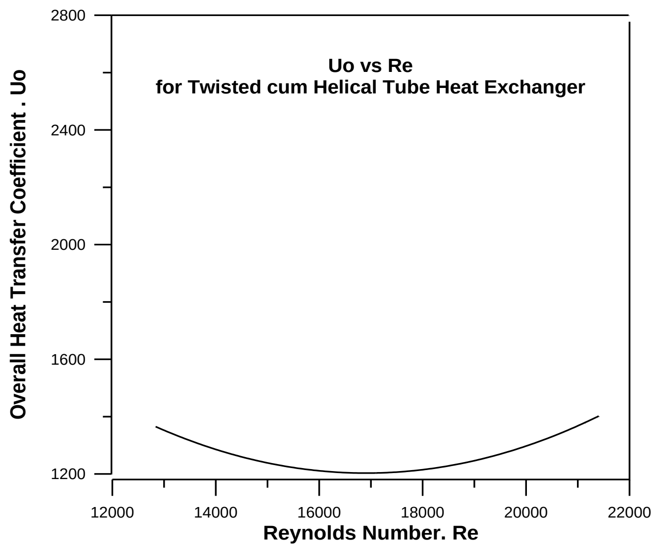


Fig.5 Re Vs Uo for straight helical tube heat exchanger

Fig.6 shows the variation of overall heat transfer coefficient with Reynolds number for twisted helical tube and straight helical tube heat exchanger. The turbulence is much aggravated in the newly configured twisted helical tube heat exchanger than that in the straight helical tube heat exchanger. It is true from the experimental evidence that the heat transfer coefficients are high for the new set up but at the cost of pressure drop (Referred from table 6).

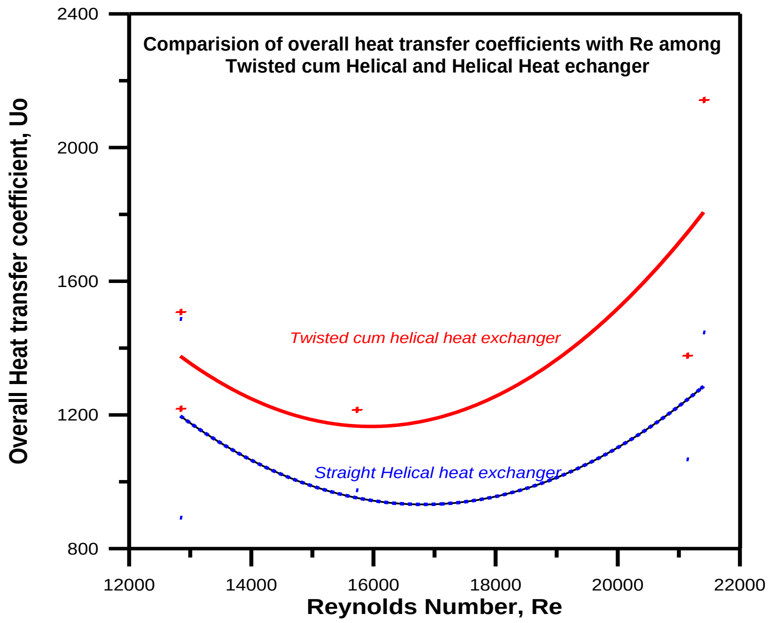


Fig.6 Re vs U_o for both twisted cum helical and straight helical tube heat exchanger

Table 6: Shows The Comparsion Of Overall Heat Transfer Coefficient Of Twisted Helical And Straight Helical Tube Heat Exchanger

U_o (twisted cum helical heat exchanger) W/m^2K	U_o (straight helical heat exchanger) W/m^2K
17787.69	13426.29
1216.54	976.176
1509.4	1484.64
1220.2	894.003
1378.7	1068.77

7. CONCLUSION

Heat transfer characteristics of the heat exchanger for a new configuration of twisted cum helical coil is studied. Experimental analysis has been carried out for counter flow under defined boundary conditions. Fluid particles are found to undergo oscillatory motion inside the pipe and this causes increase of heat transfer rates. Studies have been carried out by varying the flow rates and the direction of flows of both the shell side and tube side fluids with constant pipe diameter, pitch circle diameter and pitch of helical tube. Unlike the flow through a straight pipe, the centrifugal force caused due to the twisted coil and the curvature of the pipe causes heavier fluid (water-phase) to flow along the outer side of the pipe. High velocity and high temperature are also observed along the outer side. It was observed that the variation in flow rates has greater influence on temperature drop in tube flow. Temperature difference is maximum for lower flow rates and goes on reducing as the flow rate increases. The experimental analysis finally concludes more heat transfer coefficients than that of straight helical tube heat exchanger.

REFERENCES

1. Swapnilahire, Purushottamshelke, Bhalchandra shinde, Nilesh totala “Fabrication and analysis of helical coil counter flow heat exchanger”(2014), publication by International Journal Of Engineering Trends and Technology (ijett) – volume 15 number 5 – sep 2014
2. Mrunal P.Kshirsagar1, Trupti J. Kansara1, Swapnil M. Aher “Fabrication and analysis of tube-in-tube helical coil heat exchanger” International Journal of Engineering Research and General Science Volume 2, Issue 3, April-May 2014
3. Mostafa, nawras h., and qusay r. Al-hagag."Structural and thermal analysis of heat exchanger with tubes of elliptical shape." iraqi j. Mech. Mater. Eng 8, no. 3 (2008): 257-271.
4. Rennie, timothy j. "Numerical and experimental studies of a double-pipe helical heat exchanger." phd diss., Mcgill University, 2004.
5. Rehman, usman ur. "heat transfer optimization of shell-and-tube heat exchanger through CFD studies." (2012), publication by Chalmers university.
6. Jayakumar, j. S., s. M. Mahajani, j. C. Mandal, p. K. Vijayan, and rohidas bhoi. "Experimental and cfd estimation of heat transfer in helically coiled heat exchangers." chemical engineering research and design 86, no. 3 (2008): 221-232.