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Enhancement of Tube Side Heat Transfer using Twisted Stainless-Steel Angle

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ABSTRACT
The current research was carried out to investigate conventional heat transfer enhancement inside the tube by using twisted stainless-steel angle insert. Main objectives were to find the percentage of increment of heat transfer enhancement using twisted stainless-steel insert and to find the relation between Reynolds number and Nusselt number. A 940mm long copper tube of 26.6 mm internal diameter and 30 mm outer diameter, of which length of 762 mm has been used as the test section. A constant heat flux condition has been maintained by wrapping Nichrome wire around the test section and fiber glass insulation over the wire. K-type thermocouples and rotameter were used to measure temperature and rate of flow. With insert, heat transfer rate has been increased up to 140 percent. This technique does not rely on external power or activation. This experiment has shown simultaneous effects on Reynolds number and Nusselt number too.

Keywords: Heat transfer rate, Convective heat transfer co-efficient, Friction factor.

1. Introduction

1.1 Literature review:
The measurement of tube side heat transfer coefficient is an important part of heat transfer. Heat exchangers dealing with fluids of low thermal conductivity (gases or oils), there is a need to increase the heat transfer rate. Mesh or spiral brush inserts were used by Megerlin et al. (1974) to enhance turbulent heat transfer in short channels subjected to high heat flux. Variable roughness can be obtained by using a wire-coil insert made of a shape memory alloy (SMA) that alters its geometry in response to change in temperature proposed by Bergles and Champagne, 1999.This study mainly focuses on Reynolds number, Nusselt number, and especially on heat transfer coefficient by using stainless steel insert.

1.2 Applications:
Climate Engineering, Greenhouse effect, Evaporative Cooling, Laser Cooling, Magnetic Cooling, Radiative Cooling, Thermal Energy Storage.

1.3 Objectives:

- To find the tube side heat transfer co-efficient and friction factor.
- To find the percentage of increase of heat transfer enhancement using twisted stainless-steel angle insert and compare it to the plain tube.
- To find the relation between Reynolds number and Nusselt number.
- To find the pressure drop in tube side with twisted stainless-steel angle insert.

1.3 Methodology:

- A 940mm long copper tube of 26.6 mm internal diameter and 30 mm outer diameter, of which length of 762 mm has been used as the test section.
- A constant heat flux condition has been maintained by wrapping nichrome wire around the test section and fiber glass insulation over the wire. This was used to heat the test section.
- Outer surface temperature of the tube has been measured at five points of the test section maintaining equal distance from one point to another point by K-type thermocouples.
- Two thermometers have been used at the inlet and outlet section of the tube for measuring the bulk temperatures. At the outlet section the thermometer was placed in a mixing box.
- Pressure drop has been measured at five points of the test section by using manometer. Open loop system of water supply was used.
- The rate of flow was measured with the help of Rota meter in the travelling path of inlet water.
- Two types of temperature have been measured during the experiment. One regarding tube outer surface temperature and another regarding water inlet-outlet temperature.
- Data has been taken for only plain copper tube without insert and with insert.

2. Experimental Setups:

2.1 Insert:
Length=0.762m
Angle of twisted=18 degree
Thickness=2.9 mm
Pitch length=12 cm.

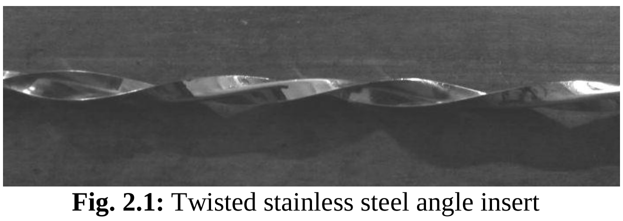

Fig. 2.1: Twisted stainless steel angle insert

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Setup:

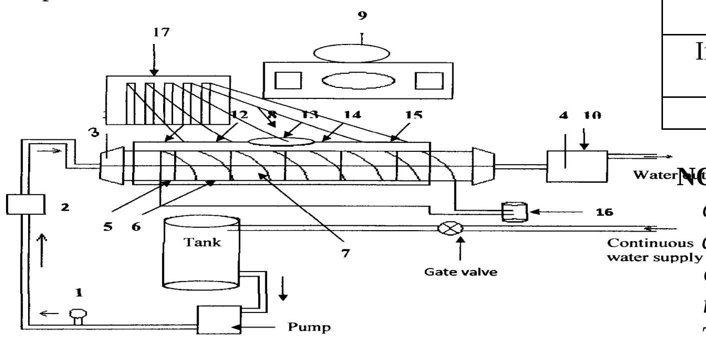

Fig. 2.2: Experimental Setup

1. Gate valve
2. Rota meter
3. Inlet Thermometer
4. Outlet Thermometer
5. Insulation
6. Test Section (copper tube)
7. Nichrome-wire coil
8. AC source
9. Thermo-electric monitor
10. Mixing box
11. Thermocouple 1
12. Thermocouple 2
13. Thermocouple
14. Thermocouple
15. Thermocouple
16. Voltage regulator
17. Manometer

(For detailed image please see Appendix)

3. Data collection and analysis

3.1 Necessary information and equation for calculation process:

Tube inside diameter=0.026 m
Tube outside diameter=0.03 m
Tube test length=0. 762 m
Thermal conductivity of copper=379W/m^{0}C
Viscosity of water µ=0.00087 kg/m.s
Density of water ρ =1000 kg/m^3
Thermal of conductivity of water, kW=0.62 w/m^{0}C
Specific heat of water (at 28^{0}C), Cp =4177 J/kg ^{0}C
Thickness of Stainless-steel insert =0.0029 m
Angle of twisted of insert =18^0
Thermal conductivity of copper, k=379 W/m °C

Equations:

Outer surface area, A_0= лd_0L
Inner surface area,A_i = лd_iL
Heat transfer rate, Q = mC_p(T_O-T_i)
Cross sectional area = лdi^2/4
Velocity, V = m/A_i, where m is the flow rate
Reynolds number, Re = ρVd_i/µ
Nusselt number, Nu = h d_i/k
Prandtl number, pr = µC_p/k
Convective heat transfer coefficient = Q/A ($T_{inner\ surface}$-T_{bulk})
Nu_d=0.023 $Re_d^{0.8}Pr^{0.4}$(By Dittus and Boelter)
The rate of heat Transfer through the tube wall by conduction is, Q=2лLK ($T_{outer\ surface}$-$T_{inner\ surface}$)/In (r_o/r_i)
Bulk temperature=T_b=(T_i+T_o)/2
Entrance length=0.623 $d_i$$Re^{0.25}$
Outer surface temperature= (Thermocouple 1+---------------+Thermocouple 5)/2
Inner surface temperature=Outer surface temp- Wall temp difference
% of error=(Nu_{exp}-Nu_{th})/Nu_{th}) x 100

NOMENCLATURE

c_p : Specific heat at constant pressure, kJ·kg^{-1}·K^{-1}
d_0 : Outer diameter
d_i : Inner diameter.
m : Mass flow rate.
T_0 : Outer surface temp.
T_i : Inner surface temp.
A_i : Tube inside area
μ : Kinematic viscosity.
ρ : Density.
h : Convective heat transfer coefficient
k : Thermal conductivity.
Nu_{exp} : Experimental nusselt no.
Nu_{th} : Theoretical nusselt no.
p : Pressure, kPa
T : Temperature, K
t : Celsius temperature, ^{o}C
V : Velocity.

3.4 Data calculation: **(Full data calculation have been shown in detail at Appendix)**

4. Results and Discussion

4.1 Summary of results:
Reynolds no. Re= 4318.46~17446.59

For plain tube:
Heat transfer rate= 626.85 ~ 3038.97 W
Convective heat transfer coefficient= 488.34 ~ 2056.99 w/m$^{2\ 0}$c
Nusselt no.Nu=20.99 ~ 80.17
Friction factor= 0.327 ~ 0.05162118

For plain tube with insert:
Heat transfer rate, Q= 1504.44 ~ 3672.09 W
Convective heat transfer co-efficient,h= 709.48 ~ 2576.58 w/m$^{2\ 0}$C
Nusselt no. Nu=30.49 ~ 87.94334461
Friction factor= 0.448 ~ 0.07420545

4.2 Discussion on results:
1. Here the heat transfer rate increases because of increasing flow rate.
2. Convective heat transfer co-efficient
Here the convective heat transfers co-efficient increases because of increasing heat transfer rate.
3. Error analysis: The reading increasing from thermocouple-1 to thermocouple-5 respectively. For minimum reading of thermocouple-1, average outer temperature decreases, wall temperature difference decreases, and inner surface temperature also decreases, and convective heat transfer coefficient also increases then experimental Nusselt number increases.

4.3 Graphical representation of different related values:

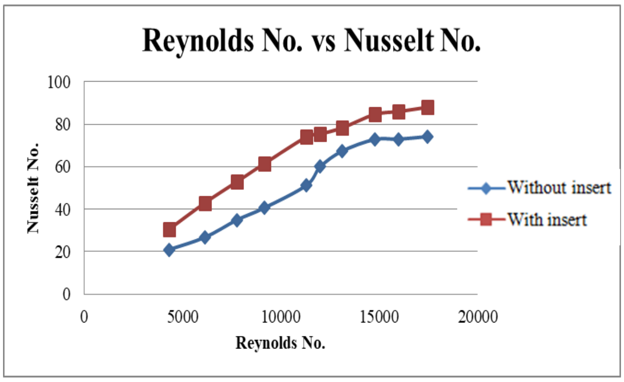

Fig. 4.1: Comparison of Nusselt no. with Reynolds no. using with insert and without insert.

From the above graph it is found that for the increasing Reynolds no. Nusselt number increases both with insert and without insert. But the increasing Nusselt no. with insert is higher than without insert. Because convective heat transfer coefficient is increased for using insert.

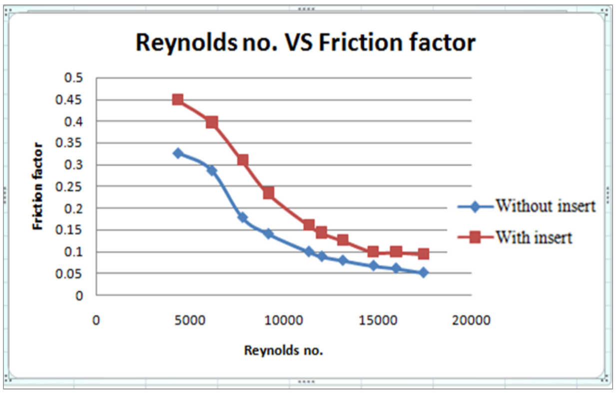

Fig. 4.2: Comparison friction factor with Reynolds no. using insert and without insert.

5. Conclusion:

The application of single-phase enhancement techniques is evaluated for tube side. Several active techniques have been identified as possibilities for tube enhancement. These techniques do require external power. But there is a power cost that needs to be considered. The present experimental study has made the simultaneous effects on Re, Nu and h which doesn't require any external power.

6. Recommendation:

1. The resistance of the heater must be known perfectly, because voltage should be controlled according to resistance.
2. Temperature reading should be taken after the flow reaches a steady state condition.

Acknowledgement:

Foremost, I would like to express my sincere gratitude to my advisor Prof. Dr. Bodius Salam (Dean, Mechanical Department of CUET) for the continuous support of my research, for his patience, motivation, enthusiasm, and immense knowledge. His guidance helped me in all the time of research and writing of this paper.

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Appendix Explanatory Material

1 Experimental setups:

Fig 2.3: Rotameter

Fig. 2.4: Manometer

Fig 2.5: Voltage regulator

Fig. 2.6: Thermocouple monitor

Fig. 2.7: Copper tube

Fig. 2.8: Test section

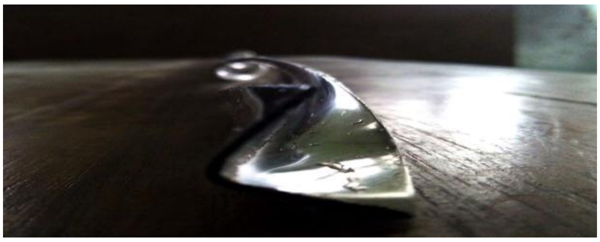

Fig. 2.9: Twisted stainless steel angle insert.

3.4 Data calculation:

3.4.1 Thermometer and thermocouple reading at various flow rates (plain tube): All temp. are in ^{0}C**(Table 3.1)**

Sr.	Inlet,T_i	Outlet,T_0	1	2	3	4	5
1	36	38	37	44	46	79	82
2	36	37.8	37	44	46	79	81
3	36	37.8	37	43	46	78	80
4	36	37.6	36	43	45	77	80
5	36	37.4	36	42	45	77	80
6	36	28	26	40	43	70	71
7	36	27.8	26	40	42	70	71
8	36	27.8	25	40	42	70	71
9	36	27.6	25	39	41	68	69
10	36	27.4	25	39	41	68	69

**First five data were taken at morning and last five data were taken at afternoon.

Calculation:

For without insert:

Tube outside diameter, d_o= 30 mm= 0.03m

Tube inside area, A_i= $\pi d_i^2/4$=0.000531 m^2

Mass flow rate, m=0.075kg/s

Heat transfer rate, Q= $mc_p(T_o-T_i)$= 626.85W

Velocity, v= m/A_i=0.14 m/s

Reynolds no.= $\rho v d_i/\mu$

= 4318.46

Here,

μ=0.00087kg/m.sec

ρ=1000kg/m^3

Wall temperature difference$\Delta T=Q\times\ln(r_{o/}r_i)/2\pi Lk$= 0.042

Outer surface temperature=(37+44+46+79+80)/5=57.20

Inner surface temperature= (57.20-0.042) ºC= 57.16 ºC

Bulk temperature = $(T_i+T_o)/2$ = (36+38)/2= 37 ºC

Heat transfer co-efficient, h =$\frac{Q}{A(T_{inner\ surface}-T_{bulk})}$

$=\frac{626.85}{0.000531\times(57.16-37)}$

=488.34 w/m^2

Nusselt number, N_u = $(hd_i)/k$ = 20.95

Friction factor, f=$\frac{\Delta p\times 2\times d_i}{\rho\times V^2\times L}$

L=0.762 m

d_i= 0.026 m

ρ = 1000 Kg/m^3

Δp = 133.42 N/m^2 ,f=$\frac{93.4\times 2\times 0.026}{1000\times 0.14^2\times 0.762}$ = 0.327

With insert:

Tube outside diameter, d_o = 30 mm= 0.03m

Tube inside area, Ai= πdi2/4

= 3.14×(0.026)2/4=0.000531 m2

Mass flow rate,

m=5×15=75ml/s=0.000075m3/s=0.075kg/s

Heat transfer rate, Q= $mc_p(T_o-T_i)$

=0.075×4177(39.8-35)

=1504.44 W

Velocity,v=m/A_i=0.000075/0.000531=0.14m/s

Re.no.=$\rho v d_i/\mu$=318.46Here,μ=0.00087kg/m.sec,ρ=1000 g/m^3,Wall temperature difference $\Delta T = Q\times\ln(r_o/r_i)/2\pi Lk$

=1504.44 ×ln (0.03/0.026)/ (2π×0.762×379)

= 0.100 ºC

Outer surface temperature = 70.80 ºC

Inner surface temperature= 70.80 - 0.100= 70.70 ºC

Bulk temperature = $(T_i+T_o)/2$ = 37.4 ºC

Heat transfer co-efficient, h = 709.48 w/m^2

Nusselt number, N_u = (709.48×0.026)/ 0.62=30.44

Friction factor, f=$\frac{\Delta p\times 2\times d_i}{\rho\times V^2\times L}$= 0.448

3.4.2 Flow rate for various Rotameter reading (plain tube):

Exp. No.	Rotameter reading (cm)	Flow rate (ml/s)	Flow rate (m^3/s)	Flow rate (kg/s)
1	5	75	0.000075	0.075
2	7.1	106.5	0.0001065	0.107
3	9	135	0.000135	0.135
4	10.6	159	0.000159	0.159
5	13.1	196.5	0.0001965	0.197
6	13.9	208.5	0.0002085	0.209
7	15.2	228	0.000228	0.228
8	17.1	256.5	0.0002565	0.257

9	18.5	277.5	0.0002775	0.278
10	20.2	303	0.000303	0.303

Table 3.2: Value of Flow rate for various Rotameter reading (plain tube)

3.4.3 Determination of Q for various velocities (plain tube):

Exp no	Cross sectional area (m^2)	Velocity(m/s) Eq-5	Heat transfer rate Q(W)Eq-3
1	0.000531	0.14	626.85
2	0.000531	0.20	801.11
3	0.000531	0.25	1015.50
4	0.000531	0.30	1063.14
5	0.000531	0.37	1149.64
6	0.000531	0.39	2613.96
7	0.000531	0.43	2667.87
8	0.000531	0.48	3001.36
9	0.000531	0.52	3015.15
10	0.000531	0.57	3038.97

Table 3.3: Value of Q for various velocities (plain tube)

3.4.4 Determination of heat transfer coefficient and Reynolds number (plain tube):

Sr.	Eq-11	Eq-14	Eq-15	Eq-12	Eq-9	Eq-6
1	0.04	57.20	57.16	37	488.3	4318.4
2	0.05	57.20	57.15	36.9	621.3	6132.22
3	0.06	56.60	56.53	36.9	812.2	7773.23
4	0.07	56.00	55.93	36.8	972.7	9155.14
5	0.07	55.60	55.52	36.7	1259	11314.3
6	0.17	50.00	49.83	26.5	1459	12005.3
7	0.17	49.80	49.62	26.4	1604	13128.1
8	0.19	49.80	49.60	26.4	2031	14769.1
9	0.20	48.40	48.20	26.3	2040	15978.3
10	0.20	48.4	48.20	26.2	2056	17446.5

Table 3.4: Value of heat transfer coefficient and Reynolds number (plain tube)

3.4.5 Determination of experimental N_u, P_r and theoretical Nu (plain tube):

Sr.	Eq-7	Eq-8	Eq-10
1	20.99	5.31	31.30
2	26.70	5.33	45.04
3	34.91	5.34	56.70
4	37.57	5.35	66.15
5	41.28	5.37	80.43
6	65.97	5.40	85.04
7	67.37	5.42	92.29
8	72.8	5.45	102.7388363
9	72.98	5.47	110.3195344
10	74.17	5.48	119.3009372

Table 3.5: Value of experimental N_u, P_r, and theoretical Nu (plain tube)

3.4.6 Determination of friction factor (f) for various pressure drop with rotameter height, h (plain tube):

Exp no.	h(cm)	P(N/m^2)	f
1	0.1	133.4	0.327
2	0.11	146.8	0.287
3	0.11	146.8	0.179
4	0.12	160.1	0.141
5	0.13	173.4	0.1
6	0.13	173.4	0.089
7	0.14	186.7824	0.079772202
8	0.15	200.124	0.067532023
9	0.16	213.4656	0.061544216
10	0.16	213.4656	0.051621184

Table 3.6: Value of friction factor (f) for various pressure drop (plain tube)

3.5 Data Calculation for plain copper tube with insert:
3.5.1 Thermometer and thermocouple reading at various flow rates:

Sr.	T_i	T_o	1	2	3	4	5
1	35	39.8	47	55	59	95	98
2	35	39.7	46	55	58	95	98
3	35	39.5	46	54	58	94	97
4	35	39.3	45	53	57	93	96
5	35	39	44	51	55	91	95
6	35	38.8	44	51	55	90	94
7	35	38.5	43	50	54	89	93
8	35	38.3	42	50	54	88	92
9	35	38.1	42	49	53	88	92
10	35	37.9	41	48	52	87	91

Table 3.7: Thermometer and thermocouple reading at various flow rates with insert.

3.5.2 Flow rate for various Rotameter reading with insert:

Exp no	(cm)	(ml/s)	(m3/s)	(kg/s)
1	5	75	0.000075	0.075
2	7.1	106.5	0.0001065	0.107
3	9	135	0.000135	0.135
4	10.6	159	0.000159	0.159
5	13.1	196.5	0.0001965	0.197
6	13.9	208.5	0.0002085	0.209
7	15.2	228	0.000228	0.228
8	17.1	256.5	0.0002565	0.257
9	18.5	277.5	0.0002775	0.278
10	20.2	303	0.000303	0.303

Table 3.8: Flow rate for various Rotameter reading with insert.

3.5.3 Determination of Q for various velocities with insert:

Exp no	(m^2)	Eq-5	Eq-3
1	0.000531	0.14	1504.44
2	0.000531	0.20	2091.80
3	0.000531	0.25	2538.74
4	0.000531	0.30	2857.18
5	0.000531	0.37	3284.69
6	0.000531	0.39	3311.02
7	0.000531	0.43	3334.84
8	0.000531	0.48	3537.31
9	0.000531	0.52	3594.98
10	0.000531	0.57	3672.09

Table 3.9: Value of Q for various velocities with insert.

3.5.4 Determination of heat transfer coefficient and Reynolds number with insert:

Exp no	Eq-11	Eq-14	Eq-15	Eq-12	Eq-9	Eq-6
1	0.100	70.8	70.7	37.4	709.4	4318.46
2	0.139	70.4	70.3	37.35	998.1	6132.22
3	0.168	69.8	69.6	37.25	1231	7773.23
4	0.189	68.8	68.6	37.15	1426	9155.14
5	0.218	67.2	66.9	37	1720	11314.3
6	0.219	66.8	66.5	36.9	1751	12005.3
7	0.221	65.8	65.5	36.75	1816	13128.1
8	0.234	65.2	64.9	36.65	2461	14769.1
9	0.238	64.8	64.5	36.55	2493	15978.3
10	0.243	63.8	63.5	36.45	2576	17446.5

Table 3.10: Value of heat transfer coefficient and Reynolds number with insert.

3.5.5 Determination of experimental N_u, P_r, and theoretical N_u with insert:

Exp no.	Eq-9	Eq-8	Eq-17
1	31.30	5.31	30.49
2	45.04	5.33	42.89
3	56.70	5.34	52.91
4	66.15	5.35	61.39
5	80.43	5.37	74.05
6	85.04	5.40	75.40
7	92.29	5.42	78.32
8	102.7388363	5.45	84.57835021
9	110.3195344	5.47	85.95726359
10	119.3009372	5.48	87.94334461

Table 3.11: Value of experimental N_u, P_r , and theoretical N_u with insert.

3.5.6 Determination of friction factor (f) for various pressure drop with insert:

Exp no.	h(cm)	P(N/m^2)	f
1	0.18	240.1	0.448
2	0.19	253.5	0.396
3	0.19	253.5	0.309
4	0.2	266.8	0.234
5	0.21	280.2	0.161
6	0.21	280.2	0.143
7	0.22	293.5152	0.12535632
8	0.22	293.5152	0.09904697
9	0.23	306.8568	0.09846981
10	0.23	306.8568	0.09420545

Table 3.12: Value of friction factor (f) for various pressure drops with insert.

3.6 Percentage increase on Nusselt no. (with insert):

no.	Eq-7	Eq-7	%Of increase	% of increase
1	20.99	30.49	45.26	
2	26.70	42.89	60.64	
3	34.91	52.91	51.56	
4	37.57	61.39	63.4	38.346
5	41.28	74.05	79.4	
6	65.97	75.40	14.3	
7	67.37	78.32	16.3	
8	72.8	84.57835021	16.2	
9	72.98	85.95726359	17.8	
10	74.17	87.94334461	18.6	

Table 3.13: Percentage increase on Nusselt no. (With insert).

** First five data were taken at morning and last five data were taken at afternoon.