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Experimental Heat Transfer using Insert for Nusselt Number Enhancement

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***Abstract** – Various heat transfer and its enhancement techniques are found in literature. Many researchers have focused on such topics typically in last decade of last century. The paper deals with experimental work of the passive techniques which do not require direct application of external power, whereas the active techniques require an. Exact method and system used for research from 1964 till around 2000 is presented. A case study of twisted tape of Y as 4.2 and 5.2. It is seen that overall heat transfer coefficient is a function of Reynolds number. .It is noticed that on the tube side the flow conditions have included both laminar and turbulent flow. Graph presents shows heat transfer data for both twisted tapes. It can be seen that the overall heat transfer coefficient in general increase with increase in Reynolds number. For a given Reynolds number the overall heat transfer coefficient increase with decrease in twist ratio i.e. tape with tighter twist. Also friction factor increase with decreases in the twist ratio* [1]

I. INTRODUCTION

The goals of enhanced heat transfer can be started as desired to boost or put up high heat fluxes. The heat transfer coefficient for fixed temperature difference, for either constant heat transfer rate or constant area can increase the heat flux.

II. CLASSIFICATION

The cataloguing of enhancement methods has been recommended by [1]. The passive techniques do not require direct tender of external energy, whereas the active techniques need an external activator / power supply to bring about the improvement. Techniques may be utilized simultaneously to yield an augmentation that is greater than the methods operating separately, called compound enhancement.

III. EXPERIMENTAL ARRANGEMENTS, RANGES & RESULT

E. Smithberg and F. Landis [2] have studied velocity distribution friction losses and heat transfer characteristics for fully established turbulent flow in tubes with twisted inserts swirl generators. Data was acquired for twist of 3.62 to 22 for both air and water. This is considered as important paper for twist tape study. C. Shivakumar and M. Raja Rao [3] studied combination of tube surface roughness with tape generated swirl flow for single-phase convective HT.

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Experiment carried out on plane and spirally corrugated (rough) tubes with and without twisted tape (y=2.92 to 10) for water. Compared to smooth tubes isothermal friction factors are 2.2 to 7 times greater and Nu 1.2 to 2.2 times greater. They stated that study of performance evaluating at equal pumping power shows HT enhancement of 35 to 70% , 20 to 40% and 20% respectively for rough tube swirl flow, smooth tube swirl flow and rough tube axial flow.

Hong and Bergles (1976) [4] have studied Heat transfer coefficient. For laminar flow of water and ethylene glycol in an electrically heated metal tube with two twisted tapes. The Nu is to be function of tape twist relation, Re and Pr. Nu were nine times of empty tubes. He also stated that friction factor is changed by tape twist only at greater Re.

J. H. Masliyah and K. Nandakumar [5] studied HT features for a laminar forced convection in fully developed condition with inside finned circular tubes with axially even heat flux-with peripherally even temperature-using FEM. It is found that Nu based on inside tube diameter was upper than that for smooth tube. This study was carried out for triangular shape fins.

The fully developed turbulent flow and HT features for tube and annuli with longitudinal internal fins were analyzed analytically by S. V. Patankar, M. Ivanovic and E.M. Sparrow [6]. He found that fins were as effective for HT surface.

The paper by R. F. Lopina and A. E. Bergles [7] summarizes results of experiment carried out with one phase water in tape produced swirl flow. For heating DC supply is used with twist ratios of 2.5 to 9.2. He concluded that improvement of about 20% could be obtained using swirl flow.

R. Sethumadhavan and M. Raja Rao [8] presented from experimental study of HT in a 25mm 1D Cu-Tube, firmly fitted with helical wire coil enclosures of changing pitch (p) and helix angle ($\propto$) and wire diameter (e). He adopted a similarity low approach ad concluded that, the preferred helix angle of wire coil promoters should be of 50^0-55^0; tube [Equivalent diameter as 19.9mm, pitch 22mm, thickness 2mm and angle 60^0 with length of 1500mm is the best at all.

G. H. Junkhan, A. E. Bergles [9] studied three popular tabulators used in fire tube boilers i.e. (a) Narrow thin metal strip bents twisted in zigzag manner, (b) Same as (a) with rounded corners, (c) twisted tape. (a), (b) and (c) shows 135, 175 and 65% rise in heat transfer coefficient. The friction increase is of 11.8 times that of plain tube for (a) 11 times for (b) and 2.7 times for (c) at Re=10000.

Shou-Shing Hsieh [10] obtained a co-relation for fully developed turbulent flow above a roughened surfaces in flat annuli with helical angle $\propto$=65^0 with three various sizes. The trials were directed in range 3000<=Re<= 30000 with water as cooling media. The co-relation presented:

$$Nu = 4.6\ Re^{0.48}\ [e/D_h]^{0.39}\ [P/e]^{0.3}\ Pr^{0.4}$$

For: Re between 3000 and 30000; 0.04 <= (e/Dh) <= 0.192; 1.44 <= (P/e) <= 7.2, Where, e: roughness height, Dh: Hydraulic Diameter, P: Pitch

Tulin Bali and Teoman Ayhan [11] introduced one more method of heat transfer augmentation by inserting a propeller type swirl generator in a circular pipe, which creates a swirling flow. (Laminar condition). He inserted swirl generator at two positions at distance 0mm and 197 mm from one end of about 2m-test section. He concluded that: Nu increases at rate of 12-58% and 30% -44% with smooth tube in first and second argument respectively. Whereas pressure losses are increases by 4.5-5.4 times and 2.6 –3.7 times of smooth tube in first and second respectively.

	Swirl at (Increases)	
	X = 0	X = 197
In Nu	12 - 58%	30 – 40%
In f	4.5 - 5.4	2.6 – 3.7%

R. Thorsen and F. Landis [12] have worked further and used turbulent air movement through tubes with twisted tapes y=3.15 and Re up to 100000 is considered. He developed a constant Heat flux condition by wounding a heater on pipe and developed a co-relation for Nu and f with heating and cooling condition.

An experimental investigation by Hagge and Junkhan [13] shows that HT can be augmented using Mechanical removed of boundary layer. A rotating blade element passing in nearby closeness to a flat plate convective surface was establish to rise the rate of convective HT by up to 11 times in definite situation. Blade element effectively scraps away the boundary layer, and resistance to heat flow reduces. The technique id useful for laminar and transitional boundary layer.

R. L. Webb [14] studied heat transfer and friction co-relations for turbulent flow in tubes taking frequent rib roughness. As per the study, various c/s of ribs can be used with various thickness and pitch; inside the tube. Experiment was carried out and shows that improvement takes place. He uses rectangular ribs with e/d as 0.01 to 0.04 and P/e:10 to 40 with various combinations.(Where, e: height of roughness element, D: ID of pipe, P: Pitch of ribs)

D. F. Dipprey and R. H. Sabersky [15] presented the results from an experimented investigation of the relation between HT and friction in smooth and rough tubes. Three rough tubes of electroplated Ni are formed with roughness height to dia. Ratios ranging from 0.0024 to 0.049. It was found that by using distilled water as flowing fluid, increase in heat transfer coefficient was about 270% which was even larger increase in friction coefficient.

The study carried out using spectral element technique by M. Greiner and P. F. Fischer, H. M. Tufo [16] shows that internally grooved passages can also work better for heat transfer enhancement. The computational domain has seven grooves proportionally into opposite wall partitions, followed by a flat section within the same length. They have plotted temperature counters for Re=600, 1200, 1800 and proves that intermittently grooved passages may offer even higher heat transfer

Youn-Jun-Jang, Hamn-Ching Chen and Je-Chin Han [[17], have studied computational method only for 3D flow and heat transfer for a two pass square channel with and without 60^0 angled parallel ribs. Square sectional ribs were engaged along one side face. The rib height to hydraulic dia. Ration (e/Dh) is 0.125 and rib pitch to height ratio (P/e) is 10. His computational results were compared with the investigational data of Ekkad and Han (1997) [18]

S. K. Saha and P. Langille [19] studied HT and pressure drop in a circular tube fitted with full-length strip, Laminar flow of water and other viscous liquids was considered. The section was heated electrically imposing constant heat flux condition. He concluded that short lengths strip up to a restricted value (0.3) of 1 and frequently spread out strip elements have been found well than full-length strips.

	F (Increases)	Nu (Increases)
Short Length Strips	8 – 58%	2 – 40%
Regularly spaced Strips	1 – 35%	15 – 75%

Saha S.K. and A. Dutta [20] have studied combination of various methods of HT augmentation using twisted tapes only. A circular tube, with laminar swirl flow of a large Pr (Between 205 and 518) and viscous fluid was used, The swirl was generated by (a) full length twisted tape inserts. (b) Regularly spaced twisted tape element and (c) Smoothly varying pitch full lengthwise twisted tape. (y =from 2.5 to 10) and Re 45 to 1150 with uniform heat flux condition. They concluded that short distance twisted tapes are found to perform well than full length twisted tapes for upper twists. Thermo-hydraulic presentation demonstrate that a twisted tape with several twists in the tape module is not much dissimilar from that with single twist in the tape module.

R. Sethumadhavan and M. Raja Rao [8] have carried out experiments on five spirally corrugated tubes of one to four corrugations starts, with common helix angle, but changeable geometrical aspect ratios, for the turbulent flow with water including 50% glycerol. They concluded that (a) all spirally corrugated tubes showed an enhancement in tube side HT (b) Tube (ID 25.2mm, pitch 7.5mm, Roughness thickness 0.59mm 4 start, 650 helix and 1500mm long was recognized as the most effective tube.

J. H. Royal and A. E. Bergles [21] studied condensation of low-pressure steam in horizontal tube of different internal geometries to investigate HT. A smooth tube, tube with two twisted tapes, four fined tubes (total 7 tubes) were studied. It was found that twisted tape inserts increases avg. HT coefficients by 30% above smooth tube and finned tubes by 150% above smooth tube. They have developed a co-relation also.

Kozlu H., B. B. Mikic and A. T. Patera [22] used micro-scale disturbance inside the surface near surface (turbulent condition). They used close wall mixing developments induced in the sub layer through suitable wall and near wall stream wise periodic disturbance. Experiment performed in wind tunnel with rectangular channels as (a) 2D intermittent microgrooves on the wall & (b) 2D micro-cylinders located in the instant locality of the wall.

The study shows that (b) above shows favorable performance at particular position and Re only. But (a) shows favorable augmentation for wider range of Re.

J. P. Chiou [23] used oil cooler as a test section using spiral spring insert for heat transfer augmentation. He used SAEIO oil flowing in tube and cooled by water from outside tube of a HEX. 16 springs are tested. He concluded that HT coefficient. Of the oil flow in tube can be triple than smooth tube at Re=1200 whereas 1.5 times at Re=6000. He also suggested to use it for small size (fixed) but more HT rate needed HEX like oil cooler.

Uttarwar S. B. and M. Raje Rao [24] have carried out HT Augmentation using spring coils of varying dia. of coil, pitch, etc. They tested seven coils. IT was found that HT results i.e. Nu is function of helix angle, Re & Pr. The co-relation developed for laminar flow. Nearby 350% improvement was noted in heat capacity and area reduction of HEX up to 70 to 80% using coils. They perform well for Re less than 200 Sethumadhavan reported in his Ph.D. that for turbulent flow 30-50% increment of HT is only observed.

Heieh S. S., K. J. Jang and Y. C. Tsai [25] reported learning on saturated boiling HT of refrigerant R600a in horizontal tubes (ID=10.6mm) with strip = cross insert, with holes and without holes longitudinal type. For inserts with perforated strips HT coefficient increases for all mass velocities. This is because the flow in the tubes with inserts was in forced convection boiling with condensed flow area and reduced hydraulic diameter in which the HT coefficient would rise as the mass velocity rises.

T. M. Liou, C. C. Chen and T.W. Tsai [26] studied local Nu distribution in the first pass of a sharp turning 2 pass, square channel with several configuration of longitudinal vortex generator ready on one wall were measured at Re-1.2/10^4 (fixed). Comparison in terms of HT and friction factor performed on 12 configurations. HT enhancement is then documented for three-selected vortex generators. It was found that a 45-degree V (with tips facing upstream) model provides improved thermal presentation among 12 configuration of all. Tests are conducted in a U shape airflow channel with one vortex generator at entrance.

W. J. Marner, A. E. Bergles and J. M. Chenoweth [27] presented the list of manufacturer and their trade names of enhanced tube manufacturer. He noted that maximum OD of tube is limited than that of tube holes of tube sheets in tube and shell HEX. This creates problem in inserting and pulling tubes through the holes in tube sheets. The layout considered by [27] above is limited to TEMA slandered.

R. Chaturvedi and Keshavkant [28] presented string of in-line propellers have been used as the augmenting device to produce a secondary flow in pipe. The propeller creates a swirl in the pipe under constant heat flux, in turbulent reign. They concluded that. (a) The inter-propeller distance of 9.72x D is recommended for maximum HT at Re≅48000.

S. S. Hsieh, I. W. Huang [29] studied testing on unadorned tubes and tubes with square and rectangular as well as cross strip inserts. The water flow in tube with 1700 to 4000 as Re is used. Out of four different inserts, based on Hyd. Dia., is found to be about 16 times more increase in HT rate at Re<=4000 while friction factor increase was about 4.5 times to bare tube.

A. E. Bergles [1] in his 1995 Max Jakob Memorial Award winner Lecture studied techniques that have been established to enhance connective heat transfer. He has classified various enhancement techniques as active, passive and compound. One of the best paper which summarizes history of heat transfer enhancement from 1860 till 1995 quotes that 5676 papers and reports are published for the benefits of heat transfer research. Also authors like have used such techniques for typical applications as heat exchangers [30], radiant heat transfer [31]. Rough surface [32], laminar flow, Turbulent heat transfer in large aspect channels analysis [33] [34] [35], augmentation using electric field [36] are also reported. Large heat flux with pipe are investigated. [37]

T. M. Liou and J. J. Hwang [38] have studied variation of Nu and f for fully developed channel flows with two rib roughened opposite walls. The Re varied from 5x10^3 to 5.4x10^4 , the rib pitch to height ratio (Pi/4) were 10, 15 and 20 and rib height to Hyd. Diameter (H/De) were 0.063, 0.081 and 0.106. Air with turbulent flow is used and heating is carried out by giving DC supply to tube (UHF) condition.

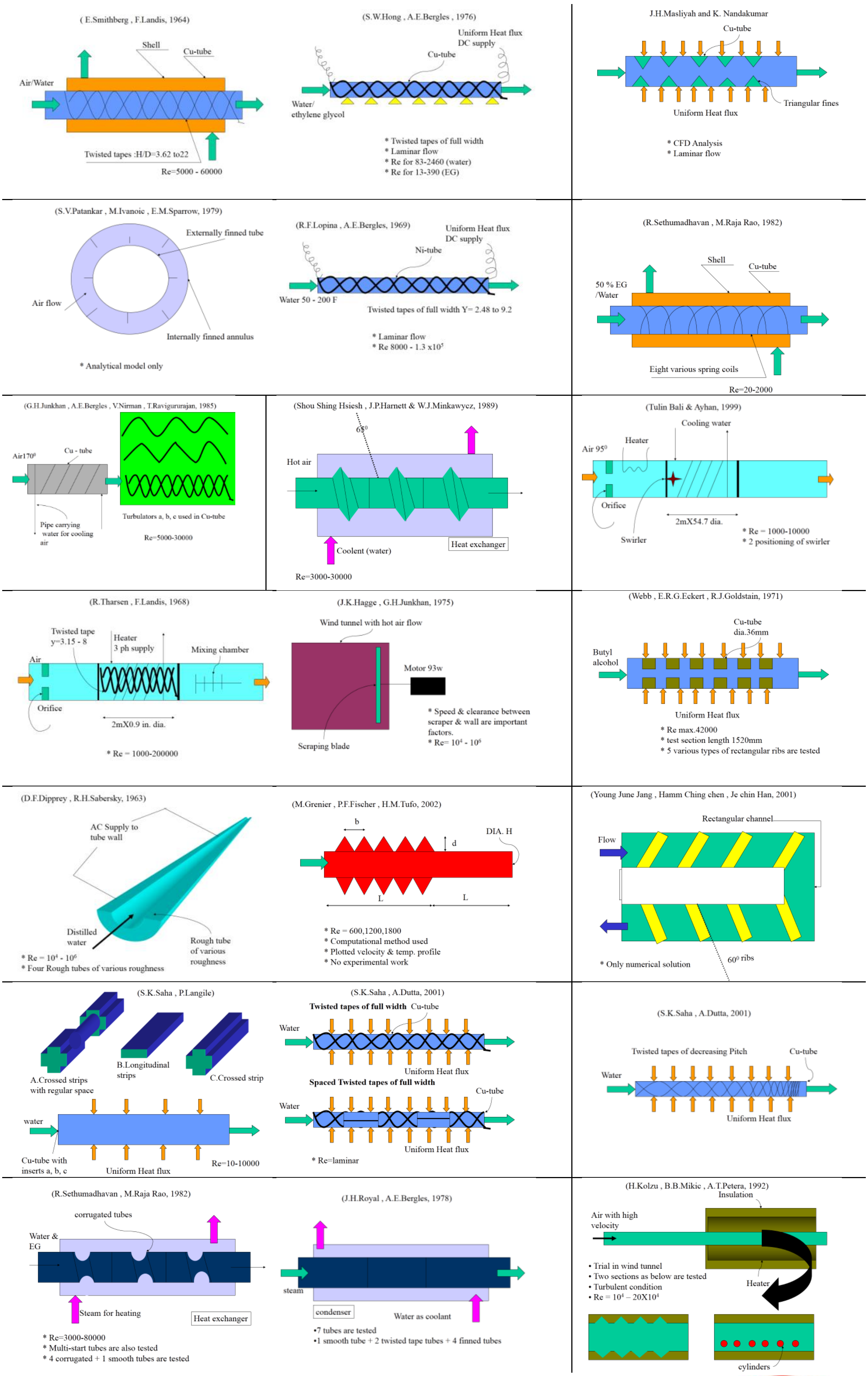
Friction factor and Nu evaluated for twisted tape generated helical flow in annuli by N. S. Gupte and A. W. Date [39]. Results have been obtained for different Y. The twisted tapes are mounted on inner tubes by soldering a surface, which is kept in a big tube. Outer tube is heated by UHF and Air flow is obtained using blower. It was concluded that it will find better conformance with research done already.

R.L. Webb and R. Narayannurthy [40] reported single-phase flow in seven 15.54mm ID tubes having internal helical rib roughness. The range of parameters were; no. of starts 18 to 45, helix angle 25 to 45^0 and rib height 0.33 to 0.55mm. The data were collected for water at 508<=Pr<=6.29. He develops co-relations for the same.

In a 25mm ID tube of pipe in pipe HEX, A. G. Patil [41] tested twisted tapes of different kinds. Such tape gives 18-56% lower isothermal friction factor than full width tapes. Uniform wall temp. Nu decreases only slightly by 5-25% for tape widths of 19.7 and 11mm resp. Based on pumping power criteria, 19.7mm tape works like full width tape almost. Such tubes also reduces 20-50% material saving.

T.S.Ravigururnajan and A.E.Bergles [42] again tested internally rough (grooved) tubes for Nu, fraction factor and Pr calculations. Roughness height of 3-tube mfg. was different. Experiment were performed for Pr 10.2 to 5.8, for water as fluid, turbulent flow and DC heating of pipe (UHF) condition. The experiment shows that a rib height to dia. Ratio of 0.02 offers finest overall performance for water at Pr=10; while at Pr=6, the e/d depends on Re.

Laminar flow co-relation for fraction factor and Nu and developed by R. M. Manglik, A. E. Bergles [43] based on experimental data for water and ethylene glycol, with tape inserts of three different twist ratios(y=3,4.5,6). They have also concluded regarding fin effect of twisted tape which found to be negligible in snug-lose to fitting by comparing laminar as well as turbulent flow experimental data they have presented combine single equation for Nu and fraction factor.


(E.Smithberg , F.Landis, 1964)
Shell
Cu-tube
Air/Water
Twisted tapes :H/D=3.62 to22
Re=5000 - 60000
(S.W.Hong , A.E.Bergles , 1976)
Uniform Heat flux
DC supply
Cu-tube
Water/
ethylene glycol
* Twisted tapes of full width
* Laminar flow
* Re for 83-2460 (water)
* Re for 13-390 (EG)
J.H.Masliyah and K. Nandakumar
Cu-tube
Triangular fines
Uniform Heat flux
* CFD Analysis
* Laminar flow
(S.V.Patankar , M.Ivanoic , E.M.Sparrow, 1979)
Externally finned tube
Air flow
Internally finned annulus
* Analytical model only
(R.F.Lopina , A.E.Bergles, 1969)
Uniform Heat flux
DC supply
Ni-tube
Water 50 - 200 F
Twisted tapes of full width Y= 2.48 to 9.2
* Laminar flow
* Re 8000 - 1.3 x10⁵
(R.Sethumadhavan , M.Raja Rao, 1982)
Shell
Cu-tube
50 % EG
/Water
Eight various spring coils
Re=20-2000
(G.H.Junkhan , A.E.Bergles , V.Nirman , T.Ravigururajan, 1985)
Air170⁰
Cu - tube
Pipe carrying
water for cooling
air
Turbulators a, b, c used in Cu-tube
Re=5000-30000
(Shou Shing Hsiesh , J.P.Harnett & W.J.Minkawycz, 1989)
65⁰
Hot air
Coolent (water)
Heat exchanger
Re=3000-30000
(Tulin Bali & Ayhan, 1999)
Cooling water
Heater
Air 95⁰
Orifice
2mX54.7 dia.
Swirler
* Re = 1000-10000
* 2 positioning of swirler
(R.Tharsen , F.Landis, 1968)
Twisted tape
y=3.15 - 8
Heater
3 ph supply
Mixing chamber
Air
Orifice
2mX0.9 in. dia.
* Re = 1000-200000
(J.K.Hagge , G.H.Junkhan, 1975)
Wind tunnel with hot air flow
Motor 93w
Scraping blade
* Speed & clearance between scraper & wall are important factors.
* Re= 10⁴ - 10⁶
(Webb , E.R.G.Eckert , R.J.Goldstain, 1971)
Cu-tube
dia.36mm
Butyl
alcohol
Uniform Heat flux
* Re max.42000
* test section length 1520mm
* 5 various types of rectangular ribs are tested
(D.F.Dipprey , R.H.Sabersky, 1963)
AC Supply to
tube wall
Distilled
water
Rough tube
of various
roughness
* Re = 10⁴ - 10⁶
* Four Rough tubes of various roughness
(M.Grenier , P.F.Fischer , H.M.Tufo, 2002)
b
DIA. H
d
L
L
* Re = 600,1200,1800
* Computational method used
* Plotted velocity & temp. profile
* No experimental work
(Young June Jang , Hamm Ching chen , Je chin Han, 2001)
Rectangular channel
Flow
* Only numerical solution
60⁰ ribs
(S.K.Saha , P.Langile)
B.Longitudinal
strips
A.Crossed strips
with regular space
C.Crossed strip
water
Cu-tube with
inserts a, b, c
Uniform Heat flux
Re=10-10000
(S.K.Saha , A.Dutta, 2001)
Twisted tapes of full width Cu-tube
Water
Uniform Heat flux
Spaced Twisted tapes of full width
Cu-tube
Water
Uniform Heat flux
* Re=laminar
(S.K.Saha , A.Dutta, 2001)
Twisted tapes of decreasing Pitch
Cu-tube
Water
Uniform Heat flux
(R.Sethumadhavan , M.Raja Rao, 1982)
corrugated tubes
Water &
EG
Steam for heating
Heat exchanger
* Re=3000-80000
* Multi-start tubes are also tested
* 4 corrugated + 1 smooth tubes are tested
(J.H.Royal , A.E.Bergles, 1978)
steam
condenser
Water as coolant
•7 tubes are tested
•1 smooth tube + 2 twisted tape tubes + 4 finned tubes
(H.Kolzu , B.B.Mikic , A.T.Petera, 1992)
Insulation
Air with high
velocity
• Trial in wind tunnel
• Two sections as below are tested
• Turbulent condition
• Re = 10⁴ – 20X10⁴
Heater
cylinders

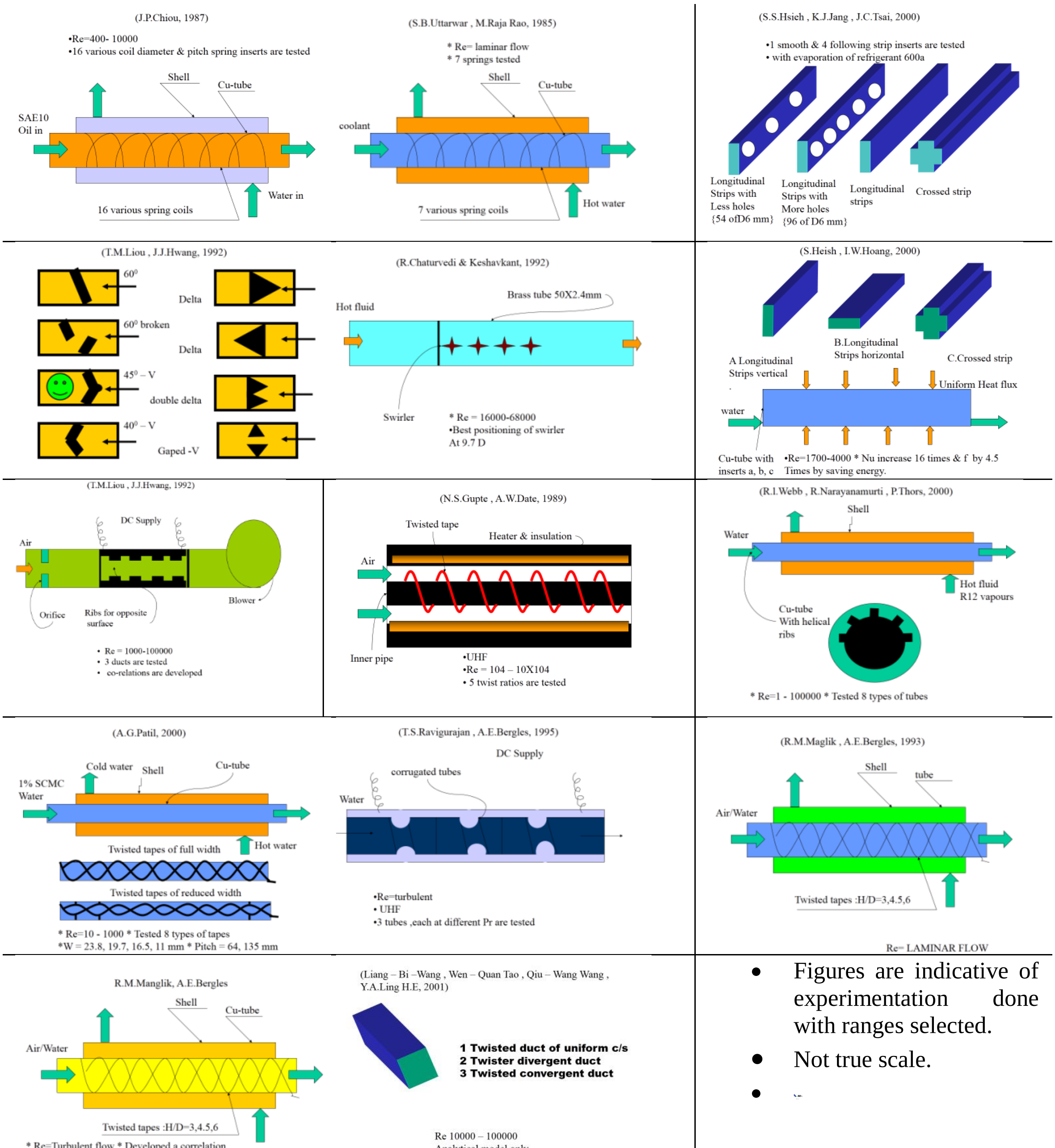


Figure 1: Literature experiments

Liang-Bi Wang, Wen-Quan Tao, Qie-Wang Wang, Ya-Ling He [44] describe the experimental and numerical study By considering all this, one of the most popular method of twisted tape is selected for analysis.

IV. EXPERIMENTAL SETUP

Though several experiments have been reported on twisted tapes over the last many years, most of them reported simulating the ideal condition by electrical heating, steam heating, etc. Experimental data on actual condition existing in a shell and tube heat exchange is having its own importance.

Thus the present experimental investigation concerned itself with the following aims - To collect data on the heat transfer and pressure drop characteristics of a single tube & shell heat exchanger (Pipe In Pipe: PIP) in the turbulent regime of fluid flow. To collect similar data with twisted tape inserts to generate swirl in the fluid flow. Different twist ratios has been used, (Y =4.2, 5.2). To compare the above data with reference to friction factor and overall heat transfer coefficient. Experimental work for evaluating the heat transfer and pressure drop characteristics of PIP heat exchanger with twisted tape inserts and without twisted tape inserts has been carried out with the help of heat balance under various conditions of flow rates and heating inputs. Hot air has been used as fluid medium in the tube side for heating water in shell side during the experiment.

Air at ambient temperature enters in the heater of 3 KW. Then the hot air enters a calming section of length (50 * D) i. e. around 800mm. Before heater air enters in a rotameter, which is used for flow measurement. Air temperature at the inlet and outlet of the test section is measured by using thermocouples, which were K- type. A test section consists of a pipe in pipe heat exchanger with 1200mm effective length. Internal pipe is made up of smooth brass, whereas outer pipe was made up of GI.

Pressure taps were manufactured. Pressure drop is measured by using a u - tube manometer. Soap bubble technique is used at all joints to identify the leakage problems. From heater to test section all the pipes and fittings are insulated with ceramic wool for avoiding heat losses to atmosphere.
The heating fluid used is the normal water available, which was circulated in the test section. Water head available in the overhead tank itself is used for pressuring water up to requirement. The flow rate of water is measured by using a rotameter. Water temperature at the inlet and outlet of the test section is measured by using thermocouples, which are K- type. Multi-channel Digital temperature indicator is used for reading temperatures. Voltage stabilizer is used to control the voltage of heater.

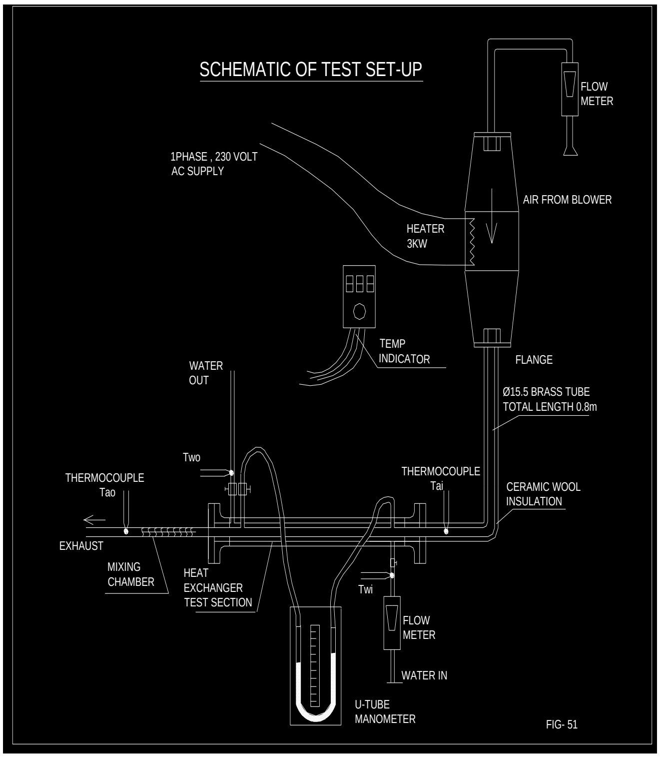


Figure 2 : Experimental setup

V. RESULTS AND DISCUSSION

The experiments conducted and results are plotted. Reynolds Number Vs Overall Heat Transfer Coefficient : Graph has been plotted to study the variation of overall heat transfer coefficient of the heat exchanger against variation in the Reynolds number of the fluid flow in the tube side of the heat exchanger. Graph has been drawn in case of each of the flow condition; Empty tube condition, Tube with twisted tapes of twist ratio Y=5.2, Tube with twisted tapes of twist ratio Y=4.2. The graph has been drawn to study the variation in the performance level of the heat exchanger at different Reynolds number of flow for various heater-input conditions.
Reynolds number Vs Friction Factor: These graphs help to understand the effect of twisted tapes on the friction characteristic of the heat exchanger. Friction factor of the tube side is considered due to the insertion of twisted tape swirl promoters. Graphs are drawn for Isothermal friction factors for: Smooth Tube only, with Twisted Tape of Y = 5.2, With Twisted Tape of Y = 4.2

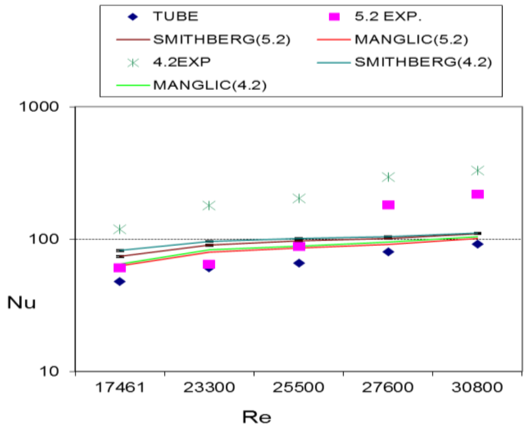


Figure 3: Re Vs Nu

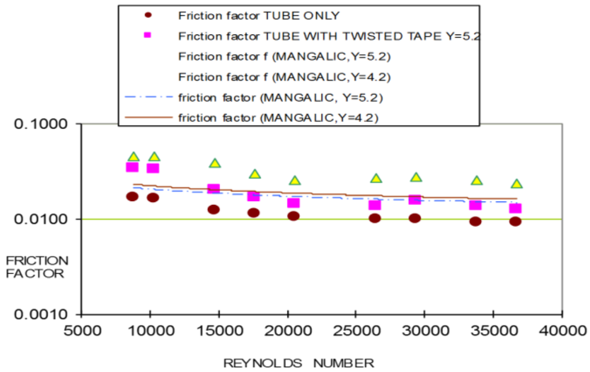


Figure 4 : Re Vs fraction factor

VI. CONCLUSION

The paper is related with experimented enhanced heat transfer technology, citing representative developments in last decades of twentieth century in specific. The authors tried their best for representing literature survey of experimental research carried out worldwide from 1964 till around 2000. The experimentation done for two tapes with Y as 4.2 and 5.2, and concludes that;
1) By experimental methods, in general it is found that the twisted tape inserts improve heat transfer performance of the shell and tube heat exchanger.
2) As per usual trend twisted tapes of lower twist ratios (tighter twists as 4.2) is found to be better. The results are showing Nu to range of 450 above.
3) The overall heat transfer coefficient is a function of Reynolds number (Re) and twist ratio(Y).
4) The friction factors are higher for the heat exchanger with twisted tape inserts as compared with empty tube condition.

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