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Augmentation of Heat Transfer in Laminar Flow Using Full Length Aluminum Twisted Tape

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Abstract*— *Low fluid velocity results in small overall heat transfer coefficient as the rate of heat transfer mainly depends upon the movement of molecules of fluids. Towards the goal of improved thermal management heat transfer augmentation is a subject of vital importance in increasing the heat transfer rate and achieving higher efficiency. The need to increase the thermal performance of heat based equipment like ovens, furnaces, and heat exchangers, thereby effecting energy, material, and cost savings as well as a consequential mitigation of environmental degradation had led to the development and use of many heat transfer enhancement techniques. Sixteen different enhancement techniques have been identified by A.E. Bergles [1], which can be classified broadly as passive and active techniques. Primarily, heat transfer augmentation methods are classified in three broad categories as Active method, Passive method and Compound method. The effectiveness of any of these methods is strongly dependent on the mode of heat transfer (single-phase free or forced convection, pool boiling, forced convection boiling or condensation, and convective mass transfer), and type and process application of the heat exchanger. Several options are available for enhancing heat transfer associated with internal flows. Enhancement may be achieved by increasing the convection coefficient and/or by increasing the convection surface area. The wire inserts or says tape provides a helical roughness element in contact with the tube inner surface. Alternatively the convection coefficient may be increased by inducing the swirl through insertion of a twisted tape. The inserts consist of a thin strip that is periodically twisted through 360 degrees. Tape inserts are inexpensive and can be easily employed to improve the thermal performance of existing system. Introduction of a tangential velocity component increases the speed of the flow, particularly near the tube wall. By coiling the tube the heat transfer may be enhanced without turbulence or additional heat transfer surface area. In this experimental project a continuous twisted insert of Aluminium material is used to study the effect of insert on different parameters like Overall heat transfer coefficient, Reynolds Number, Effectiveness, and the Temperature Variation etc. This paper gives revising the use of such techniques by using twisted aluminum tape to understand the enhancement in rate of heat transfer for pipe flow. Numbers of cases are studied by using heat exchanger with and without inserts, changing the condition of flow as parallel and counter flow and also by changing the path of hot fluid

I. INTRODUCTION

The method of improving the performance of heat transfer system is referred to as Heat Transfer Augmentation or Heat Transfer Intensification. This leads to reduce the size and cost of heat exchanging applications.

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Heat transfer enhancement technology has been developed and widely applied to the equipments like refrigeration, automotive process industry, chemical industry, etc. Many technologies which involve active and/or passive techniques are available for augmentation. The research is carried earlier by W. J. Marnerand, A. E. Bergles [1] which shows the results regarding augmentation of highly viscous laminar heat transfer inside tubes with constant wall temperature. A highly viscous Newtonian liquid, Polybutene 20, was used as the test fluid. The heat transfer results were obtained in a horizontal test section with nearly constant wall temperature. Isothermal pressure drop and heat transfer data were obtained over a wide range of the parameters: Reynolds number. 15.1-575; Prandtl number, 1260-8130; Graetz number, 868-6570; and bulk to wall viscosity ratio, 0.00464-42.5. J. P. Du Plesis and D.G. Kroger[2] in the paper ‘Heat transfer correlation for thermally developing laminar flow in a smooth tube with at twisted tape insert’ gives the complete step by step procedure for the implementation of the final correlative equation.

Influences of the twisted tape insertion on heat transfer and flow friction characteristics in a concentric double pipe heat exchanger have been studied experimentally by Watcharin Noothong, Smith Eiamsa-ard and Pongjet Promvonge[3].

In the experiments, the swirling flow was introduced by using twisted tape placed inside the inner test tube of the heat exchanger with different twist ratios.

While in ‘heat transfer and friction factor characteristics of laminar flow through a circular tube fitted with right and left helical screw-tape inserts’ by P. Sivashanmugam and P.K. Nagarajan [4] have performed experimental investigation on heat transfer and friction factor characteristics of circular tube fitted with right-left helical screw inserts of equal length, and unequal length of different twist ratio. The experimental data obtained were compared with those obtained from plain tube published data. The heat transfer coefficient enhancement for right-left helical screw inserts is higher than that for straight helical twist for a given twist ratio.

An experimental investigation of heat transfer an friction factor of a smooth tube fitted with full length twisted tape inserts for laminar flow have been studied under uniform wall heat flux condition by V. N. Kapatkar, B. Dr. A. S. Padalkar and C. Sanjay Kasbe[5].The experiments has been carried out to study the tape fin effect by using full length tape inserts of different materials

Siva Rama Krishna, Govardhan Pathipaka et al[6]did Experimental investigation of heat transfer characteristics of circular tube fitted with straight full twist insert and presented their work in ‘Heat transfer and pressure drop studies in a circular tube fitted with straight full twist’. The heat transfer coefficient increases with Reynolds number and decreasing spacer distance with maximum being 2 in. spacer distance for both the type of twist inserts. Also, there is no appreciable increase in heat transfer enhancement in straight full twist insert with 2 in. spacer distance. Experiments were carried out in turbulent flow using straight full twist insert with 4 in. spacer and similar trend of increasing Nusselt number with Reynolds number was observed. Performance evaluation analysis was made and the maximum performance ratio was obtained for each twist insert corresponding to the Reynolds number of 2550.

In 'Pressure drop and heat transfer augmentation due to coiled wire inserts during laminar flow of oil inside a horizontal tube' by M.A. Akhavan-Behabadi, Ravi Kumar et al[7], An experimental investigation has been carried out to study the enhancement in heat transfer coefficient by coiled wire inserts during heating of engine oil inside a horizontal tube. The test-section was a double pipe counter-flow heat exchanger.

While in 'Enhancement of heat transfer using varying width twisted tape inserts' by S. Naga Sarada, A.V. Sita Rama Raju, K. Kalyani Radha and L. Shyam Sunder[8]presented the results obtained from experimental investigations of the augmentation of turbulent flow heat transfer in a horizontal tube by means of varying width twisted tape inserts with air as the working fluid. In order to reduce excessive pressure drops associated with full width twisted tape inserts, with less corresponding reduction in heat transfer coefficients.

For decades, many engineering techniques have been devised for improving the convective heat transfer rate from the wall surfaces leading to the compact heat exchanger and increasing the heat transfer efficiency. The work done in this area is enormous as technical literature on the subject, now estimated at over 9000 technical papers and reports, which has been disseminated periodically in numerous bibliographic reports, reviews, and monographs and edited texts as this is very useful thermal processing of biochemical, food, plastic, and pharmaceutical media, to avoid thermal degradation of the end product. The implementations of this technology direct from research laboratories into the commercial industry floor have been more effective than predicted.

II. PROBLEM DEFINITION

Heating or cooling of viscous liquids in the process industries, heating or cooling of oils, heating of circulating fluids in solar collectors, heat transfer in compact heat exchangers are examples of laminar flow heat transfer in tubes. Heat transfer augmentation techniques play a vital role for laminar flow as well as transient flow heat transfer, since the heat transfer coefficients are generally low for laminar flow in plain tubes.

Thermal loads are increasing in a wide variety of applications like microelectronics, transportation, lighting, utilization of solar energy for power generation etc. Micro electromechanical systems (MEMS) technology and nanotechnology are also rapidly emerging as a new revolution in miniaturization. The thermal load control technologies with extended-surface such as fins and micro channels have already reached their limits. Hence, the management of high thermal loads in high heat flux applications offers challenges and the thermal conductivity of heat transfer fluid have become vital.

Traditional heat transfer fluids such as water, engine oil, and ethylene glycol (EG) are inherently poor heat transfer fluids and thus major improvements in cooling capabilities have been constrained.

So it is required to device a system which will conquer the limitations in previous methods by enhancing the heat transfer rate and reducing the size as well as increasing the performance.

III. SET-UP

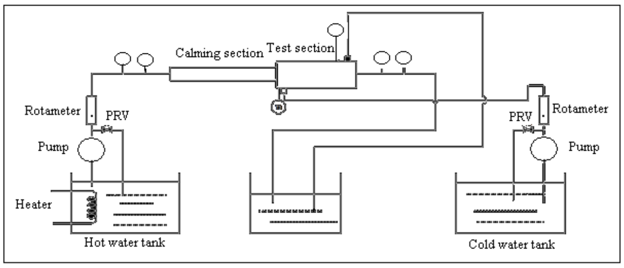

Figure 1 Experimental set-up

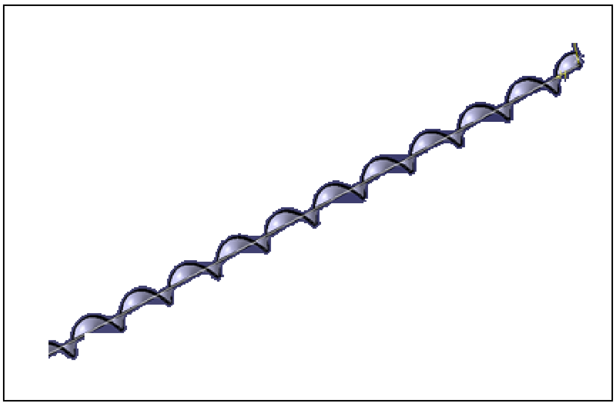

Figure 2 Twisted tape

The schematic diagram of the experimental set-up is shown in Fig.1. It consists of calming section, test section, rotameters and inlet tank with the storage capacity 0.25 m^3 for supplying water, and outlet mixing section. Calming section with the dimension 2000 mm long, 28 mm ID, 32 mm OD made of aluminum tube is used to eliminate the entrance effect. The test section is of smooth stainless steel pipe with the dimension 1800 mm long with 28 mm ID, 32 mm OD. The test section is fitted with jacket for admitting hot or cold water according the case under study. Over the jacket no insulating material is wound as the system we are considering is inlet and outlet pipe of heat exchanger only and we are considering only the heat exchanger as the system. One end of the test section is attached with the calming section, and while the other end is attached with the mixing section (length 200 mm, ID 28 mm, OD 32 mm), where two baffles are provided inside the pipe at a distance of 100 mm from the flange connection for efficient mixing of outlet fluid. Flanges are used for attachments, and 50.90 mm thick non-conducting polypropylene disc is placed in-between the flanges to prevent the heat conduction flow to the calming section, and the mixing section. Also flanges are used to remove the calming section or the mixing section from the test section to insert the twisted inserts. Five RTD PT 100 type temperature sensors are placed one just before the test section for inner and outer pipe, while the other two after the test section for inner and outer pipe to measure the inlet and out let temperature of hot and cold fluids. The hot water tank with the in-built PID controller and heater is to supply hot water at constant temperature. The temperature of hot water is maintained at 60°C to 70°C with the deviation of temperature plus or minus 1°C by Thirstier controlled heating. Also one more RTD PT 100 type temperature sensors is used to measure the hot tank temperature. Rotameters with the flow range 1-100 LPH is provided in the hot water line as well as in cold water lone to measure the flow rate of hot and cold water respectively. Two calibrated Rotameters having flow ranges of (1- 100 LPH) to cover the full laminar ranges are attached to the calming section to measure the flow. The water at constant temperature is being taken from the inlet tank through centrifugal pump as shown in Fig.1. The by-pass valve attached to Rotameter to regulate the flow rate to the test section. The two pressure tapes, one just before the test section and the other just after test section are provided for pressure drop measurement. Pipes are used to flow the water from different sections. Materials used for experimental prototype are aluminum and mild steel.

Technical Details of Twisted Insert

The geometrical configuration of straight full twist inserts is shown in Fig. 2. The straight full twist inserts is made by twisting a strip of 28 mm width manually. The thickness of the strip used for the insert is 3 mm. The twist ratio 'Y' defined as the ratio of length of one twist to diameter of the twist is taken as 4.5. The length of the twisted strip is 1800 mm, same as the test section, full twist single direction is made by twisting in one direction and left–right is made by twisting in alternate directions. The material used for the twisted tape is aluminum with conductive heat transfer coefficient of 236 W/m-K.

Specification of Aluminum tape: (all values are in %)

Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn
0.578	0.616	0.0426	0.0134	0.0937	0.011	0.009	0.057
Ti	Pb	Sn	V	Zr	Sr	Al	
0.0132	<0.05	0.0246	0.0069	<0.005	<0.01	98.3	

IV. SPECIFICATIONS

The Table 1 gives specification of all the material, components and parts which are used in the fabrication of experimental prototype.

Table 1Specifications

Sr. No.	Name of the Component	Specification	Quantity
1	Pump	Kirloskar make – 0.5 HP, single phase self-priming 1"×1"	1
		Kirloskar make – 1 HP, single Phase Higher Temperature withstand (@80 °C) 1 ¼" × 1"	1
2	Rota-meter	'Star' Make Acrylic Body Top Bottom ½" connection Rota-meter, Range – 0 to 100 LPH	2
3	Temperature Indicator	'Shreeji' make 12 point single phase temperature indicator 92 × 92 cutout, Range – 0 to 2000 °C	1
4	Temperature sensing element	Thermocouple wire 1/36" gauge, 'K' type Cr-Al type, Range – 500 °C to 4000 °C	20 meters
5	Heater	1500 Watts	1
6	Insert	Aluminum flat 28mm × 3mm × 1800mm Long with twist	1
7	Tank	Made up of M S 18G sheet, Size – 400 mm × 400 mm × 400 mm	2
8	Piping	'B' class GI piping with elbow, union, barrel nipples, spiral pipe	6 meters
9	Valve	1" Gunmetal ball valve	1

V. CASES OF STUDY

Case I – Hot Water In, Cold Water Out, Parallel Flow, Without Twisted Insert

Case II – Hot Water In, Cold Water Out, Counter Flow, Without Twisted Insert

Case III-Cold Water In, Hot Water Out, Parallel Flow, Without Twisted Insert

Case IV – Cold Water In, Hot Water Out, Counter Flow, Without Twisted Insert

Case V - Hot Water In, Cold Water Out, Parallel Flow, With Aluminum Twisted Insert

Case VI – Hot Water In, Cold Water Out, Counter Flow, With Aluminum Twisted Insert

Case VII-Cold Water In, Hot Water Out, Parallel Flow, With Aluminum Twisted Insert

Case VIII – Cold Water In, Hot Water Out, Counter Flow, Without Twisted Insert

VI. RESULTS

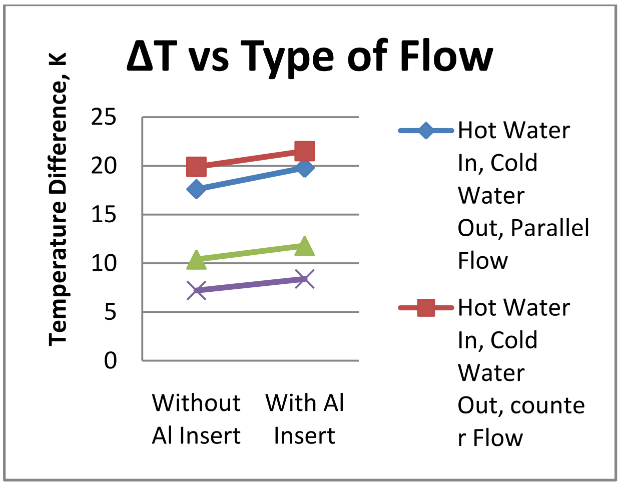

Figure 3 ΔT vs. Type of Flow

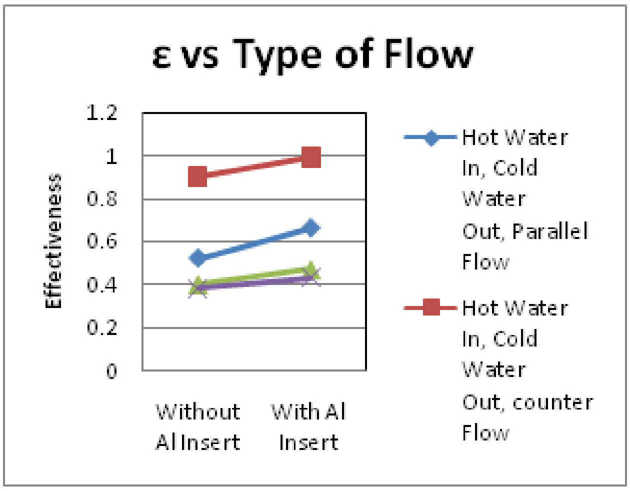

Chart 1- ε vs. Type of Flow

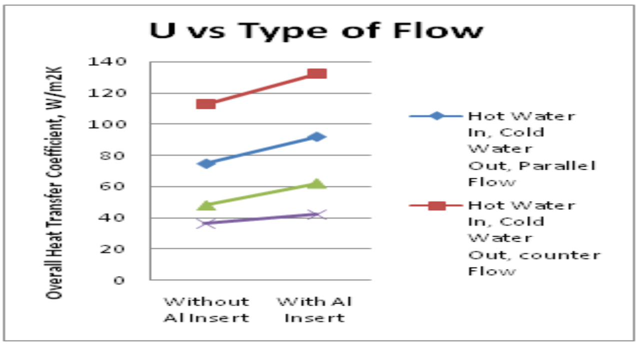

Figure 4 U vs. Type of Flow

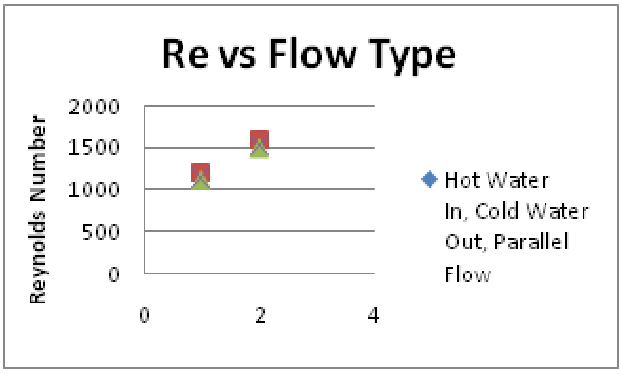

Figure 5 R_e vs. Flow Type

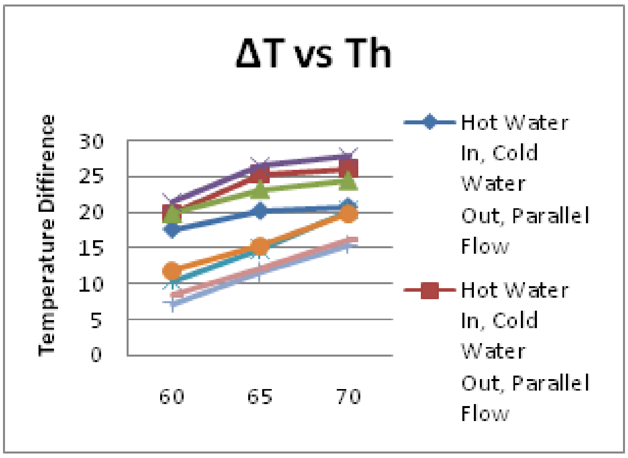

Figure 6 ΔT vs. Th

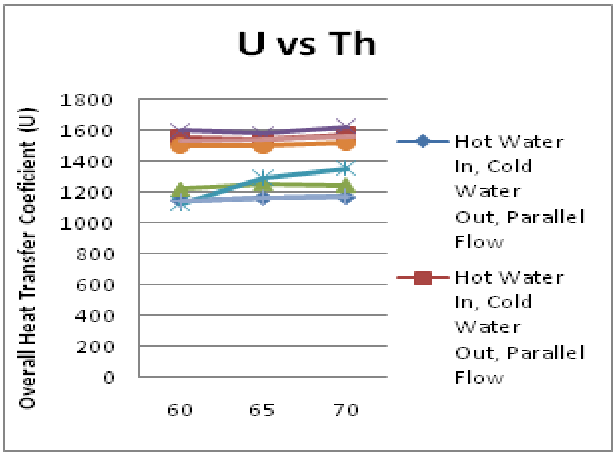

Figure 7 U vs. Th

VII. DISCUSSION AND CONCLUSION

Heat transfer and pressure drop in circular tube fitted with regularly spaced twisted tape elements have been experimentally investigated by S. K. Saha, A. Datta and S.K. Dhal [9] in 'Friction and Heat Transfer Characteristics of Laminar Swirl Flow Through a circular tube fitted with Regularly Spaced Twisted Inserts'. During the study laminar swirl flow of viscous fluid having intermediate Prandlt number range was considered. The swirl was generated by regularly spaced twisted tape elements with single twist in the tape module and connected by thin circular rod. The tape width and the rod diameter were both varied. The effect of higher than zero phase angle between consecutive tape elements have been studied. Heated as well as isothermal friction factor data has been generated. Reynolds number, Prandlt number, twist ratio, space ratio, tape width, rod diameter, and phase angle govern the characteristics. Pinching of tapes in one place rather than connecting the tape elements by rod is better proposition thermo hydraulic point of view. They had found out that reducing tape width results in poor results. In the previous section various results of the experiment have been plotted in the format of tables and graphs. These results can be interpreted in various ways.

1. Effect of Twisted insert on temperature and heat loss

There is obvious increment in the heat transfer and thus in the temperature difference, temperature difference between only hot water inlet and outlet is considered for the study.

21 ^oC of heat loss has been observed in the cross flow with twisted inserts when hot water was flowing through the inner pipe and cold water in the cooling jacket. The observations shows that implementation of twisted insert results in 3 ^oC of hike, which considering the experimental condition is good. It has been also observed that if the temperature of hot water entering the test section is increased, the rate of heat dissipation increases and so does the temperature difference. Similarly, for counter flow heat exchanger results were more impressive than that of parallel flow.

But for the cold water running through the inner pipe, results were poor as compared to hot water flowing through inner pipe. More temperature difference was found in the case of Hot water in, Cold Water Out, Cross Flow with Twisted Tape Insert compared with Cold Water In, Hot Water Out, and Cross Flow with Twisted Tape Insert.

2. Effect of Twisted Insert on Effectiveness

Effectiveness of heat exchanger is analogous to the efficiency of any system. The maximum effectiveness was observed in the case in which hot water was flowing through the inner pipe while cold water was flowing through the jacket. The flow type was counter flow with aluminum twisted insert. The effectiveness was found out to be 0.99. the readings shows that the heat transfer in the case of twisted inserts is always more than that of without inserts that means the effectiveness of the former will be always more than the latter and the calculations proved the same. Similarly, for cross flow the effectiveness is always more than that of parallel flow. As the temperature of the hot water entering the test section is increased there was no any prominent variation in the effectiveness nor in the pattern.

3. Effect of twisted insert on Overall Heat Transfer Coefficient, U

As predicted, it is found that the overall heat transfer coefficient increases by the use of twisted insert. The maximum U was found out to be 134 W/m^2K for cross flow with twisted insert when hot water at 70^oC was flowing through inner pipe and cold water was in cooling jacket. On an average 20 W/m^2K difference was found in the cases with and without insert. As the temperature of hot water entering the test section has been increased the heat transfer rate also increases resulting in temperature drop and increase in Overall Heat Transfer Coefficient. Though the increment is not huge but it is fairly modest considering the range of readings.

4. Effect of twisted Inserts on Reynolds Number

The main aim of the experiment is to enhancing the heat transfer rate of Laminar flow. That means the flow of the output water should not go beyond 2000. The Reynolds number for the case with maximum heat transfer rate, temperature difference, Effectiveness and Overall Heat Transfer Coefficient was found out to be around 1600, while the inlet water has Reynolds number of 1000. As the temperature of hot water entering the test section increased, fluid flow or velocity increased resulting in the increase of Reynolds number.

5. Effect of Twisted Insert on Pressure of Fluid

It is observed that the pressure difference between the inlet and outlet fluid flow increased after the use of twisted inserts. The inlet pressure was kept constant by keeping the flow of fluid constant. The outlet pressure was found to be increased by an amount of 0.01 N/cm^2 as compared to plain flow. The total pressure difference was found out to be 0.03 N/cm^2 between inlet and outlet. This was caused by the friction losses from the insert and resistance to flow due to insert.

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