Enhancement of Heat Transfer Rate by using Twisted Tapes in Tube in Tube Heat Exchanger

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Abstract— Impact of the twisted tape insertion on heat transfer and flow friction characteristics in a concentric double pipe heat exchanger have been studied through experimentally. 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, y = 5.0 and 7.0. The experimental results revealed that the increase in heat transfer rate of the twisted-tape inserts is found to be strongly effect by tape-induced swirl or vortex motion. Experimentation are carried out in three phase. In first phase, the air flow through the smooth circular duct and heat transfer characteristics are observed. In second phase, a GI Sheet twisted tapes with twist ratio of 7.0 are inserted inside the circular duct and the changes in characteristics are observed. These changes are occurred due the destruction of flow behaviour. In third phase, instead of tapes with twist ratio 5.0 is inserted. Heat transfer rate and heat transfer coefficient of both types are also compared to without twisted tapes. Over the range investigated, the maximum Nusselt numbers for using the enhancement devices with y = 5.0 and 7.0 are higher than that for the plain tube. In addition, the effects of the twisted tape on the heat transfer enhancement are also investigated.

Key words: Heat Transfer Coefficient, Twisted Tapes, Twist Ratio

I. Introduction

The issue concerning the thermal management have become essential in numerous industrial fields, so many manufacturer try to design the component as compact as possible which affect more heat generation. This increase in heat generation will reduce the life of device. Hence, device has been accompanied with a crucial requirement for effective cooling schemes. The heat generated within the system must be dissipated to the surrounding to maintain the system at recommended working temperature consequently functioning effectively and reliably. This is especially important in cooling of gas turbine blades, process industries, cooling of evaporators, thermal power plants, air conditioning equipments, radiators of space vehicle and automobiles and modern electronic equipments. The traditional methods of reducing the thermal resistance are by increasing the surface area, or by reducing the thermal boundary layer thickness on the surface to be cooled. Increasing the surface area is effective but it results in the increase in material cost and mass of the device as well. One of the methods to reduce boundary layer thickness is by the generation of passive vortices. In this technique the flow field is altered by an obstacle (Twisted tape, baffles, corrugated rib etc.) to generate a vortex oriented in the direction of the flow. The resulting change in the flow due to an obstacle alters the local thermal boundary layer. The net effect of this modification is an average increase in the heat transfer for the affected area.

The need to increase the thermal performance of the systems, thereby affecting energy, material and cost savings have led to development and use of many techniques termed as “Heat transfer Enhancement”. This techniques also termed as “Heat transfer Intensification”. Augmentation techniques increase convective heat transfer by reducing the thermal resistance in a heat exchanger. Heat transfer augmentation techniques refer to different methods used to increase rate of heat transfer without affecting the overall performance of the system. These techniques broadly divided in two groups: passive and active. Active techniques involve external power input for the enhancement of heat transfer; Examples of active techniques include induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream. Passive techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices, for example, use of inserts, use of rough surfaces, extended surfaces etc.

At present, the technology of the twisted-tape insert is widely used in various industries. Insertion of twisted tapes in a tube provides a simple passive technique for enhancing the Convective heat transfer by introducing swirl into the bulk flow and by disrupting the boundary layer at the tube surface due to repeated changes in the surface geometry. It has been explained that such tapes induce turbulence and superimposed vortex motion(swirl flow) causing a thinner boundary layer and consequently resulting in a high heat transfer coefficient and Nusselt number due to repeated changes in the twisted tape geometry.

II. Literature review

An extensive literature review of all type of heat transfer heat exchanger augmentation techniques using external inserts up to 1985 has been discussed by Bergles [1]. In the following subscriptions, literature involving recent work on passive heat transfer augmentation techniques involving twisted tape, wire coils, dimples, ribs, and fins as an inserts has been reviewed.

A. Twisted Tape in Laminar Flow

Twisted tape increases the heat transfer coefficient with an increase in the pressure drop. Different configurations of twisted tapes, like full-length twisted tape, short length twisted tape, full length twisted tape with varying pitch, reduced width twisted tape and regularly spaced twisted tape have been studied widely by many researchers. S.K. Shah & Dutta.[2] concluded that the short length twisted tapes performs better than the full length twisted tapes because the swirl generated by the short length twisted tape decays slowly downstream which increases the heat transfer coefficient with minimum pressure drop. Regularly spaced twisted tape decreases the friction factor and reduced the heat transfer coefficient but the reduction in heat transfer coefficient is not much because the spacing of twisted tape disturbs the swirl flow. Patil et al. [3] worked on the passive augmentation techniques to increase the rate of heat transfer and from this review they found that twisted tape inserts mixes the bulk flow well and therefore performs better in laminar flow. Because of laminar flow thermal resistant was not limited to thin region. The result also shows twisted tape insert is more effective, if no pressure drop penalty is considered. They also concluded that twisted tape insert is not effective in turbulent flow, because it blocks the flow and therefore pressure drop increases. Saha and A.S. Yadav et al. [4] inserts the half length of twisted tape to influence heat transfer and pressure drop in a U-bend double pipe heat exchanger have been studied experimentally. In the experiment, the swirling flow was introduced by using half-length twisted tape placed inside the inner test tube of the heat exchanger. In this work, the results obtained from the heat exchangers with twisted tape inserts are compared with those without twisted tape. The experimental results revealed that the increase in heat transfer rate of the twisted tape inserts is found to be strongly influenced by tape- induced swirl or vertex motion. The heat transfer coefficient is found to be increased by 40 % with half-length twisted tape inserts when compared with plain heat exchanger. It is also observed that the thermal performance of plain heat exchanger is better than half-length twisted tape by 1.3-1.5 times. Gaikwad and Mali [5] investigated the heat transfer enhancement by using twisted wire brush inserts in double pipe heat exchanger. In this review, the Nusselt number obtained for the tube with twisted wire brush inserts varied from 1.55 to 2.35 times in comparison to those of the plain tube. The inner convective heat transfer coefficient for twisted wire brush inserts is approximately 9-11% higher than that for plain tube. The friction factor values for twisted wire brush inserts decreases by about7-8% than that obtained for plain tube. Manglik and Bergles [6] experimentally studied effect of twisted tape in laminar flow. They concluded that the main reason for heat transfer augmentation by twisted tape inserts are partitioning of tube flow resulting in higher flow velocities as well as reduction in hydraulic diameter increasing the heat transfer coefficient. Lokanath and Misal [7] studied twisted tapes in shell and tube heat exchanger for different fluids. Their study revealed that twisted tapes with tighter twists are expected to give higher overall heat transfer coefficients. K. Shivakumar [8] investigated heat transfer, friction factor, and pressure drop characteristics in a pipe fitted with the Al twisted tape and Cu twisted tape inserts with different twist ratio for laminar flow. The result obtained from this experiment that heat transfer augmentation was enhanced by 1.1 to 1.3 times compared to the Aluminum. The experimental results reveal that for the different material of inserts the Reynold number various from 2570 to 7891 for same twist ratio y= 4.3 of both the materials.

B. Twisted Tape in Turbulent Flow

S. Darewar [9] Investigated heat transfer enhancement by using twisted tape inserts. An aluminum twisted tape of three different twist ratios (y= 3.0, 4.0, and 5.0) were used for the experiment. The effect of fixed and rotary twisted tape on heat transfer enhancement and pressure drop was studied in this experiment. The experimental result shows that for rotary twisted tape inserts at higher RPM heat transfer rate increases as compared to fixed twisted tape. The higher Nusselt number obtained in this experimentation is 2.025 times the smooth pipe without inserts. Sarada [10] obtained the results from experimental investigations of the augmentation turbulent flow heat transfer in a tube by means of varying width twisted tape inserts. Twisted tapes used in the experiment are of five different widths (26-full width, 22, 18, 14 and 10). It was found that the enhancement of heat transfer with twisted tape inserts as compared to plain tube varied from 36 to 48 % for full width (26 mm) and 33 to 39 % for reduced width (22 mm) inserts. Ventisislav D. Zimparov and Plamen J.Penchev [11] evaluated the performance of angled spiraling tape inserts, a round tube inside a twisted square tube and spiraled tube inside the annulus for enhancement in the annulus side in tube-in-tube heat exchanger. The result shows that for most of the cases, angled spiraling tube inserts techniques are most efficient. Smith et.al. [12] Investigated the heat transfer enhancement and pressure loss by insertion of single twisted tape, full length dual and regularly spaced dual twisted tapes as swirl generators in round tube under axially uniform wall heat flux conditions. They found from the experiment that full length dual twisted tapes yield higher heat transfer enhancement than regularly spaced twisted tapes.

III. Experimental Setup

A. Experimental Setup and its Components

Fig. 3.1 shows the actual photograph of the experimental setup. It is a double pipe heat exchanger consisting of calming section, test section, control panel, flow measuring devices, nichrome heater wire and blower fan with speed regulator. Control panel consist of measuring instruments like voltmeter, ammeter, temperature indicator and control devices such as dimmer stat and regulator etc.

The circular tube is used for this investigation and made up of copper. The Blower fan is used to draw the air from entrance to exit section. The flow developed through smooth copper pipe with dimension of 1000 mm in length, inner pipe-26 mm ID and 28 mm OD. Outer PVC pipe dimensions are 900 mm in length, 58 mm ID and 60 mm OD. The outer pipe is well insulated using 10 mm dia. of asbestos rope to reduced heat losses to atmosphere. The uniform flux plate type heater is fabricated from Nichrome wire to heat the air. This heater is connected in series with dimmer stat in order to supply the same amount of heat to heater. A blower fan is used to inject the air through the copper pipe. The air is passed over the Nichrome wire heater and after getting heated this air is flow through copper pipe. The velocity of air is controlled by using regulator which is fixed on control panel. Two pressure taping one just before the test section and the other just after the test section for pressure measurement. Thermocouples are used to measure the inlet and outlet temperatures of water and air, which is indicated on temperature indicator. Experimental set up consist of several component which are briefly describe as follows.

Fig. 3.1: Experimental Setup

1) Circular Duct

Circular tube is the main part where the experimentation is carried out. Circular tube is a hollow duct which has space for twisted tape. In this circular tube, twisted tapes are inserted with twisted tape holder. At the one end exhaust fan is attached and other end is open to atmosphere through which air flows inside the tube. On the front inlet of the tube a heater is provided to heat the air. Two pressure taps are provided across the test section which is connected U-tube manometer. For the fabrication initially circular pipe is size 1220 mm x 25 mm is used.

2) Twisted Tape

The galvanized sheet strip of length 90 cm, width 20 mm and thickness 1.80 mm were taken. Holes are drilled at both ends of every tape so that the two ends could be fixed to the metallic clamps. Desired twist was obtained using a length machine. One end was kept fixed on the tool post of lathe while the other end was given a slow rotary motion by rotating the chuck side. During the whole operation the tape was kept under tension by applying a mild pressure on tool post side to avoid its distortion. Three tapes with varying twists ratios were fabricated (y=5.0 and 7.0) as shown in fig.3.2. The ends portions of the fabricated tapes were cut and holes of 3 mm size were drilled for joining the two tapes. Three tapes with the same twist ratio and twist in the same direction were joined by using small screws with nuts, thus giving a length of 1m, which is sufficient enough for the double pipe heat exchanger, used for the experiment.

Fig. 3.2: Twisted Tapes (y=5.0)

3) Blower Fan

Blower fan is used to produce airflow through the duct. Fan produce air flows with high volume and low pressure. Blower fan is attached at inlet of circular duct which inject the air through pipe. The fan used in project is having specifications as speed- 12000 rpm, the speed of fan is controlled by regulator.

4) Voltmeter

In the experimental set voltmeter is the one of the measuring device which is used to measure the voltage given to the heater. The input supply is connected in series with the heater and voltmeter. The range of voltmeter is 0-440V.

5) Ammeter

Digital Ammeter is used to measure the current flowing through heater. The heater input is measured by voltmeter and ammeter. The range of ammeter is 0-5 Amp.

6) Rotameter

For rotameter calibration, water is collected in a bucket. Weight of water is collected and time of collection is noted to calculate mass flow rate of water and keeping this flow rate constant for further procedure to take the readings.

7) Dimmer Stat

Experimentation is carried out at various input of the heater plate. Dimmer stat is used to vary input given to the heater plate. Dimmer stat is installed on the control panel and coil type dimmer stat is used in the set up.

8) U tube manometer

Pressure drop across the test section is measured by U tube manometer. This U tube manometer is attached to the two pressure taps given across the test section which shows the pressure loss in terms of difference in manometer fluid level. Water is used as a manometeric fluid. U tube manometer consists of opaque glass tube of 8 mm outer diameter and 6 mm inner diameter. This U tube manometer is connected to the pressure tap by polyethylene tube of 8 mm inner diameter and 10 mm outer diameter.

9) Temperature Indicator

One end of thermocouples is attached at the various locations in duct and other ends are connected to temperature indicator to record all readings at one place. Digital temperature indicator is used in order to get the temperature readings from different places of duct.

10) Heater

To heat the air, heater is placed in front of blower. The nichrome wire plate type heater (1500 w) is used in the experiment.

11) Speed Regulator

In experimentation, inlet air velocity is to be set at particular value and such different velocity has to be set for different experimentation. To set different velocity or mass flow rate the speed of fan should be regulated by some means. Speed regulator is connected in series with input supply and blower.

12) Toggle switch

The temperature indicator, voltmeter, ammeter required external power supply which is given through toggle switch. Toggle switch is used to make measuring instrument in ON and OFF mode.

IV. EXPERIMENTATION PROCEDURE

The experimentation is carried out in three phase.

A. Phase 1: Experimentation without Twisted Tapes

1) First experimentation is carried out when no twisted tapes are present inside the circular channel.
2) Set an input (say 118 Volt, 1.6 Amp) to the plate heater with the help of dimmer stat and wait for the temperature to become steady.
3) Start the blower fan and inject the hot air through copper pipe as it passed over the heater. And wait to reach the temperature T1 of test section at the steady state.

4) Velocity is measured with hot wire anemometer by keeping the sensor in flow stream. Note down the reading of temperature indicator and U-tube manometer.
5) Gradually increase the velocity (0.98, 1.12, 1.26, 1.38 m/s) by regulating air flow and note observations for same input.
6) Now change the input by regulating dimmer stat. Experimentation is carried out for two different inputs by regulating the dimmer stat keeping velocity constant.

B. Phase 2: Experimentation with Twisted Tape (Twist Ratio of 5.0)

1) In this phase, solid twisted tape of twist ratio of 5.0 is use to enhance the heat transfer rate through the circular duct.
2) Inserts the spoke of 23mm in length at five location of twisted tape as a holder and ensure tapes should be properly placed.
3) Insert twisted assembly inside the circular duct to cover the test section.
4) Start the set up and follow the same procedure as above and note down the readings.

C. Phase 3: Experimentation with Twisted Tape (Twist Ratio of 7.0)

1) The twisted tapes of twist ratio (7.0) are used in a circular duct.
2) Follow the same procedure as stated above and note down the readings.

V. HEAT TRANSFER ENHANCEMENT TECHNIQUES

Heat transfer enhancement or augmentation techniques refer to the improvement of thermo hydraulic performance of heat exchangers. Existing enhancement techniques can be broadly classified into three different categories.

1) Passive Techniques
2) Active Techniques
3) Compound Techniques

A. Passive Technique

These techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficients by disturbing or altering the existing flow behavior (except for extended surfaces) which also leads to increase in the pressure drop. In case of extended surfaces, effective heat transfer area on the side of the extended surface is increased. Passive techniques hold the advantage over the active techniques as they do not require any direct input of external power. Heat transfer augmentation by these techniques can be achieved by using:

1) Treated Surfaces

This technique involves using pits, cavities or scratches like alteration in the surfaces of the heat transfer area which may be continuous or discontinuous. They are primarily used for boiling and condensing parts of component.

2) Rough Surfaces

These surface modifications particularly create the disturbance in the viscous sub-layer region. These techniques are applicable primarily in single phase turbulent flows.

3) Extended Surfaces

Plain fins are one of the earliest types of extended surfaces used extensively in many heat exchangers. Finned surfaces have become very popular now a day’s owing to their ability to disturb the flow field apart from increasing heat transfer area.

4) Displaced Enhancement Devices

These inserts are used primarily in confined forced convection. They improve heat transfer indirectly at the heat exchange surface by displacing the fluid from the heated or cooled surface of the duct with bulk fluid from the core flow.

5) Swirl flow devices

They produce swirl flow or secondary circulation on the axial flow in a channel. Helical twisted tape, twisted ducts and various forms of altered (tangential to axial direction) are common examples of swirl flow devices. They can be used for both single phase and two-phase flows.

6) Coiled Tubes

In these devices secondary flows or vortices are generated due to curvature of the coils which promotes higher heat transfer coefficient in single phase flows and in most regions of boiling. This curvature of coils makes heat exchangers more compact.

B. Active Technique

These techniques are more complex from the use and design point of view as the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. It finds limited application because of the need of external power in many practical applications. In comparison to the passive techniques, these techniques have not shown much potential as it is difficult to provide external power input in many cases. Various active techniques are as follows:

1) Mechanical Aids

Examples of the mechanical aids include rotating tube exchangers and scrapped surface heat and mass exchangers. These devices stir the fluid by mechanical means or by rotating the surface.

2) Surface Vibration

They have been used primarily in single phase flows. A low or high frequency is applied to facilitate the surface vibrations which results in higher convective heat transfer coefficients.

3) Fluid Vibration

Instead of applying vibrations to the surface, pulsations are created in the fluid itself. This kind of vibration enhancement technique is employed for single phase flows.

4) Injection

In this technique, same or other fluid is injected into the main bulk fluid through a porous heat transfer interface or upstream of the heat transfer section. This technique is used for single phase heat transfer process.

5) Suction

This technique is used for both two phase heat transfer and single phase heat transfer process. In two phase nucleate boiling vapor is removed through a porous heated surface whereas in single phase flows fluid is withdrawn through the porous heated surface.

6) Jet Impingement

This technique is applicable for both two phase and single phase heat transfer processes. In this method, fluid is heated or cooled perpendicularly or obliquely to the heat transfer surface.

C. Compound Technique

A compound augmentation technique is the one where more than one of the above mentioned techniques are used in combination with the purpose of further improving the thermo-hydraulic performance of a heat exchanger.

VI. Results & discussion

The experimentations are carried out on the concentric tube with and without using twisted tapes (i.e. passive heat transfer enhancement methods). Heat transfer coefficient and friction factors are calculated for all cases. The various characteristics are compared for different twisted tapes at constant parameter like Reynolds number and mass flow rate. Results are classified into following three parts. The main aim of study is to increase the heat transfer rate by using various twisted tapes in a tube. During the experimentation heat transfer rate are calculated and compare with each other. From the result it is found that heat transfer rate is more in case of twisted tapes of twist ratio y=5.0 as compare to other two cases. It is observed that degree of turbulence is increases by inserting the twisted tapes inside the tube. Heat transfer rate is increased to greater extend by using twisted tape y=5.0 in a tube. Thermal performance of twisted tapes with twist ratio of 5.0 is good for all ranges of Reynolds number (200383-307545) and input supply.

VII. Conclusion

In this experiment, the various characteristic are studied for the different cases viz. without twisted tapes, with twisted tapes having twist ratio 5.0 and twisted tapes with twist ratio 7.0. These characteristics are compared to each other and the following conclusions are made.

1) The heat transfer in circular tube with both twisted tapes having twist ratio(y=5.0 and y=7.0) is found to be more as compare without twisted tape in a tube. The increased in heat transfer occurs due to more turbulence is generated within the tube by using twisted tapes.
2) Friction factor reduces, as the Reynolds number increases. This is because with increase in Reynolds number, velocity increases. As friction factor is inversely proportional to velocity, friction factor decreases. This friction factor is found to be more in twisted tapes of twist ratio of 5.0.
3) Heat transfer coefficient in a circular tube is near about twice for twisted tape (y=5.0) and 50% for twisted tape (y=7.0) over when no twisted tapes inserts in a tube.
4) Nusselt number is increases as heat transfer coefficient increases, this is because heat transfer coefficient is directly proportional to Nusselt number Nu = (hd/k).
5) The spaced provided between the twisted tapes and surface reduced eddies formation behind the twisted tapes which results in increased heat transfer rate.
6) The enhancement efficiency is increased by 79.11% with twisted tape (y=5.0) as compared to without twisted tape inserts in a tube.

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