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Comparison of the overall heat transfer coefficient value of double pipe heat exchanger without and with various twisted inserts of different twist ratios

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Abstract: *Techniques for heat transfer augmentation are relevant to several engineering applications. In recent years, the high cost of energy and material has resulted in an increased effort, aimed at producing more efficient heat exchange equipment. Furthermore, sometimes there is a need for miniaturization of a heat exchanger in specific applications, such as space application, through an augmentation of heat transfer. For this process a double pipe heat exchanger is chosen which is normally used for improving the process of heat exchange between two fluids which are at different temperatures.*

In an attempt to improve heat exchanger performance in a better way a twisted sheet is inserted into the inner pipe. These types of twisted sheet inserted heat exchangers can be useful in overhead condensers, compression inter stage coolers etc.The main objective of our project is to create turbulence in the hot fluid channel with the help of twisted sheet inserts so that an increase in the heat transfer coefficient can be identified. By conducting experiments, the overall heat transfer coefficient value of double pipe heat exchanger without and with various twisted inserts of different twist ratios will be compared.

Keywords – *Aluminum twisted tubes, Counter flow, Double pipe heat exchanger, Heat exchangers, Heat transfer co-efficient.*

1. INTRODUCTION

1.1 HEAT EXCHANGERS

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other. Heat exchangers are commonly used in practice in a wide range of applications, from heating and air-conditioning systems in a household, to chemical processing and power production in large plants. Heat exchangers differ from mixing chambers in that they do not allow the two fluids involved to mix. In a car radiator, for example, heat is transferred from the hot water flowing through the radiator tubes to the air flowing through the closely spaced thin plates outside attached to the tubes.

In heat exchangers the temperature of each fluid changes as it passes through the exchangers and hence the temperature of the dividing wall between the fluids also changes along the length of the exchanger. Heat exchangers are designed to deliver a certain heat transfer rate for a certain specified condition of flow rates and temperatures. A double pipe heat exchanger is a normal heat exchanger consisting of hot and cold fluid channels aligned properly.

Heat transfer in a heat exchanger usually involves convection in each fluid and conduction through the wall separating the two fluids. In the analysis of heat exchangers, it is convenient to work with an overall heat transfer coefficient U that accounts for the contribution of all these effects on heat transfer. The rate of heat transfer between the two fluids at a location in a heat exchanger depends on the magnitude of the temperature difference at that location, which varies along the heat exchanger. In the analysis of heat exchangers, it is usually convenient to work with the logarithmic mean temperature difference LMTD, which is an equivalent mean temperature difference between the two fluids for the entire heat exchanger.

In general, for any heat exchanger the heat transfer coefficient depends mainly on

- No. of tubes
- Velocities in the tube and shell
- Tube outside diameter
- Baffle spacing
- Baffle cut
- Length of the tubes
- Tube pitch
- Logarithmic mean temperature difference

1.2 CLASSIFICATIONS OF HEAT EXCHANGE PROCESSESS:

Heat exchangers are classified on the basis of nature of heat exchange process, relative direction of fluid motion, design and constructional features, and physical state of fluids

- Direct contact (or open) heat exchangers.
- Indirect contact heat exchangers
  a) Regenerators
  b) Recuperators

1.2.1 Direct contact heat exchangers:

In a direct contact or open heat exchanger the exchange of heat takes place by direct mixing of hot and cold fluids and transfer of heat and mass takes place simultaneously. The use of such units is made under conditions where mixing of two fluids is either harmless or desirable.

Examples:

- Cooling towers.
- Jet condensers.
- Direct contact feed heaters.

1.2.2 Indirect contact heat exchanger:

a) Regenerators
b) Recuperators

Regenerators:

In a regenerator type of heat exchanger the hot and cold fluids passes alternately through a space containing solid particles, these particles providing alternatively a sink and a source for heat flow.

Examples:

- I.C engines and gas turbines.
- Open heart and glass melting furnaces.
- Air heaters of blast furnaces.

A regenerator generally operates periodically (the solid matrix alternately stores heat extracted from the hot fluid and then delivers it to the cold fluid). However, in some regenerators the matrix is made to rotate through the fluid passes arranged side by side which makes the heat exchange process continuously.The performance of these regenerators is affected by the following parameters:

- Heat capacity of regenerating materials.
- The rate of absorption.
- The release of heat.

Advantages:

- Higher heat transfer coefficient.
- Less weight per KW of the plant.
- Minimum pressure loss.
- Quick response to load variation.
- Small bulk weight.
- Efficiency quite high.

Disadvantages:

- Costlier compared to recuperative heat exchangers.
- Leakage is the main trouble; therefore, perfect sealing is required.

Recuperators or surface heat exchangers:

' Recuperators ' is the most important type of heat exchanger in which the flowing fluids exchanging heat are on either side of dividing wall(in the form of pipes are tubes generally). These heat exchangers are used when two fluids cannot be allowed to mix i.e., when the mixing is undesirable.

Examples:

- Automobile radiators.
- Oil coolers; inter coolers, air pre heaters, economizers, super heaters, condensers and surface feed heaters of a steam power plant.
- Milk chiller of pasteurizing plant.
- Evaporators of an ice plant.

Advantages:

- Easy construction
- More economical
- More surface area of heat transfer

- Much suitable for stationary plant

Disadvantages:

- Less heat transfer coefficient
- Less generating capacity
- Soothing problems.

1.3 PHYSICAL STATE OF FLUIDS:

Depending upon the physical state of fluids the heat exchangers are classified as follows:

a) condensers
b) Evaporators

a) Condensers:

In systems involving heat transfer, a condenser is a device or unit used to condense a substance from its gaseous to its liquid state, typically by cooling it. In so doing, the latent heat is given up by the substance, and will transfer to the condenser coolant. Condensers are typically heat exchangers which have various designs and come in many sizes ranging from rather small (hand-held) to very large industrial-scale units used in plant processes. For example, a refrigerator uses a condenser to get rid of heat extracted from the interior of the unit to the outside air. Condensers are used in air conditioning, industrial chemical processes such as distillation, steam power plants and other heat-exchange systems. Use of cooling water or surrounding air as the coolant is common in many condensers.

b) Evaporators:

An evaporator is used in an air-conditioning system to allow a compressed cooling chemical, such as Freon or R-410A, to evaporate from liquid to gas while absorbing heat in the process. It can also be used to remove water or other liquids from mixtures. The process of evaporation is widely used to concentrate foods and chemicals as well as salvage solvents. In the concentration process, the goal of evaporation is to vaporize most of the water from a solution which contains the desired product. In the case of desalination of sea water, the reverse purpose applies; evaporation removes the desirable drinking water from the undesired product, salt. One of the most important applications of evaporation is in the food and beverage industry. Foods or beverages that need to last for a considerable amount of time or need to have certain consistency, like coffee, go through an evaporation step during processing.

2. TYPES OF HEAT EXCHANGERS

The heat exchangers can be broadly divided into various types based on the direction of fluid motion, constructional features of the heat exchanger.

2.1 RELATIVE TO DIRECTION OF FLUID MOTION:

According to the relative direction of two fluid streams the heat exchangers are classified into three categories:

a) Parallel flow or unidirectional flow
b) Counter flow
c) Cross flow

2.1.1 Parallel flow heat exchanger

In a parallel flow heat exchanger, as the name suggests, the two fluid streams (hot and cold) travel in same direction. The two streams enter at one end and leave at other end. The flow arrangement and variation of temperatures of the fluid streams in case of parallel flow heat exchangers are shown in fig. It is evident from the b that the temperature difference between the hot and cold fluids goes on decreasing from inlet to outlet. Since this type of heat exchanger needs a large area of heat transfer, it is rarely used in practice.

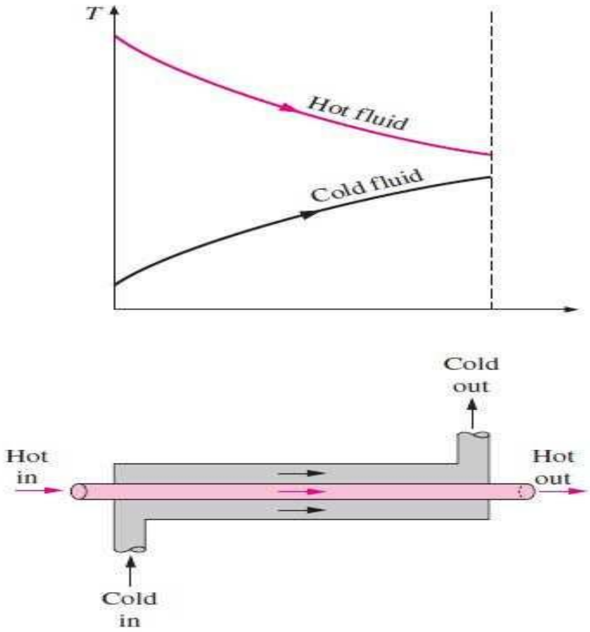
Examples:

1. Oil coolers
2. Oil heaters
3. Water heaters etc.

Advantages of parallel flow:

a) When the two fluids are required to be brought to nearly the temperature.
b) Outlet temperature of the fluid being cooled can reach a limiting temperature. If water is kept above a 32^0 F, freezing can be avoided.

c) Reduce the limiting temperature.



2.1 Parallel flow heat exchanger Disadvantages of parallel flow:

a. The large temperature difference at the ends causes large thermal stresses.
b. The opposing temperature and contraction of the construction materials due to diverse fluid temperature can lead to eventual material failure.
c. The temperature of cold fluid exiting the heat exchanger never exceeds the lowest temperature of the hot fluid.
d. It is less efficient.

2.1.2 Counter flow heat exchangers:

In a counter flow heat exchanger, the two fluids flow in opposite directions. The hot and cold fluids enter at the opposite ends. The flow arrangement temperature distributions for such a heat exchanger are shown schematically in fig. the temperature difference between the two fluids remains more or less nearly constant. This type of heat exchanger, due to counter flow, gives maximum rate of heat transfer for a given surface area. Hence such heat exchangers are most avowed for heating and cooling of fluids.

Advantages of counter flow:

a. The more uniform temperature difference between the two fluids minimizes the thermal stresses throughout the exchanger.
b. The outlet temperature of the cold fluid can approach the highest temperature of the hot fluid.
c. The more uniform temperature difference produces a more uniform rate of heat transfer throughout the heat exchanger.

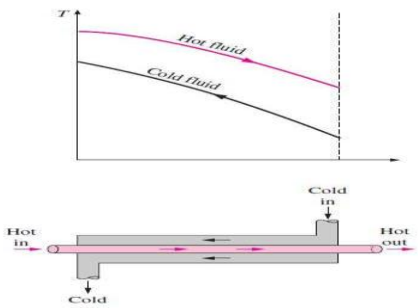
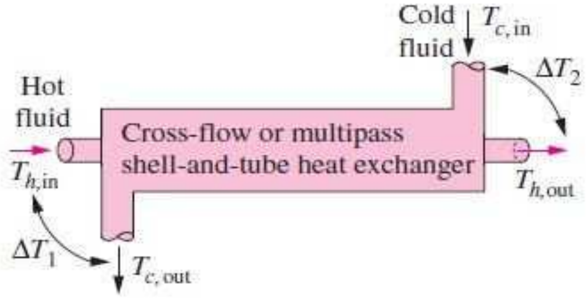


Fig:2.2 counter flow heat exchanger

2.1.3 Cross flow heat exchanger:

In cross flow heat exchangers, the two fluids (hot and cold) cross one another in space, usually at right angles. Fig shows a schematic diagram of common arrangements of cross flow heat exchangers.

Fig: 2.3 cross flow heat exchanger



2.2 BASED ON DESIGN AND CONSTRUCTIONAL FEATURES:

On the basis of design and constructional features the heat exchangers are classified as under:

a) Concentric tubes
b) Shell and tubes
c) Multiple shell and tube passes
d) Compact heat exchangers

Concentric tubes heat exchanger:

In this type two concentric tubes are used, each carrying one of the fluids the direction flow may be parallel or counter as depicted in figure. The effectiveness of heat exchanger is increased by using swirling flow.

- For our experimentation we have chosen double pipe heat exchanger having counter flow where twisted inserts are used.
- A double pipe heat exchanger, in its simplest form is just one pipe inside another larger pipe. One fluid flows through the inside pipe and the other flows through the annulus between the two pipes. The wall of the inner pipe is the heat transfer surface.

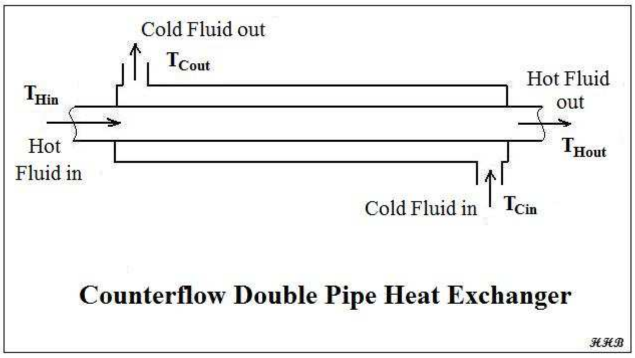


Fig 2.4: Double pipe heat exchange

2.3 USING OF TWISTED INSERTS IN HEAT EXCHANGER:

Heat exchangers have several industrial and engineering applications. The design procedure of heat exchangers is quite complicated, as it needs exact analysis of heat transfer rate. Whenever inserts are used for the heat transfer enhancement, along with the increase in the heat transfer rate, the pressure drop also increases. This increase in pressure drop increases the pumping cost. So to increase heat transfer rate with low cost some augmentation techniques are used.

2.4 DOUBLE PIPE HEAT EXCHANGER WITH TWISTED INSERTS:

In this type of heat exchanger hot fluid is surrounded by cold fluid. The hot fluid is being made to flow in brass hollow channel where as cold fluid is flown in the mild steel channel. In our project for this double pipe heat exchanger for obtaining of better effectiveness, the flow is made to be counter flow. In addition to normal heat exchanger, here we are using the twisted inserted sheets which are of different twist ratios are inserted in the hot fluid channel. For insertion and removal of these twisted inserts one end of the hot fluid channel is provided with a removable cap. The experimentation is done without any inserts and with inserts of different twist ratios. Due to the inserts the heat transfer coefficient is found to be improved as the twisted sheet inserts are creating turbulence, which makes the hot fluid to exchange heat with cold fluid very effectively. In general double pipe heat exchanger has many advantages related to its construction simplicity and its operating conditions. The twisted sheet inserted double pipe heat exchanger enhances its merits. The advantages and disadvantages of this twisted insert double pipe heat exchanger are as following:

ADVANTAGES:

- Complex swirl flow on the shell side induces the maximum turbulence to improve heat transfer.
- Powerful tube side turbulence is achieved even at high viscosities and/or low velocities.
- Effectiveness can be improved.
- Laminar flow of fluid can be converted inside the equipment by the use of twisted inserts.

DISADVANTAGES:

- Proper opening should be provided for inserting and removing of twisted sheets inside the hot channel.
- Because of creation of turbulence inside the hot fluid channel, the velocity of hot water will be more, which makes difficult to operate the system at higher flow rates.
- If the inserts are not twisted properly, they may become the obstacle for proper flow of fluid thereby causing the problem.

APPLICATIONS:

- Power systems.
- Food processing systems.
- Chemical reactors.
- Space or aeronautical applications.
- Oil coolers of heat engines.
- Condensers.
- Evaporators.
- Milk chillers of pasteurizing plant

3. EXPERIMENTATION

3.1 Preparation of Experimental Setup & Experimentation

The major components in the double pipe heat exchanger are

1. Brass rod
2. Mild steel rod
3. Aluminum twisted sheets.

The hot fluid is made to flow through the brass rod, having thermal conductivity of 1100W/m-K. for better heat transfer rate brass is being selected for the carrying of hot fluid. The cold fluid is to made to flow through the mild steel channel, having thermal conductivity of 50W/m-K. for the twisted inserts initially aluminum sheets are taken and are twisted to different twist ratios.

Table 3.1: specifications of components.

From the heat transfer view point, smaller diameter tubes yield higher heat transfer coefficients and result in a more compact exchanger. However, large diameter tubes are easier to clean and more rugged. The foregoing common sizes represent a compromise. For chemical cleaning, smaller sizes can be used provided that the tubes never plug completely. Large tube diameters are often required for condensers and boilers.

3.2 ***ALUMINUM SHEETS TWISTING***

For creating the turbulence in the hot fluid channel flow, twisted sheets are inserted. Here we have twisted the aluminum sheets to different twist angles to check the variation in the effectiveness of heat exchanger when inserts are kept in the fluid flow channel.

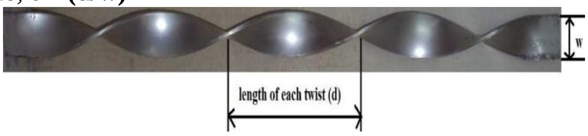
1. For twisting the sheets initially a long sheet of aluminum is taken and is cut into 3 equal strips of width 30mm and length 740mm.
2. Then each sheet is twisted to different twist ratios using the fitting equipment, a PVC tube (support) of length nearly 720mm and a handle is used in the process.
3. One aluminum strip is taken and is kept in the PVC tube which is shorter in length to the strip.
4. Then one end of the strip is fixed in the fitting equipment base tightly in vertical position and the other end is provided with the handle.
5. Then the handle is rotated manually completely to make a turn, then each complete turn gives one twist.
6. The 3 strips are being twisted in the similar way varying the no of turns so that each twist is having different twist ratios.
7. The twists are being made assuming to have different twist ratios which can be done by varying the no of rotations of the handle in the equipment.
8. The twisting should be done properly as per requirement making sure that there are no extra turns.

9. Following these steps will result in the twisted strip of aluminum as shown in below figure which is the required component.
10. The procedure is continued for all the 3 strips, and the strips are made of different twist ratios, which can be obtained by varying the no of rotations.
11. The aluminum strips that were twisted in different rotations of handle are as shown in the figure below

3.3 CALCULATION OF TWIST RATIOS:

For measuring the twist ratios, initially the length of each twist in a strip is to be calculated, say it be'd'. The length of each twist in each 3 strips will be calculated to be d_1, d_2, d_3.
The values for the strips are 136mm, 179mm, 245mm respectively. The width of each strip is known to be 'w' = 30mm. The ratio of length d and width w gives the twist ratio.

Twist ratio, **t = (d/w)**



The twist ratios are calculated to be **4.53, 5.96, and 8.16** respectively. These twisted inserts are used in the double pipe heat exchanger hot fluid channel where there one end of the brass rod can be open and closed whenever needed. This is provided for inserting and removing of twisted inserts.

3.4 EXPERIMENTAL PROCEDURE:

The experimental setup is fabricated, where brass is provided for carrying of hot fluid and mild steel is provided for carrying of cold fluid. The valves of inlet and outlet are provided for both the tubes such that the flows of hot and cold fluids are to be in counter flow. The flow is made to be counter flow for the double pipe heat exchanger for obtaining better results. Initially the water is being supplied to both the pipes inlet valves, where the normal water (at room temp) flows into both the pipes. We have the outlet collection of both hot and cold fluids at different ends. At the starting of the experiment the flow rate for both the outlets are measured, i.e., the time taken for collection of 1000 ml of water at the output is calculated in terms of time (seconds). The flow rates for both hot and cold fluids are made such that there is a difference between their flow rates. The cold fluid is made to have better flow rate than hot fluid because the more the existence of hot fluid movement in the heat exchanger, more is the chance for heat exchange in the system. Then the water which is flowing into the hot fluid pipe is heated with the help of heater provided with the system. Here the system is left to operate, with water flowing into the inlets of both pipes and coming out of outlets of the pipes. During this in and out flow process, the hot fluid gains temperature as it is being heated. Initially no insert is provided inside the double pipe heat exchanger. A reading is taken at that moment which is the reference value. The readings that were taken are temperatures of cold and hot fluids at their inlets and outlets. The further readings are taken at an interval time of 10 to 15 minutes. The readings are taken till an equilibrium condition is obtained. The outlet and inlet temperatures of hot and cold fluids at steady state are taken. Then the hot and cold fluid inside the apparatus is completely flown out of the pipes. Now the brass pipe end is opened, which is provided with a cap. Here one of the twisted sheets of aluminium is inserted into the brass pipe and the cap is closed tightly. Now the above procedure of flowing of hot and cold fluids with known flow rate and obtaining of readings at steady state is carried out. The obtained values can be useful for calculating the effectiveness of the heat exchanger under such conditions. Again the total fluid is flown out and the procedure is continued with other 2 twisted sheets, readings are obtained and calculations at such conditions are done. Then the required comparisons are made related to the different operating conditions in the double pipe heat exchanger. The effectiveness is compared for double pipe heat exchanger without and with twisted inserts of different twist ratios.

3.3 LINE DIAGRAMS OF DOUBLE PIPE HEAT EXCHANGER WITH TWISTED INSERTS:

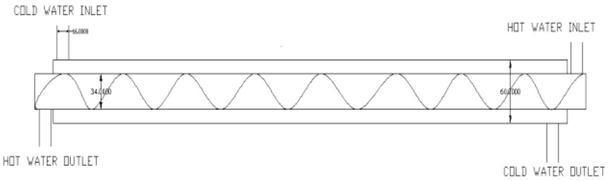


Fig 3.1: Model diagram with more no of twists.

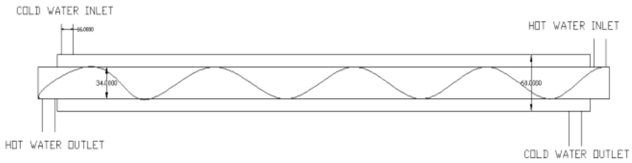


Fig 3.2: Model diagram with medium no of twists.

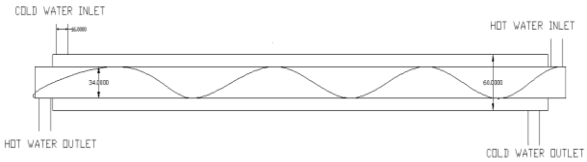


Fig 3.3: Model diagram with less no of twists.

4. RESULTS & DISCUSSIONS

The results have been obtained through various experiments and all the input and output data are being stated as follows:

The flow rates of hot and cold fluids at their outlets are calculated and tabulated.

Fluid	Quantity (ml)	Time(sec)
Hot water	1000	15
Cold water	1000	25

Table 4.1: Flow rates

Flow rate of hot fluid = 0.032 Kg/Sec

Flow rate of cold fluid = 0.048 Kg/Sec

The flow rate is kept constant for all the experiments where it is done without and with twisted sheets inserts of various twist ratios.

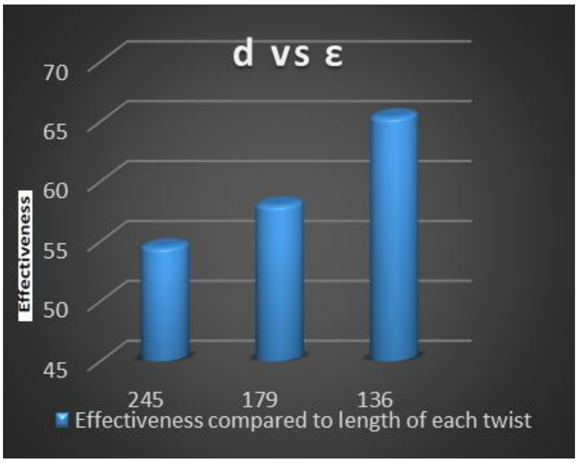
The effectiveness and heat transfer coefficient values are calculated accordingly to the values obtained at steady state.

Twist ratio	Effectiveness
No twist inserted	50%
8.16	54.5%
5.6	58%
4.53	55.3%

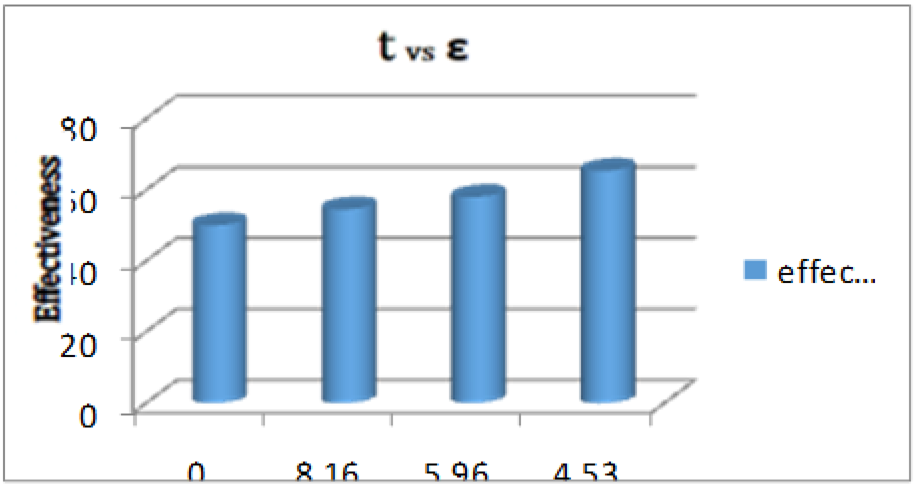
Table 4.2: Readings of all experiments.

Graphs have been plotted with obtained results taking the parameters of effectiveness, twist ratios and length of each twist.

Graph plotted between effectiveness of heat exchanger and length of each twist



Graph plotted between effectiveness of heat exchanger and length of each twist:



5. Conclusion

The inclusion of twisted inserts into the hot fluid pipe of double pipe heat exchanger in counter flow resulted in an increase in its effectiveness. The effectiveness is improved with decrease in the length of each twist (no of turns) and decrease in the twist ratio. The increase in the effectiveness value of the heat exchanger is due to the creation of turbulence in the hot fluid channel using the twisted sheets inserts of different twist angles.

The effectiveness of heat exchanger without inserts = **50%**

The effectiveness of heat exchanger with inclusion of twists

Twist ratio	Effectiveness
8.16	54.5 %
5.96	58 %
4.53	65.38%

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