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# Modelling of a Parallel and Counter Flow Heat Exchanger

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A B S T R A C T

Heat exchangers are one of the important devices in cooling and heating processes in factories, industries, transport and other applications. They are found in large constructions to support cooling processes such as in fossil fuel power plants. A double pipe heat exchanger comprising of both parallel and counter flow always comprise of very high cost ranging around **50,000** rupees and more in the market as it is fabricated with highly expensive materials consisting of highly heat resisting steel alloys. Since vapour state working fluid is not required by the labs, high heat strength materials would not be optimal. Fabricating the double pipe heat exchanger with minimum cost is the main objective of the present work. It has been fabricated with optimal cost by making modifications in the design by replacing the outer pipe with optimal material having the least cost and best quality which is made suitable for the purpose of the lab.

*Keywords:* Double pipe heat exchanger, Copper pipe, CPVC Pipe, Overall heat transfer coefficient, heat transfer rate, parallel flow, counter flow, thermal conductivity

## 1. Introduction

Heat exchanger is a device which facilitates the transfer of heat from hot fluid to cold fluid without mixing hot and cold fluid. Heat exchangers are used in many engineering processes like those in refrigerating and air conditioning systems, power systems, food processing systems, chemical reactors and space or aeronautical applications.

As the fluid passes through the heat exchanger, the temperature of each fluid inside it changes while it passes through the exchangers and so does the dividing wall temperature between the fluid changes along its length. Heat transfer rate is the major measure of a heat exchanger and a double pipe heat exchanger is one such simplest form of heat exchanger consisting of hot and cold fluid paths aligned in a perfect way.

It is always convenient to work with an overall heat transfer coefficient U in the analysis of heat exchangers. The magnitude of temperature difference of two fluids at a location which varies along the length of heat exchanger is dependant upon the rate of heat transfer at that location. which varies along the heat exchanger. It is always advisable to follow the logarithmic mean temperature difference LMTD as it indicates the mean temperature difference between any two fluids.

### 1.1 Classification of heat exchangers:

Heat exchangers are classified based on different aspects like the nature of heat exchange processes, depending on the flow configuration and based on its type.

#### 1.1.1 Nature of heat exchange process:

a) Direct contact type heat exchanger

In this heat exchanger, complete mixing of heat and mass transfer takes place simultaneously with direct mixing of hot and cold fluids. Some of the examples are water cooling towers, jet condensers in steam plants and direct contact feed heaters, etc.

b) Indirect Contact Heat Exchanger

These heat exchangers are further classified into two types:

a) Regenerators: Here hot and cold fluids flows alternately when hot fluid passes, the heat transfer to the solid matrix and then stopped the flow of hot fluid, next cold fluid is passed on the matrix which takes heat from solid matrix. Examples are open hearth and blast furnaces.

b) Recuperators: The cold fluid flows simultaneously on either side of the separating wall. Examples are super heaters, condensers, economizers and air pre-heaters in steam power plants and automobile radiators.

#### 1.1.2 Relative Direction of motion of fluids

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

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1.1.3 Parallel Flow Heat Exchanger

Parallel flow heat exchangers, also referred to as co current flow heat exchangers are heat exchanging devices in which hot and cold fluids move parallel to and in the same direction as each other. Although this configuration typically results in lower efficiencies than a counter flow arrangement, it also allows for the greatest thermal uniformity across the walls of heat exchanger. From the below figure it is understood that the difference between the temperature of hot and cold fluids goes on decreasing from inlet to outlet. This type of heat exchanger needs more available space and is so less used.

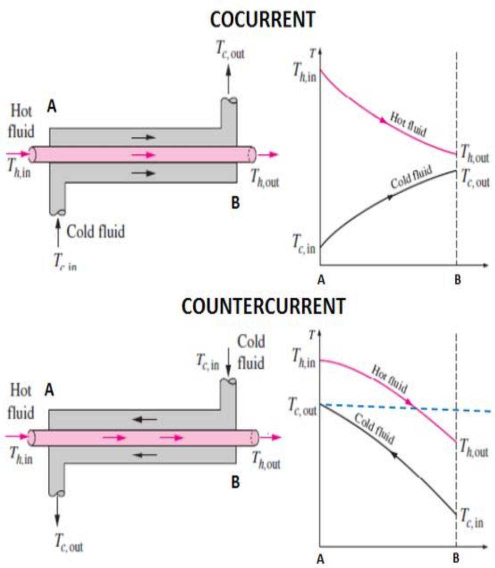


**Figure1.Types of Flows in Double Pipe Heat Exchanger**

1.1.4 Counter Flow Heat Exchangers

Counter flow heat exchangers, also known as counter-current flow heat exchangers are designed such that the fluids move anti-parallel which means parallel but in opposite directions to each other within the heat exchanger. The hot and cold fluids enter at the opposite ends. 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. The most commonly employed of the flow configurations, a counter flow arrangement typically exhibits the highest efficiencies as it allows for the greatest amount of heat transference between fluids and consequently the greatest change in temperature.

**Materials used in fabrication of heat exchanger :**

1. Inner pipe : Copper (Inner diameter = 24.6mm , Outer diameter = 25.4mm)
2. Outer pipe :CPVC (Inner diameter = 50.25mm , Outer diameter = 50.8mm)
3. CPVC ball valves
4. CPVC elbow pipe

The Hot Fluid is made to flow through the copper rod, having thermal conductivity of 385 w/m k for better heat transfer and also resists corrosion, oxidation. The cold fluid is made to flow through CPVC channel, having thermal conductivity of 0.139W/m k which is economical and non-corrosive.

From the heat transfer view point , smaller diameter tubes yield higher heat transfer coefficients and result in a more compact heat exchanger. However ,larger diameter tubes are easier to clean and more rugged. 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.

**Figure 2. Experimental Setup**

**Fabrication of double pipe heat exchanger :**

Inner copper pipe (1inch) is kept inside the outer CPVC pipe(2 inch) by using 2-inch x 1-inch reducer. Cross joints are used for flow inlet and outlets of cooling water. CPVC (1 inch) pipe is used for connection from the geyser to the inner copper pipe. Elbow pipe is used at the bend of geyser to the inne pipe. Thermocouples are placed near the inlet and outlets for the temperature readings.

- **<u>2. Literature Review</u>**

**K. Simhadri et al [1]**: Their paper revealed about improving the the heat exchanger performance by inserting a twisted sheet into the inner pipe. Their main objective was 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. They conducted several experiments and the overall heat transfer coefficient value of double pipe heat exchanger without and with various twisted inserts of different twist ratios are compared. To obtain better effectiveness they considered counter flow and in addition to these twisted inserted sheets of different twist ratios are inserted in the hot fluid channel. This journal explained various merits and demerits of twisted sheets inside a double pipe heat exchanger and its various applications

**S.Perumal et al [2]** performed an experimental study on heat transfer, friction factor and thermal performance of concentric tube heat exchanger using different enhancement techniques.Various enhancement methods like rough surfaces, coiled tubes, surface tension devices are used to improve the performance of double pipe heat exchanger.These are used to augement the heat transfer by creating turbulence in fluid flow.

**Idongesit Effiong Sampson et al [3]** performed an experimental investigation on design and operation of double pipe heat exchanger for both parallel and counter flows.The heat exchange duty allows calculation of log mean temperature difference and that together estimated overall heat transfer coefficent allows calculation of the required heat transfer surface area.Then pipe sizes, pipe lengths and number of bends can be determined.The counter flow enhances more area of heat transfer.

**Timothy J. Rennie et al [4]** performed an experimental study of double pipe helical heat exchanger with parallel and counter flow configuration. Overall heat transfer coefficients were calculated and heat transfer coefficients in the inner tube and the annulus were determined using Wilson plots. They calculated a Nusselt numbers for the inner tube and the annulus. Heat transfer rates, however, are much higher in the counter flow configuration, due the increased log mean temperature difference.

**Paisarn Naphon et al [5]** investigated a heat transfer characteristics and the pressure drop in the horizontal double pipes with twisted tape insert. The twisted tape is made from the aluminium strip with thickness of 1 mm and the length of 2000 mm.R22 is used as the refrigerant for chilling the water. They compared tube with twisted insert to without twisted tape. The twisted tape insert has significant effect on enhancing heat transfer rate. However, the pressure drop also increases. The heat transfer rate increases with increasing tube-side Reynolds number.

**N. R. Chaudhari et al [6]** Their paper revealed about the optimal design of the heat exchanger which has been formulated as a geometric programming with a single degree of difficulty. Although the necessary equations for heat transfer and the pressure drop in a double pipe heat exchanger are available, using these equations the optimization of the system cost is laborious. Their main objective was to optimise the design and cost of the heat exchanger. Since the optimal design minimizes the weighted sum of the heat transfer cost, the pumping cost and the cost of the utility used, by changing the weights one can achieve higher heat transfer by appropriate changes.

**Patel et al [7]** Double pipe heat exchanger is one of simplest type of heat exchanger, generally used for the purpose of sensible heating or cooling. In this paper it describes the different techniques which may help to enhance the heat transfer rate. Heat exchangers are modified in space of annular, also using Nano particle in water and compared with the conventional heat exchanger. Double pipe heat exchanger is practically investigated and results are validated with Ansys CFD software. Results shows that heat transfer rate of modified heat exchanger are higher than the conventional heat exchanger.

**Anup Kumar Dwivedi et al [8]** experimented and analysed thermal conductivity,heat transfer rate and overall heat transfer rate of different materials like copper, aluminium and steel. It was found that copper has high magnitude in all the above mentioned properties in both parallel and counter flow.

## 2 Analysis and Experimental Procedure

Heat exchangers are used to transfer that energy from one substance to another. In process plants it is necessary to control the temperature of incoming and outgoing process streams. These streams can either be gases or liquids. Heat exchangers raise or lower the temperature of these streams by transferring heat to or from the stream.

As with any process the analysis of a heat exchanger begins with an energy and material balance. Before doing a complete energy balance a few assumptions can be made. The first assumption is that the energy lost to the surroundings from the cooling water or from the Ubends in the inner pipe to the surroundings is negligible. We also assume negligible potential or kinetic energy changes and constant physical properties such as specific heats and density.

These assumptions also simplify the basic heat-exchanger equations.

**Procedure :**

- ✔ Initially the geyser is set to a certain temperature keeping all the valves in closed position.
- ✔ The valve is then opened after reaching the requied temperature.
- ✔ The experiment is first done in accordance with the parallel flow by keeping both the hot fluid and cold fluid flow in same direction.
- ✔ The temperature readings are noted for parallel flow
- ✔ Then the heat exchanger is changed to counter flow using the change over mechanism.
- ✔ The temperature readings are noted down for counter flow type.
- ✔ The calculations are then performed an the overall heat transfer coefficient of the heat exchanger is calculated.

- **4 . Observations and Calculations**

**Overall Heat Transfer Coefficient**

Overall heat transfer coefficient is used to find out the heat transferred from the inner pipe to the outer pipe. it consists of all the conductive and convective resistances (k and h respectively) between inner fluid and outer fluid.

**Overall heat transfer coefficient to be calculated by using**

q= uA$\Delta t_m$

u = q/A$\Delta t_m$ Kcal/hr.$m^2$℃

Calculated $U_i$ based on $A_i = \pi d_i$L

$U_o$ based on $A_o = \pi d_o$L

U = ($U_i$+$U_o$)/2

**Calculation of Heat transfer rate is:**

$Q_h$ = Heat transfer rate from hot water

= $M_h C_{ph}(t_{hi}$-$t_{ho})$ KJ/sec

$Q_c$ = Heat transfer rate to the cold water

= $M_c C_{pc}(t_{co}$-$t_{ci})$ KJ/sec.

Q = $\left(\frac{Q_h+Q_c}{2}\right)$ KJ/sec.

**LMTD**: When heat capacities of both streams are constant and there is no phase change at constant pressure for streams that contain a single component: For counter current flow, the logarithmic mean temperature difference is given

LMTD-logarithmic mean temperature difference which can be calculated as per the following formula:

LMTD = $\Delta t_m = \frac{(\Delta t_i - \Delta t_o)}{ln\left(\frac{\Delta t_i}{\Delta t_o}\right)}$

Where $\Delta t_i$ = $t_{hi}$ -$t_{ci}$ (for parallel flow)

= $t_{hi} - t_{co}$ (for counter flow)

$\Delta t_o$ = $t_{ho}$ - $t_{co}$ (for parallel flow)

= $t_{ho}$ - $t_{ci}$ (for counter flow)

**Parallel Flow:**

Where

$t_{hi}$ = 45.5 Temperature of Hot (fluid) water input °C

$t_{ho}$ = 39.5 Temperature of Hot (fluid) water output °C

$t_{ci}$ = 31.5 Temperature of cold (fluid) water input °C

$t_{co}$ = 37.5 Temperature of cold (fluid) water output ℃

Inner diameter of copper $d_1$= 24.6 mm

Outer diameter of copper $d_2$ = 25.4 mm

Length of the Heat Exchanger (L)= 1199 mm

Area of Inner Tube $A_i$= $\pi d_1$L=∏ *24.6*1199 =92738.2mm²

Area of Outer Tube $A_o$=$\pi d_2$L=∏*25.4*1199 =95754.6mm²

Hot Water Flow Rate($M_h$) = 0.0408 kg/sec

cold water Flow Rate($M_o$) = 0.0304 kg/sec

for water C $_{ph}$ = C $_{pc}$= C $_p$= 4.187 KJ/Kg.K

**1.Heat Transfer rate**:

$Q_h$ = Heat transfer rate from hot water

= $M_h C_{ph}(t_{hi}$-$t_{ho})$ KJ/sec

= (0.040816)(4.187)(45.5-39.5)

=1.0242 KJ/sec

=1024.2 J/sec

$Q_c$= Heat Transfer rate to the cold water

= $M_c C_{pc}(t_{co}$-$t_{ci})$ KJ/sec.

= (0.03048) (4.187) (37.5-31.5)

= 0.7647 KJ/sec

= 764.7 J/sec

q=($Q_h$+$Q_c$)/2

=894.45 W

**2. LMTD** - logarithmic mean temperature difference which can be calculated as per the following

**Formula:**

LMTD = $\Delta t_m = \frac{(\Delta t_i - \Delta t_o)}{ln\left(\frac{\Delta t_i}{\Delta t_o}\right)}$

Where $\Delta t_i$ = $t_{hi}$ -$t_{ci}$ (for parallel flow)

=45.5-31.5

=14 K

$\Delta t_o$ = $t_{ho}$ - $t_{co}$ (for parallel flow)

= 39.5-37.5

=2 K

$\Delta t_m = \frac{(\Delta t_i - \Delta t_o)}{ln ln\left(\frac{\Delta t_i}{\Delta t_o}\right)}$

=(14-2)/ln(14/2)

=6.16 K

**3.Overall heat transfer coefficient can be calculated by using**

Q=UA $\Delta T_m$

u=$\left(\frac{q}{A * \Delta T_m}\right)$ KJ/sec.mm$^2$.K℃

$u_i=\left(\frac{q}{A_i \Delta T_m}\right)$

=1564 W/m$^2$K

$u_o=\left(\frac{q}{A_o \Delta T_m}\right)$

=1514.2 W/m$^2$K

$u=(u_i+u_o)/2$

u=1539.1 W/m$^2$K

**Counter Flow:**

Where

$t_{hi}$ = 45.2 Temperature of Hot (fluid) water input ℃

$t_{ho}$ = 38.2 Temperature of Hot (fluid) water output ℃

$t_{ci}$ = 31.2 Temperature of cold (fluid) water input ℃

$t_{co}$ = 41.2 Temperature of cold (fluid) water output ℃

Inner diameter of copper $d_1$= 24.6 mm

Outer diameter of copper $d_2$ = 25.4 mm

Length of the Heat Exchanger (L)= 199 mm

Area of Inner Tube $A_i= \pi d_1 L$ =92738.2mm$^2$

Area of Outer Tube $A_o=\pi d_2 L$ =95754.6mm$^2$

Hot Water Flow Rate($M_h$) =0.0408kg/sec

cold water Flow Rate($M_c$) =0.03048kg/sec

for water $C_{ph}= C_{pc}= C_p$=4.187 KJ/KgK

**1.Heat Transfer rate**:

$Q_h$ = Heat transfer rate from hot water

= $M_h C_{ph}(t_{hi}$-$t_{ho})$ KJ/sec

= (0.0408)(4.187)(45.2-39.2)

=1.0242 KJ/sec

=1024.2 J/sec

$Q_c$= Heat Transfer rate to the cold water

= $M_c C_{pc}(t_{co}$-$t_{ci})$ KJ/sec.

= (0.03048) (4.187) (37.2-31.2)

= 0.7647 KJ/sec

= 764.7 J/sec

$q=(Q_h+Q_c)/2$

=894.45 W

2. LMTD- logarithmic mean temperature difference which can be calculated as per the following

**Formula:**

LMTD = $\Delta t_m = \frac{(\Delta t_i - \Delta t_o)}{ln\left(\frac{\Delta t_i}{\Delta t_o}\right)}$

Where $\Delta t_i= t_{hi}$-$t_{co}$ (for counter flow)= 4 K

$\Delta T_o = t_{ho}$-$t_{ci}$ (for counter flow) =7 K

LMTD = $\Delta t_m = \frac{(\Delta t_i - \Delta t_o)}{ln\left(\frac{\Delta t_i}{\Delta t_o}\right)}$

$=\left(\frac{4-7}{ln\left(\frac{4}{7}\right)}\right)$

=5.36 K

**3.Overall heat transfer coefficient can be calculated by using**

q=uA $\Delta$Tm

u=$\left(\frac{q}{A * \Delta T_m}\right)$ KJ/sec.mm$^2$.K℃

$u_i=\left(\frac{Q}{A_i \Delta T_m}\right)$

=1800 W/m$^2$K

$u_o=\left(\frac{q}{A_o \Delta T_m}\right)$

=1789 W/m$^2$K

$u=(u_i+u_o)/2$

u=1794.5 W/m$^2$K

**Precautions**

- Valves which must be opened, and which must be in closed state should be considered before starting the experiment.
- Reading after attaining steady only be used for calculations
- Care should be taken while measuring hot water at the outlet for flow rate

**Results**

The overall heat transfer coefficient of the parallel and counter flow heat exchanger is

For counter flow= U=1794.5 W/m$^2$K

For parallel flow= U=1539.1 W/m$^2$K

## 3 Conclusions

The complete design and fabrication of the parallel and counterflow heat exchanger was done around 10000 rupees. And the calculations of the double pipe heat exchanger have been done.

- From the study the following conclusions have been drawn:
- The overall heat transfer coefficient of the heat exchanger for counter flow was found to be U=1794.5 W/m$^2$K
- The overall heat transfer coefficient of the heat exchanger for parallel flow was found to be U=1539.1 W/m$^2$K
- From the above values it is concluded that the heat transfer in counter flow arrangement is more than that of in parallel flow arrangement

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