# TITLE: CONCENTRIC TUBE HEAT EXCHANGER

## 1.0 INTRODUCTION

A heat exchanger is an equipment in which heat exchange takes place between 2fluids that enter and exit at different temperatures. The main function of heatexchanger is to either remove heat from a hot fluid or to add heat to the cold fluid. The direction of fluid motion inside the heat exchanger can normally categorised as parallel flow, counter flow and cross flow. In this experiment, we study only the parallel flow and counter flow. For parallel flow, also known as co-current flow, both the hot and cold fluids flow in the same direction. Both the fluids enter and exit the heat exchanger on the same ends. For counter flow, both the hot and cold fluids flow in the opposite direction. Both the fluids enter and exit the heat exchanger on the opposite ends. In this experiment, we focused on the shell and tube heat exchanger. Examples in practice in which flowing fluids exchange heat are air intercoolers and preheaters, condensers and boilers in steam plant, condensers, condensers and evaporators in refrigeration units, and many other industrial process in which a liquid or gas is required to be either cooled or heated.

There are three main types of heat exchanger:

i. Recuperator

Fluids exchanging heat are on either side of a dividing wall

ii. Regenerator

Hot and cold fluids pass alternatively a sink and a source for heat flow

iii. Evaporative Type

A liquid is cooled evaporatively and continuously in the same space as the coolant.

An example of the latter type is the cooling tower. Very often when term” heat exchanger” is used it refers to the recuperative type, which is by far the most commonly used in engineering practice. The main purpose of heat exchanger is to remove the heat from the hot fluid and transfer it into the cold fluid. There are 3 types of heat exchanger, parallel flow, counter flow, and cross flow. However, in this experiment, we only consider the counter-flow heat exchanger and parallel flow. Counter flow exists when the two fluids flow in opposite directions. Each of the fluids enters the heat exchanger at opposite ends. Because the cooler fluid exits the counter flow heat exchanger at the end where the hot fluid enters the heat exchanger, the cooler fluid will approach the inlet temperature of the hot fluid. Parallel flow exists when two fluids flow in parallel directions. Each of the fluids enters the heat exchanger at parallel end.

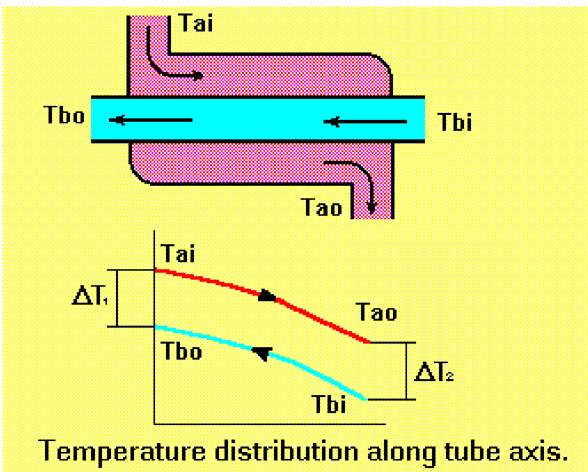


Figure 1: Counter-flow heat exchanger

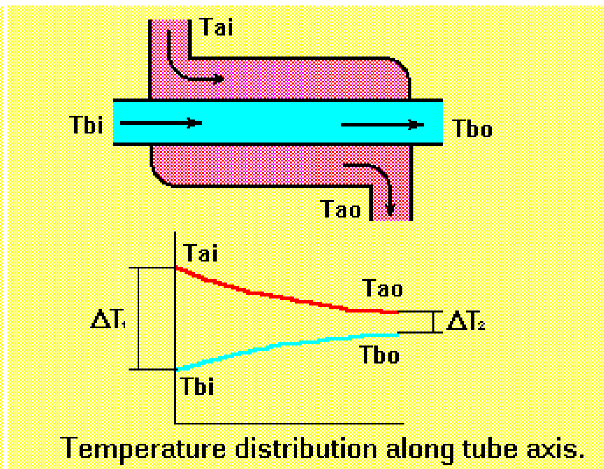


Figure 2: Parallel-flow heat exchanger

## 2.0 OBJECTIVE

The main objective for this experiment is to demonstrate the effect of the flow rate variation on the performance characteristics of a counter-flow and parallel flow concentric tube heat exchanger. Specific objectives for this experiment include:

i. Learning how the operation of concentric tube heat exchanger.
ii. Developing a set of experiments to obtain statistically significant trends for the overall heat transfer coefficient and the inside heat transfer coefficient as a function of water velocity.

iii. Observing the difference between parallel-flow and counter flow operation of the heat exchanger.

## 3.0 THEORETICAL BACKGROUND

Background

The way that a heat exchanger works is hot water and cold water enter the exchanger, where the process of cold water gaining some heat and the hot water losing some takes place, before they both exit the exchanger. What is actually happening is, the hot water is heating either the inside or the outside of the tubes in the exchanger, depending on where it is flowing, by what is known as convection.

Then the heat is conducted through the tubes to the other side, either the outside or the inside, where it is then convected back into the cold water raising its temperature. Convection is a mode of heat transfer that involves motion of some fluid that either absorbs heat from a source or gives heat to some surrounding. Conduction is a mode of heat transfer in which the heat is moving through a stationary object or fluid. For a heat exchanger that flows parallel or counter current then the coefficient of heat transfer is called the over all coefficient of heat transfer. It is calculated using the log mean temperature difference, which is found two different ways, depending of whether the flow is parallel or counter.

A heat exchanger is a device by which thermal energy is transferred from one fluid to another. The types of heat exchangers to be tested in this experiment are called single-pass, parallel-flow and counter-flow concentric tube heat exchangers. In a parallel-flow heat exchanger, the working fluids flow in the same direction. In the counter flow exchanger, the fluids flow in parallel but opposite directions.

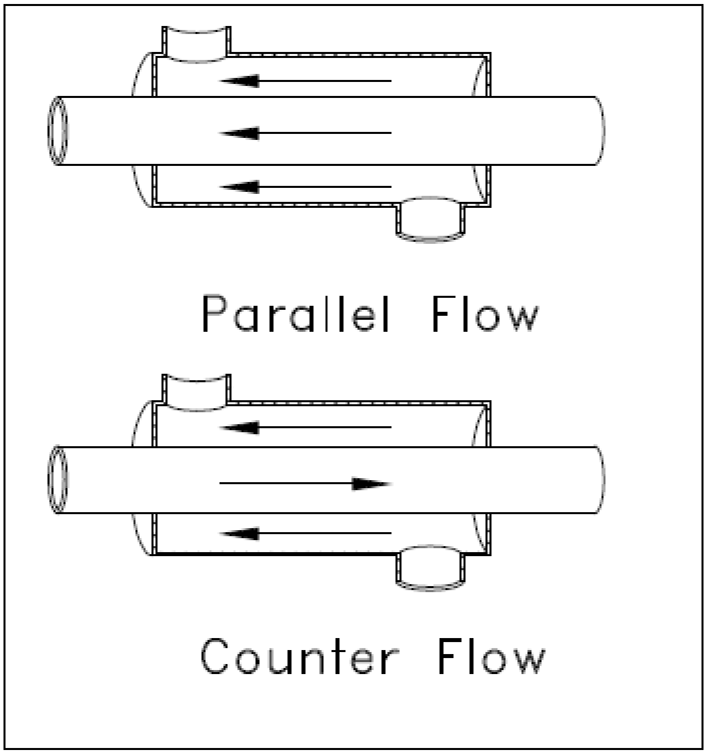


Figure 3: Concentric Tube Heat Exchangers

The variables that affect the performance of a heat exchanger are the fluids' physical properties, the fluids' mass flow rates, the inlet temperature of the fluids, the physical properties of the heat exchanger materials, the configuration and area of the heat transfer surfaces, the extent of scale or deposits on the heat transfer surfaces, and the ambient conditions.

The equations for calculating the performance characteristics : power emitted, power absorbed, power lost, efficiency (η); logarithmic mean temperature difference ($\Delta T_m$), and overall heat transfer coefficient (U).

The efficiency for the cold medium is:

$$\eta_c = (T_{c,out} - T_{c,in} / T_{h,in} - T_{c,in}) \text{ x } 100$$

The efficiency for the hot medium is:

$$\eta_h = (T_{h,in} - T_{h,out} / T_{h,in} - T_{c,in}) \text{ x } 100$$

The mean temperature efficiency is:

$$\eta_{mean} = (\eta_c + \eta_h) / 2$$

The power emitted is given below ( where $\dot{V}_h$ is the volumetric flow rate of the hot fluid) :

$$\text{Power Emitted} = \dot{V}_h \ \rho_h \ C_{ph} \ (T_{h,in} - T_{h,out})$$

The power absorbed is given below (where $\dot{V}_c$ is the volumetric flow rate of the cold fluid) :

$$\text{Power Absorbed} = \dot{V}_c \ \rho_c \ C_{pc}(T_{c,out} - T_{c,in})$$

The power lost is therefore:

Power lost = Power Emitted – Power Absorbed

The overall efficiency (η) is:

η = (Power Absorbed/Power Emitted) x 100

The logarithmic mean temperature difference ($\Delta T_m$) is:

$$\Delta T_m = (\Delta T_1 - \Delta T_2) / \ln(\frac{\Delta T_1}{\Delta T_2})$$

$$= (T_{h,in} - T_{c,out}) - (T_{h,out} - T_{c,in}) / \ln [(T_{h,in} - T_{c,out}) / (T_{h,out} - T_{c,in})]$$

The overall heat transfer coefficient (U) is :

$$U = \text{Power Absorbed} / A_s \Delta T_m$$

where the surface area ($A_s$) for this heat exchanger is 0.067 m².

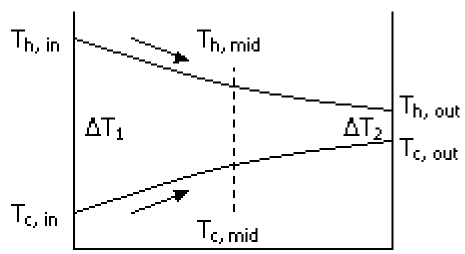


Figure 4: Graph of Parallel flow

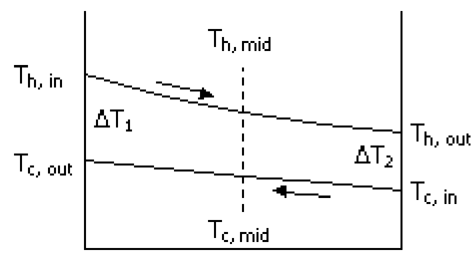


Figure 5: Graph of Counter Flow

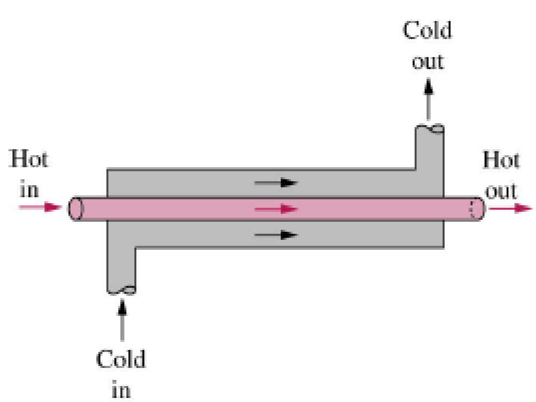


Figure 6: Schematic Diagram of Parallel Flow

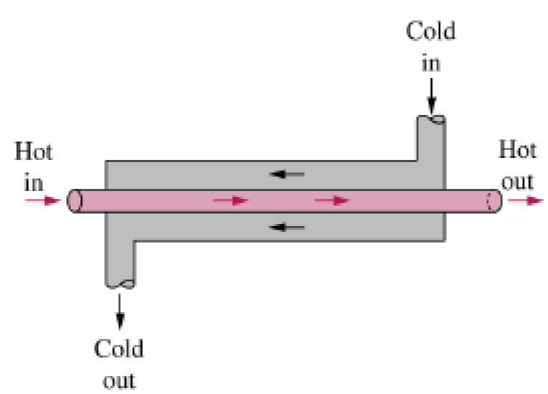


Figure 7: Schematic Diagram of Counter Flow

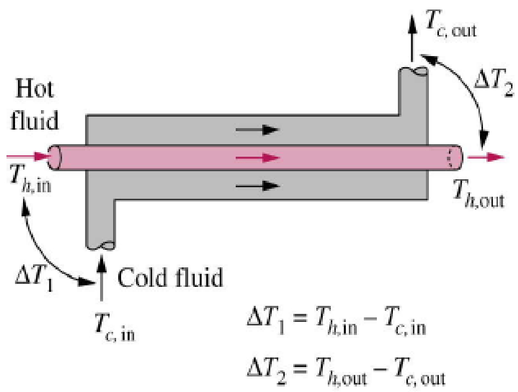


Figure 8 : Calculation Temperature of Parallel-Flow

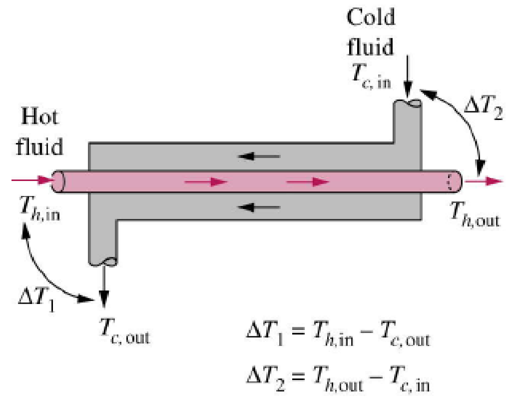


Figure 9 : Calculation Temperature of Counter-Flow

## 4.0 APPARATUS

The apparatus for this experiment is the H900 Concentric Tube Heat Exchanger. This apparatus has a tank with a heater inside to heat water to a specified temperature. The temperature setting is adjusted at the thermostat on the front panel. Once the water is heated to the desired temperature it is transferred by a water pump next to the tank. On the pump there is a knob which varies the pump pressure. When using a volumetric flow rate above 2 L/min. the switch should be set to the highest pressure.

The hot water is pumped through a pipe to an insulated tube for which heat will be exchanged. The actual heat exchange takes place in the insulated tubing for which cold water flows concentricity around the hot water tube in two different flow arrangements. These two arrangements, parallel and counter flow, can be changed by opening and closing certain valves within the network of hot and cold water tubing. Each flow arrangement is shown on a diagram located on the front panel. It is worthwhile to note that the temperature at cold-in changes to temperature at cold-out when a counter flow arrangement is used. The same situation applies to the temperature at cold-out, which changes to temperature cold-in for the counter flow. The other readings remain the same. The flow rates can be adjusted for both cold and hot water by turning the valve knobs on the right side of the panel. Thermometers are located at the inlet, exit and middle of the insulated heat exchanger tubing for both hot and cold water.

Figure 10: Concentric Tube Heat Exchanger

Figure 11: Digital clock

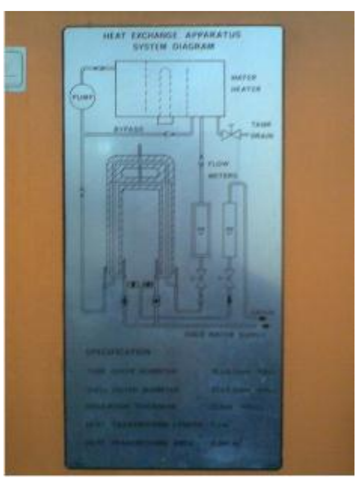


Figure 12 : Heat Exchanger Apparatus System Diagram

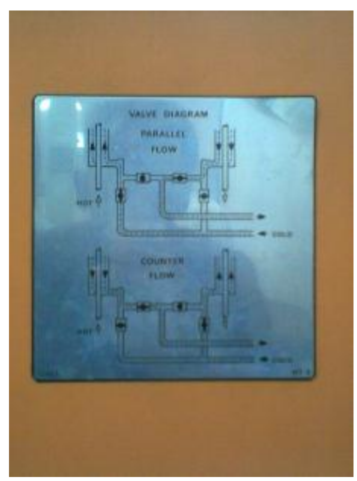


Figure 13 : Parallel Flow and Counter Flow of Valve Diagram

## 5.0 EXPERIMENTAL PROCEDURE

1. Configure the experiment for counter-flow heat exchanger operation. The required hot water inlet temperature to $T_{h,in}$ = 60 ºC with the decade switch is set. Then, the cold water volumetric flow rate ($\dot{V}_c$) to run at a constant 2,000 cm³/min is also set.
2. Initially the hot fluid volumetric flow rate ($\dot{V}_h$) to 1,000 cm³/min is set. After 5 minutes the six temperature readings are recorded in following table. Then, this for volumetric flow rates of 2,000, 3,000 and 4,000 cm³/min is repeated.
3. Look up values for density ( $\rho_c and \rho_h$ ) and constant pressure specific heat ( $C_{pc} and C_{ph}$ ) for the cold fluids at a temperature of $T_{c,in}$ and for the hot fluids at a temperature of $T_{h,in}$.
4. Using the data, the following heat exchanger performance factors: power emitted, power absorbed, power lost, efficiency ( $\eta$ ), logarithmic mean temperature difference ( $\Delta T_m$ ), and overall heat transfer coefficient ( $U$ ) are calculated and recorded in the table.
5. The experiment is repeated and set up for parallel flow with the same steps for the counter flow.

## 6.0 RESULT

**Counter Flow**

| $\dot{V}_h$ (cm³/min) | $T_{h,in}$ (ºC) | $T_{h,mid}$ (ºC) | $T_{h,out}$ (ºC) | $T_{c,in}$ (ºC) | $T_{c,mid}$ (ºC) | $T_{c,out}$ (ºC) |
|---|---|---|---|---|---|---|
| 1,000 | 60.0 | 53.0 | 47.20 | 28.50 | 31.00 | 35.50 |
| 2,000 | 60.0 | 55.5 | 50.50 | 28.50 | 33.00 | 38.00 |
| 3,000 | 60.0 | 57.0 | 52.70 | 28.50 | 34.00 | 39.70 |
| 4,000 | 60.0 | 58.0 | 54.00 | 28.50 | 34.80 | 40.05 |

Table 1: Volumetric flow rate and temperature for counter flow

T = 60℃ , $\rho_h$= 983.3 kg/m³ , $C_{ph}$ = 4.185 kJ/kg.K

T = 28.5℃ $\rho_c$ =996.3 kg/m³ , $C_{pc}$ = 4.179 kJ/kg.K

| $\dot{V}_h$ (cm³/min) | Power Emitted (W) | Power Absorbed (W) | Power Lost (W) | Efficiency ($\eta$) (%) | $\Delta T_1$ (ºC) | $\Delta T_2$ (ºC) | $\Delta T_m$ (ºC) | U W/(m². ºC) |
|---|---|---|---|---|---|---|---|---|
| 1,000 | 877.89 | 485.746 | 392.144 | 55.33 | 24.50 | 18.70 | 21.47 | 337.684 |
| 2,000 | 1303.118 | 1318.454 | -15.335 | 101.18 | 22.00 | 22.00 | 0.00 | 0.00 |
| 3,000 | 1502.015 | 2331.581 | -829.566 | 155.23 | 20.30 | 24.20 | 22.19 | 1568.055 |
| 4,000 | 1646.044 | 3205.924 | -1559.880 | 194.77 | 19.95 | 25.50 | 22.61 | 2116.154 |

Table 2: Volumetric flow rate, power, efficiency, logarithmic mean temperature difference ($\Delta T_m$) and overall heat transfer (U) for counter flow

## Parallel Flow

| $\dot{V}_h$ (cm³/min) | $T_{h,in}$ (ºC) | $T_{h,mid}$ (ºC) | $T_{h,out}$ (ºC) | $T_{c,in}$ (ºC) | $T_{c,mid}$ (ºC) | $T_{c,out}$ (ºC) |
|---|---|---|---|---|---|---|
| 1,000 | 60 | 52.00 | 47.90 | 29.00 | 33.00 | 34.50 |
| 2,000 | 60 | 55.00 | 51.00 | 29.00 | 34.50 | 35.60 |
| 3,000 | 60 | 56.00 | 53.00 | 29.00 | 35.00 | 37.70 |
| 4,000 | 60 | 57.00 | 54.00 | 29.00 | 36.00 | 39.50 |

Table 3: Volumetric flow rate and temperature for parallel flow.

T = 60℃ , $\rho_h$= 983.3 kg/m³ , $C_{ph}$ = 4.185 kJ/kg.K

T = 29℃ $\rho_c$ =996.2 kg/m³ , $C_{pc}$ = 4.178 kJ/kg.K

| $\dot{V}_h$ (cm³/min) | Power Emitted (W) | Power Absorbed (W) | Power Lost (W) | Efficiency ($\eta$) (%) | $\Delta T_1$ (ºC) | $\Delta T_2$ (ºC) | $\Delta T_m$ (ºC) | U W/(m². ºC) |
|---|---|---|---|---|---|---|---|---|
| 1,000 | 829.881 | 381.528 | 448.353 | 45.97 | 25.50 | 18.90 | 22.04 | 258.421 |
| 2,000 | 1234.533 | 915.667 | 318.866 | 74.17 | 24.40 | 22.00 | 23.18 | 589.607 |
| 3,000 | 1440.289 | 1810.524 | -370.240 | 125.71 | 22.30 | 24.00 | 23.14 | 1167.814 |
| 4,000 | 1646.044 | 2913.487 | -1267.440 | 177.00 | 20.50 | 25.00 | 22.68 | 1917.692 |

Table 4: Volumetric flow rate, power, efficiency, logarithmic mean temperature difference ($\Delta T_m$) and overall heat transfer (U) for parallel flow.

## 7.0 SAMPLE CALCULATION

*Note:*

- *The liquid properties refer table A-2 Boiling and Freezing Point Properties*
- *This calculation parallel flow and counter flow has been taken the data* **1000 cm³/min cold water and 1000 cm³/min hot water volume flow rate.**

**<u>Counter Flow</u>**

By refer to the table of saturated water properties :

At T= 60℃

$\rho_h$ = 983.3 kg/m³

$C_{ph}$ = 4.185 kJ/kg.K

At T= 28.5℃

<u>We need to do interpolation to find $\rho_C$ and $C_{pc}$.</u>

At T= 25 , ρ = 997 kg/m³

At T= 30 , ρ = 996 kg/m³

$$(30 – 28.5) / (30 – 25) = (996 - \rho_c) / (996 – 997)$$

$$\rho_c = 996.3 \text{ kg/m}^3$$

At T= 25 , $C_p$ = 4.180 kJ/kg.K

At T= 30 , $C_p$ = 4.178 kJ/kg.K

$$(30 – 28.5) / (30 – 25) = (4.178 - Cp) / (4.178 – 4.180)$$

$$C_{pc} = 4.179 \text{ kJ/kg.K}$$

Power Emitted = $\dot{V}_h\ \rho_h\ C_{ph}\ (T_{h,in} - T_{h,out})$

= (1000 x 1/60 x 1/10⁶) m³/s x 983.3 kg/m³ x 4.185 kJ/kg.K x (60 – 47.2)K

= 877.89W

Power Absorbed = $\dot{V}_c\ \rho_c\ C_{pc}(T_{c,out} - T_{c,in})$

= (1000 x 1/60 x $1/10^6$) m³/s x 996.3 kg/m³ x 4.179 kJ/kg.K x (35.5-28.5)K

= 485.746W

Power lost = Power Emitted – Power Absorbed

= 877.89 – 485.746

= 392.144W

The overall efficiency (η) is:

η = (Power Absorbed/Power Emitted) x 100

= (485.746 / 877.89) x 100

= 55.33 %

The logarithmic mean temperature difference ($\Delta T_m$) is:

$$\Delta T_m = (\Delta T_1 - \Delta T_2) / \ln(\frac{\Delta T_1}{\Delta T_2})$$

$\Delta T_1 = (T_{h,in} - T_{c,out})$

= (60 – 35.5)

= 24.5 ºC

$\Delta T_2 = (T_{h,out} - T_{c,in})$

= (47.2 – 28.5)

= 18.7 ºC

$\Delta T_m = (\Delta T_1 - \Delta T_2) / \ln(\frac{\Delta T_1}{\Delta T_2})$

= (24.5 –18.7) / ln (24.5/18.7)

= 21.47 ºC

The overall heat transfer coefficient (U) is :

U = Power Absorbed / $A_s \Delta T_m$

U = 485.746/ (0.067x21.47)
= 337.684 W/m². ºC

**Parallel Flow**

By refer to the table of saturated water properties :

At T= 60℃

$\rho_h$ = 983.3 kg/m³

$C_{ph}$ = 4.185 kJ/kg.K

At T= 28.5℃

We need to do interpolation to find $\rho_C$ and $C_{pc}$.

At T= 25 , ρ = 997 kg/m³

At T= 30 , ρ = 996 kg/m³

(30 – 29) / (30 – 25) = (996 - $\rho_c$ ) / (996 – 997)

$\rho_c$ = 996.2 kg/m³

At T= 25 , $C_p$ = 4.180 kJ/kg.K

At T= 30 , $C_p$ = 4.178 kJ/kg.K

(30 – 29) / (30 – 25) = (4.178 - Cp) / (4.178 – 4.180)
$C_{pc}$ = 4.178 kJ/kg.K

Power Emitted = $\dot{V}_h \ \rho_h \ C_{ph} \ (T_{h,in}$ - $T_{h,out}$ )
= (1000 x 1/60 x 1/$10^6$) m³/s x 983.3 kg/m³ x 4.185 kJ/kg.K x (60 – 47.9)K
= 829.881W

Power Absorbed = $\dot{V}_c \ \rho_c \ C_{pc}(T_{c,out}$ - $T_{c,in}$ )
= (1000 x 1/60 x 1/$10^6$) m³/s x 996.2kg/m³ x 4.178 kJ/kg.K x (34.5-29)K

= 381.528 W

Power lost = Power Emitted – Power Absorbed

= 829.881– 381.53

= 448.353 W

The overall efficiency (η) is:

η = (Power Absorbed/Power Emitted) x 100

= (381.528 / 829.881) x 100

= 45.97 %

The logarithmic mean temperature difference ($\Delta T_m$) is:

$$\Delta T_m = (\Delta T_1 - \Delta T_2) / \ln(\frac{\Delta T_1}{\Delta T_2})$$

$\Delta T_1 = (T_{h,in} - T_{c,out})$

= (60 – 34.5)

= 25.5 ºC

$\Delta T_2 = (T_{h,out} - T_{c,in})$

= (47.9 – 29)

= 18.9 ºC

$\Delta T_m = (\Delta T_1 - \Delta T_2) / \ln(\frac{\Delta T_1}{\Delta T_2})$

= (25.5 –18.9) / ln (25.5/18.9)

= 22.04 ºC

The overall heat transfer coefficient (U) is :

U = Power Absorbed / $A_s \Delta T_m$

U = 381.528 / (0.067x22.04) = 258.421 W/m². ºC

## 8.0 REFERENCE

1. Thermodynamics An Engineering Approach Sixth Edition (SI Units) by Yunus A. Cengel And Michael A. Boles. (Mc Graw Hill)
2. http://en.wikipedia.org/wiki/Heat_exchanger