Experiment No: 2

Objective

To determine the effectiveness of shell and tube, cross flow & plate heat exchangers

Theory

A *heat exchanger* is an equipment which facilitates the flow of thermal energy between two or more fluids at different temperatures. Heat exchangers are employed in a variety of domestic, commercial, and industrial applications, such as power generation, refrigeration, air conditioning, process industry, manufacturing industry etc. Classification of heat exchangers is presented in Fig. 1.

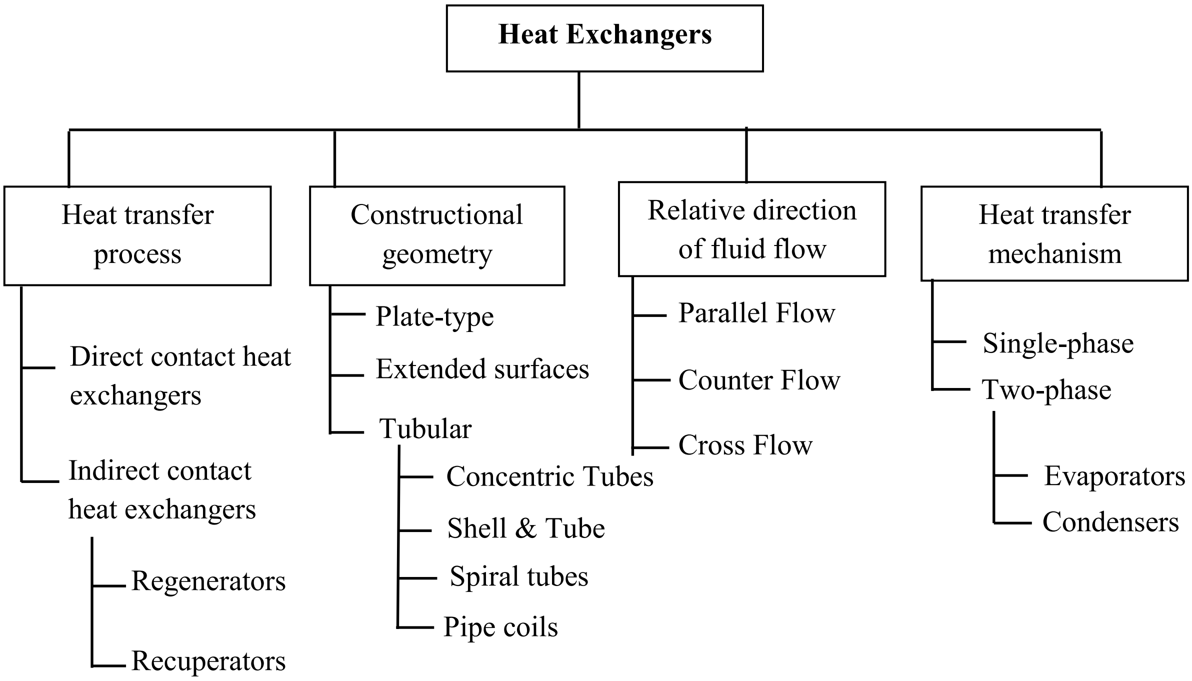

Fig. 1 Classification of Heat Exchangers

<u>Parallel flow heat exchanger</u>

In a parallel flow heat exchanger, the two fluid streams (hot and cold) flow through the heat exchanger in the same direction. The two fluid streams enter at one end of the heat exchanger and leave at the other end. The schematic and the temperature profile of the fluid streams in parallel flow heat exchanger are shown in Fig. 2. From the temperature profile (Fig. 2(b)), it is clear that the temperature difference between the fluid streams decreases from the inlet to the outlet of the heat exchanger. Parallel flow heat exchangers are rarely employed due to their requirement of large surface area for heat transfer.

*Examples:*Oil heaters, oil coolers, water heaters etc.

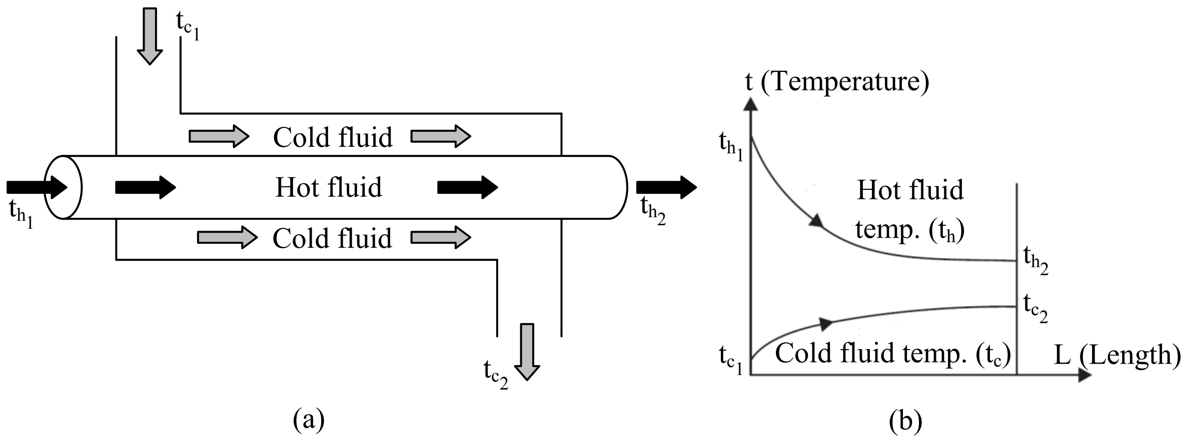

Fig. 2 Parallel Flow Heat Exchanger

Temperature difference$(\theta_1) = t_{h_1} - t_{c_1}$ ... (1)

Temperature difference$(\theta_2) = t_{h_2} - t_{c_2}$ ... (2)

Log mean temperature difference (LMTD) $= (\theta_1 - \theta_2)/\ln(\theta_1 - \theta_2)$ ... (3)

<u>Counter flow heat exchanger</u>

In a counter flow heat exchanger, the two fluid streams flow in relatively opposite directions. The fluid streams enter at opposite ends. Figure 3 shows the schematic and the temperature profile of the fluid streams for such a heat exchanger. The temperature difference between the two fluid streams remains nearly constant (Fig. 3(b)). Counter flow heat exchangers provide the maximum heat transfer rate for a given surface area. Hence, they are the most widely used heat exchangers.

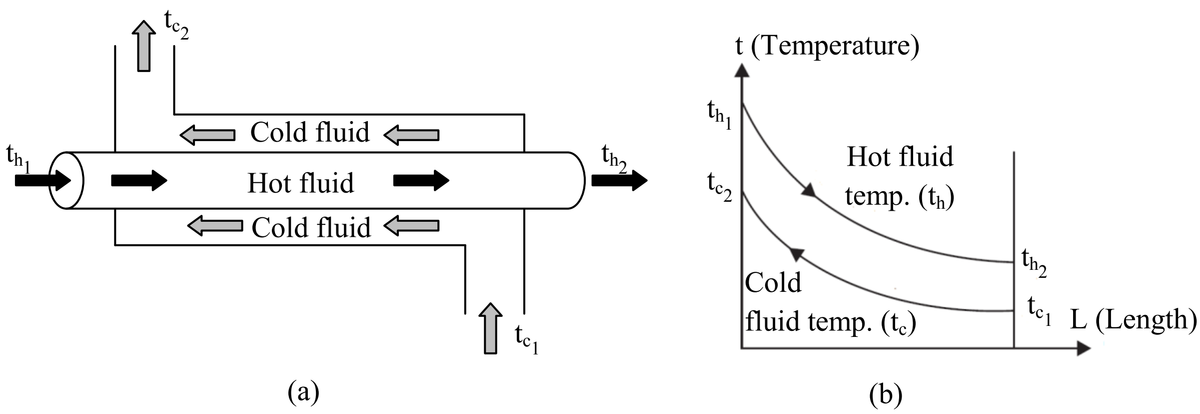

Fig. 3 Counter Flow Heat Exchanger

Temperature difference$(\theta_1) = t_{h_1} - t_{c_2}$ ... (4)

Temperature difference$(\theta_2) = t_{h_2} - t_{c_1}$ ... (5)

Log mean temperature difference (LMTD) $= (\theta_1 - \theta_2)/\ln(\theta_1 - \theta_2)$ ... (6)

Cross flow heat exchanger

In a cross-flow heat exchanger, the paths of the two fluid streams through the heat exchanger are usually at right angles to each other. Figure 4 shows a schematic diagram of cross-flow heat exchanger. The cross flow heat exchanger in our laboratory is of finned type and the cooling media used is air.

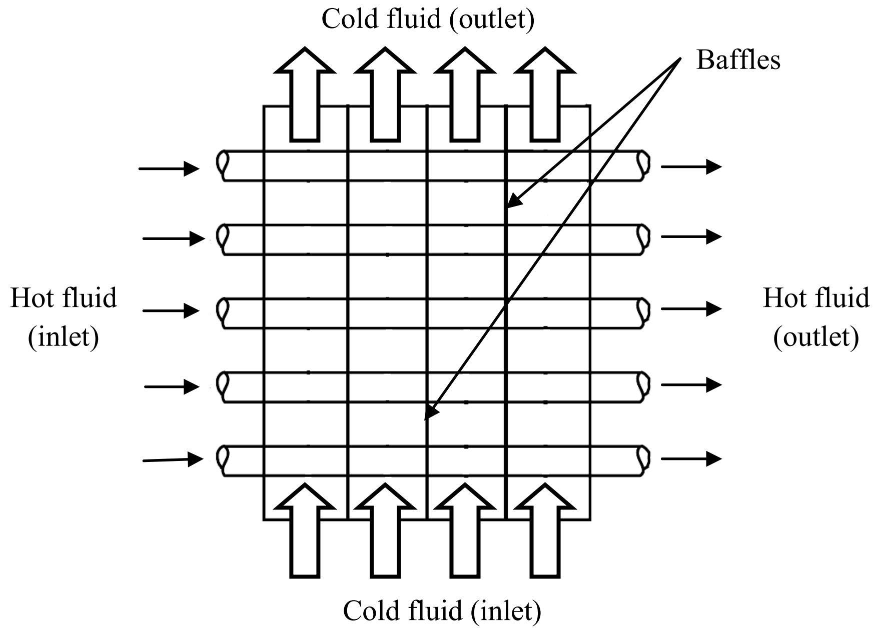

Fig. 4 Cross Flow Heat Exchanger

Shell & tube heat exchanger

This type of heat exchangers has a bundle of tubes enclosed in a shell, usually cylindrical. The tubes are arranged parallel to the shell axis. One fluid stream is passed through the bundle of tubes, while the other fluid stream is flows through the shell over the tubes (Fig.5). Overall heat transfer between the fluid streams is enhanced by the use of multiple shell & tube passes. With the use of baffles, the shell-side fluid stream is re-routed and made to flow back-and-forth over the tubes.

Plate heat exchanger

Plate heat exchangers consist of a number of thin corrugated metal plates arranged together. The fluid streams enter the heat exchanger through frame connections and are then distributed to the plates. The two fluid streams pass through alternate spaces formed between the successive plates. Thanks to the corrugations on the metal plates and the small spacing between the plates, the fluid flow is essentially turbulent which improves the overall heat transfer between the fluid streams. Also, the eddies generated in the flow clean the heat exchanger surface, thus minimizing fouling. Plate heat exchangers are widely used in industries due to their low cost, easy maintenance, and high thermal efficiency.

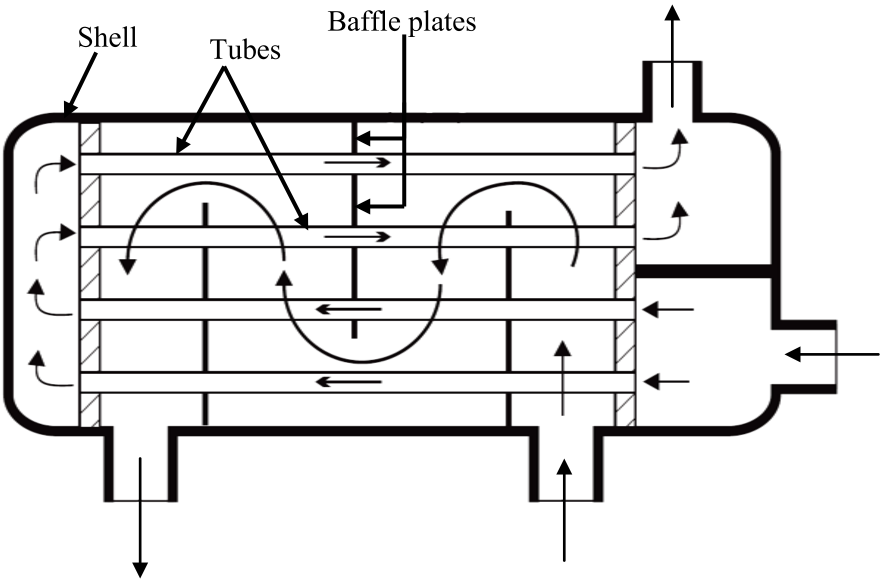

Fig. 5 Schematic of Shell & Tube Heat Exchanger[a]

Effectiveness of a heat exchanger

The effectiveness (ϵ) of a heat exchanger is defined as the ratio of the actual heat transfer to the maximum possible heat transfer.

$$\in = \frac{\text{actual heat transfer}}{\text{maximum possible heat transfer}} \qquad \ldots (7)$$

$$\text{Actual heat transfer} = Q = m_h C_{ph}(t_{h1} - t_{h2}) = m_c C_{pc}(t_{c2} - t_{c1}) \qquad \ldots (8)$$

where

$m_h . C_{ph} = C_h =$ hot fluid capacity rate

$m_c . C_{pc} = C_c =$ Cold fluid capacity rate

$$\begin{aligned}\text{Maximum possible heat transfer} = Q_{max} &= C_h(t_{h1} - t_{c1}) \text{ or} \\ &= C_c(t_{h1} - t_{c1})\end{aligned}$$

Q_{max} is the minimum of these two values i. e.

$$Q_{max} = C_{min}(t_{h1} - t_{c1}) \qquad \ldots (9)$$

[a]Rajput, R.K., 2007, *Engineering Thermodynamics*, Laxmi Publications, New Delhi.

$$\in \;= \frac{C_h(t_{h1}-t_{h2})}{C_{min}\,(t_{h1}-t_{c1})} \text{ or} \quad \ldots(10)$$

$$= \frac{C_c(t_{c2}-t_{c1})}{C_{min}\,(t_{h1}-t_{c1})} \quad \ldots(11)$$

<u>Determination of overall heat transfer coefficient</u>

To determine the overall heat transfer coefficient U for a given heat exchanger, we use the following relation:

$$\mathrm{NTU} = \frac{U\,A}{C_{min}} \quad \ldots (12)$$

where,
NTU = Number of Transfer Units (Dimensionless)
U = Overall heat transfer coefficient $\left(\frac{W}{m^2 K}\right)$
A = Heat transfer surface area (m^2)

C_{min} = Minimum of C_h or C_c (kJ/K)

In the present study, steam is condensing while passing through the heat exchanger. Hence, $C_h \rightarrow \infty$. Thus, the capacity ratio, $C_r = C_{min} / C_{max} = 0$. For such a case, NTU can be calculated using the following relationship between ϵ and NTU[b]:

$$\mathrm{NTU} = -\ln(1-\epsilon) \quad \ldots (13)$$

Hence, from equations (12) and (13), we have

$$U = -C_{min} \times A \times \ln(1-\epsilon) \quad \ldots (14)$$

[b]Kays, W. M., and London, A.L., 1984, *Compact Heat Exchangers*, McGraw-Hill, New York.

Procedure

1. Fire the boiler as per instructions in the boiler manual. Wait till it operates satisfactorily at desired pressure and mass flow rate.
2. Check the setting of pressure reducing valve (PRV), it should reduce the pressure of steam to around 3 bar, confirm it from the reading of the pressure gauge after the PRV on the main steam header.
3. Separate inlet and outlet valves for the steam are provided for cross flow, plate type, and shell & tube heat exchangers. Open the outlet valves first and then the inlet valves for letting steam into the heat exchangers.
4. In case of cross flow heat exchanger, measure the air velocity at the inlet to the blower with the help of a digital anemometer.
5. In case of plate type or shell & tube type heat exchanger, note the water flow rate to the heat exchanger from the digital display.
6. Note down the pressure of steam from pressure gauge on steam header. Note the steam flow rate, temperature of steam at inlet of the heat exchanger, steam condensate temperature, and temperature of incoming and outgoing water from the digital display.
7. Vary the air flow rate (in case of cross flow heat exchanger) with the help of damper at the inlet of the blower and note down the readings. Take at least 3-4 readings in such manner.
8. Vary the water flow rate (in case of plate and shell & tube heat exchangers) by turning the water inlet valve to the respective heat exchanger and note down the readings. Take at least 3-4 readings in such manner.
9. Determine the effectiveness and overall heat transfer coefficient for the three heat exchangers.

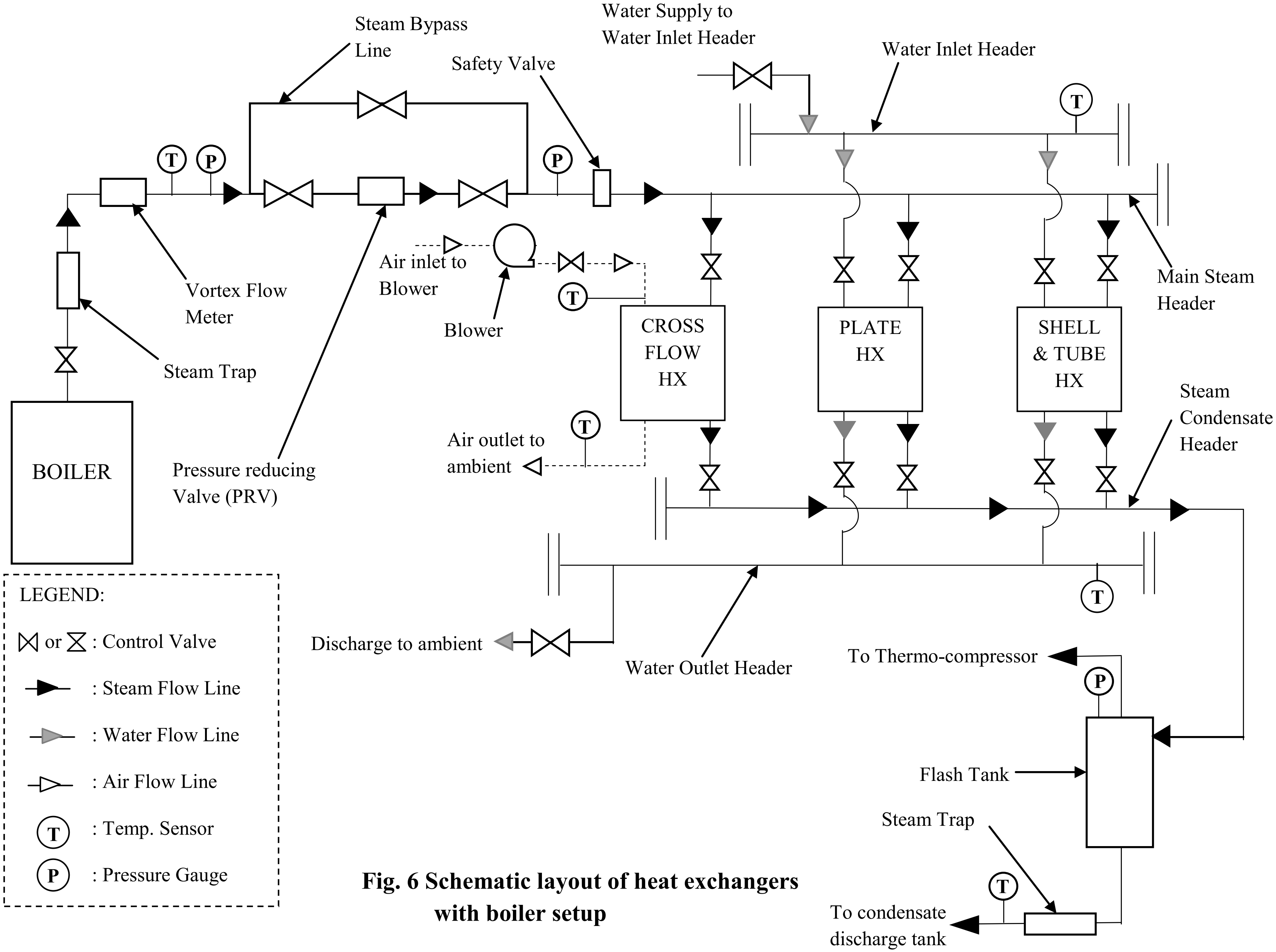

Fig. 6 Schematic layout of heat exchangers with boiler setup

Observations

For cross flow heat exchanger

Heat transfer surface area, A = _____________ m^2

Cross-section area of the air inlet, A_c = _____________ m^2

S. No.	Steam flow rate, m_s (kg/h)	Air flow velocity (m/s)	Steam pressure (bar)	Steam inlet temperature, t_{h1} (^oC)	Steam condensate temperature, t_{cond} (^oC)	Air inlet temperature, t_{c1} (^oC)	Air outlet temperature, t_{c2}(^oC)
1							
2							
3							
4							
5							
6							

For Plate type heat exchanger

Heat transfer surface area, A = _____________ m^2

S. No.	Steam flow rate, m_s (kg/h)	Water flow rate (LPH)	Steam pressure (bar)	Steam inlet temperature, t_{h1} (^oC)	Steam condensate temperature, t_{cond} (^oC)	Water inlet temperature, t_{c1} (^oC)	Water outlet temperature, t_{c2}(^oC)
1							
2							
3							
4							
5							
6							

For shell & tube heat exchanger

Heat transfer surface area, A = _____________ m^2

S. No.	Steam flow rate, m_s (kg/h)	Water flow rate (LPH)	Steam pressure (bar)	Steam inlet temperature, t_{h1} (^oC)	Steam condensate temperature, t_{cond} (^oC)	Water inlet temperature, t_{c1} (^oC)	Water outlet temperature, t_{c2}(^oC)
1							
2							
3							
4							
5							
6							

Calculations

1. Calculation of effectiveness (ϵ)
   - Use Eq. (11) to calculate ϵ.

2. Calculation of overall heat transfer coefficient (U)
   - Use Eq. (14) to calculate U.

Results

For cross flow heat exchanger

S. No.	Steam flow rate, m_s (kg/h)	Air flow rate, m_c (kg/h)	Steam pressure (bar)	Effectiveness, ϵ	Overall heat transfer coefficient, U ($W/m^2.K$)
1					
2					
3					
4					
5					
6					

For Plate type heat exchanger

S. No.	Steam flow rate, m_s (kg/h)	Water flow rate, m_c (kg/h)	Steam pressure (bar)	Effectiveness, ϵ	Overall heat transfer coefficient, U ($W/m^2.K$)
1					
2					
3					
4					
5					
6					

For shell & tube heat exchanger

S. No.	Steam flow rate, m_s (kg/h)	Water flow rate, m_c (kg/h)	Steam pressure (bar)	Effectiveness, ϵ	Overall heat transfer coefficient, U ($W/m^2.K$)
1					
2					
3					
4					
5					
6					

Further reading:

- Kern, D.Q., 1965, *Process Heat Transfer*, McGraw-Hill, Tokyo.
- Kays, W. M., and London, A.L., 1984, *Compact Heat Exchangers*, McGraw-Hill, New York.
- Kakac, S., and Liu, H., 2002, *Heat Exchangers: Selection, Rating, and Thermal Design*, CRC Press LLC, Boca Raton, Florida.