

Introduction to Heat Exchangers

Agenda

1. Heat exchanger description
2. Parallel flow heat exchangers
3. Counter flow heat exchangers
4. Effectiveness
5. NTU
6. Phase Change
7. Constant specific heat
8. Examples

Reason for Heat Exchangers

A heat exchanger is a piece of equipment built for efficient heat transfer from one medium to another (hot and cold fluid).

Common Example

The classic example of a heat exchanger is found in an internal combustion engine in which a circulating fluid known as engine coolant flows through radiator coils and air flows past the coils, which cools the coolant and heats the incoming air.

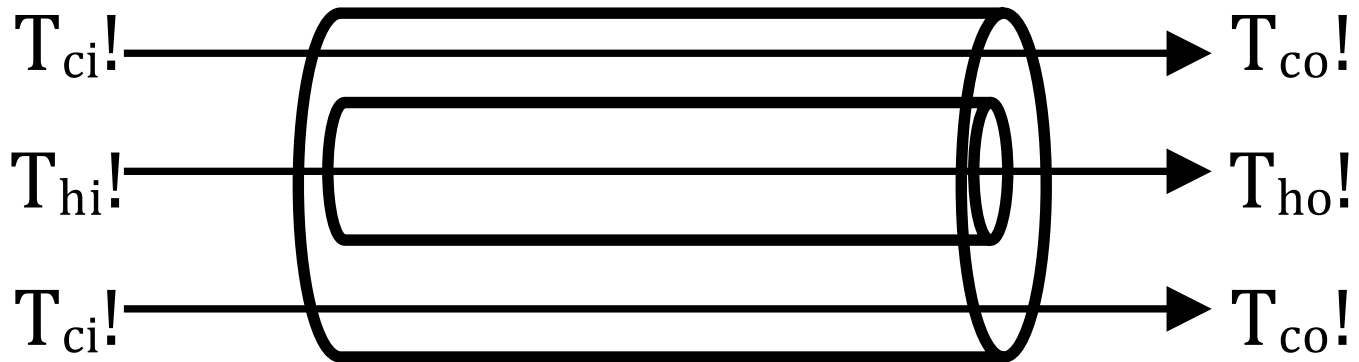
Two Main Types of Heat Exchangers

The two main types of heat exchangers that exist:

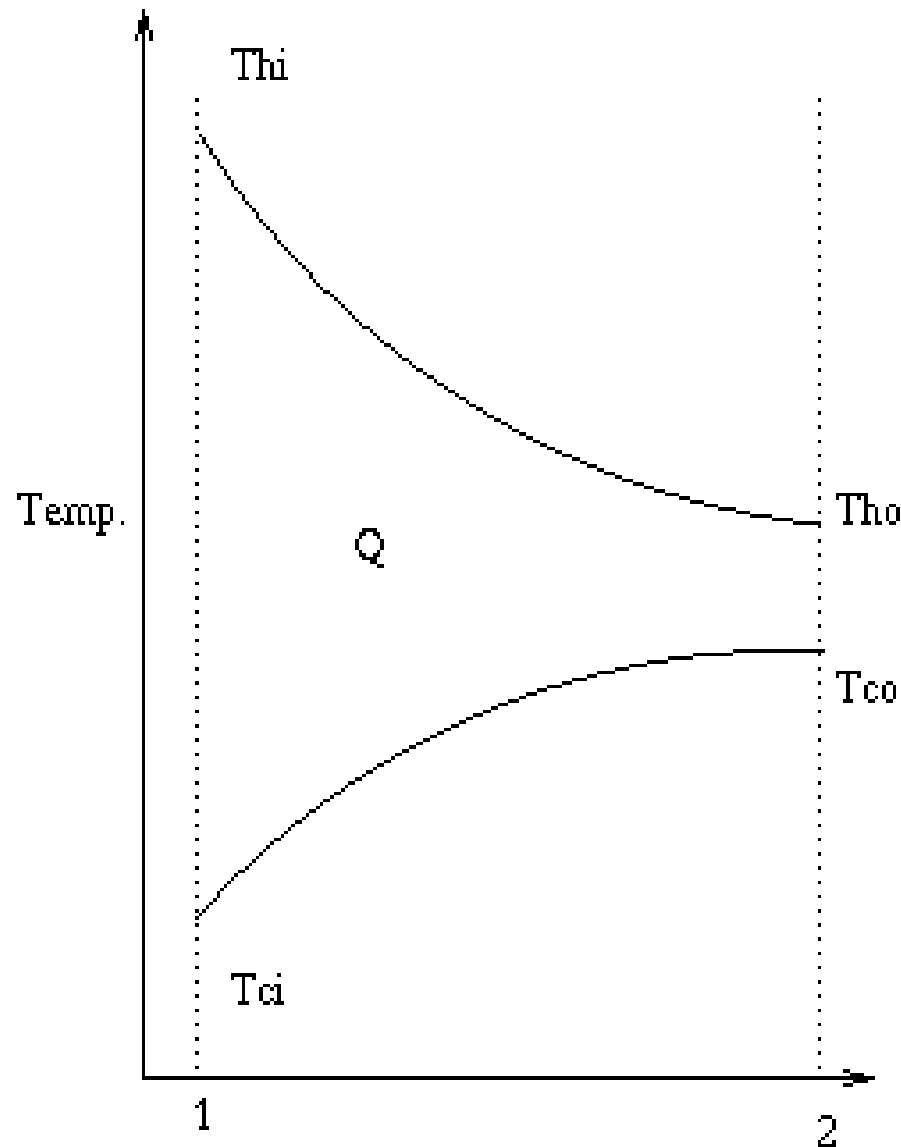
1. Parallel Flow Heat Exchanger
2. Counter Flow Heat Exchanger

Parallel Flow Heat Exchanger

In parallel flow heat exchangers, the two mediums enter the exchanger at the same end, and travel in parallel to one another to the other side.



Temperature Profile for Parallel Flow

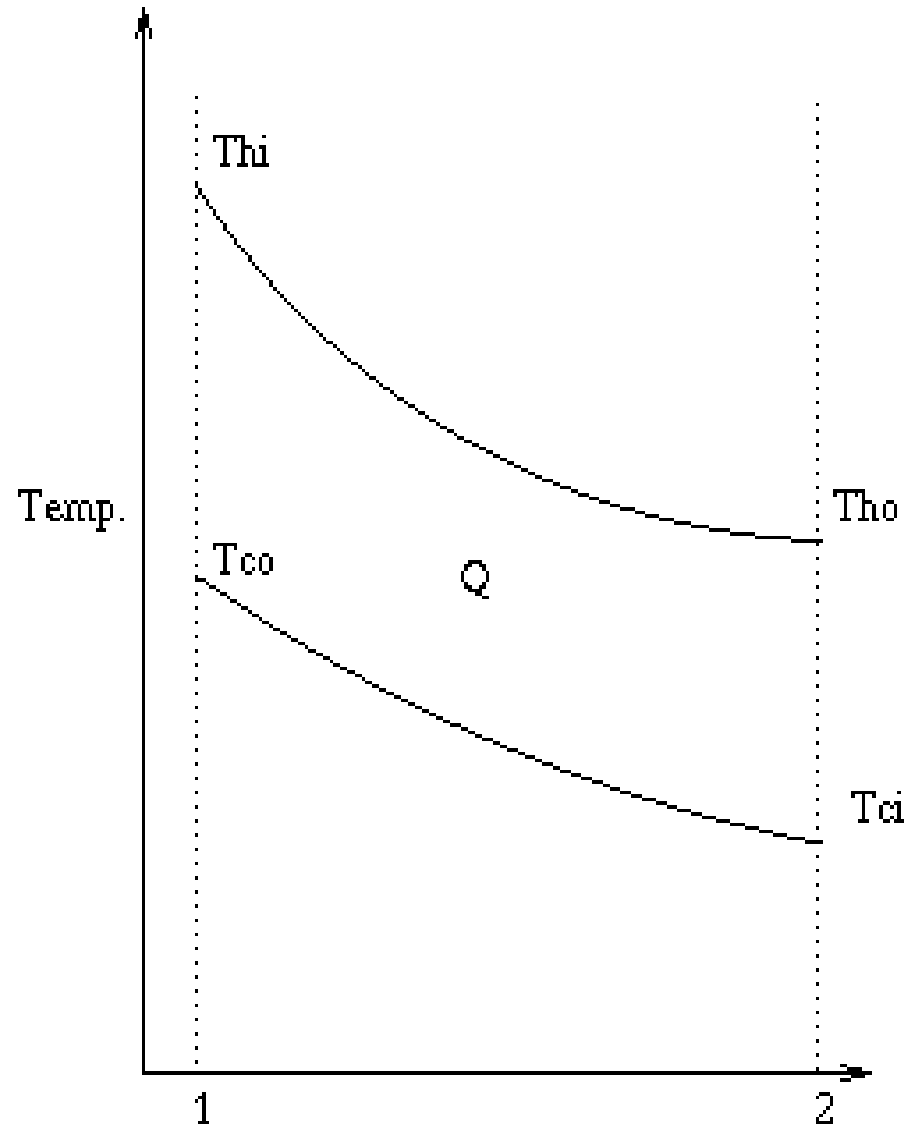


Counter Flow Heat Exchanger

In counter flow heat exchangers the fluids enter the exchanger from opposite ends. The counter flow design is most efficient, in that it can transfer the most heat from the heat transfer medium.



Temperature Profile for Counter Flow



Effectiveness

The effectiveness of a heat exchanger is defined as:

- $\epsilon = \frac{q}{q_{max}}$
- q_{max} is always based on counterflow heat exchanger for all configurations.
 - ϵ is better as it approaches 1.

Effectiveness Cont.

Since,

$$\dot{Q} = \dot{m} C_p \Delta T$$

the effectiveness can be written in terms of heat capacitance rate [W/K], C , and change in temperature [K], ΔT .

The heat capacitance rate is defined in terms of mass flow rate [kg/s], \dot{m} , and specific heat [kJ/(kgK)], c_p :

$$C = \dot{m} c_p$$

$$\dot{Q}$$

$$\dot{Q} = \dot{m} C_p \Delta T$$

Effectiveness Cont.

Therefore, effectiveness is then written as:

$$\epsilon = \frac{C_c (T_{c,i} - T_{c,e})}{C_{\#} (T_{h,i} - T_{c,i})} \quad \epsilon = \frac{C_h (T_{h,i} - T_{h,e})}{C_{\#} (T_{h,i} - T_{c,i})}$$

Where,

and C_h and C_c correspond to hot and cold fluid heat capacitance rates, respectively.

Number Transfer Units

The Number of Transfer Units (NTU) Method is used to calculate the rate of heat transfer in heat exchangers.

NTU can be defined as:

$$NTU = \frac{UA}{\dot{m}c_p}$$

NTU Cont.

UA refers to:

U = overall heat transfer coefficient [$\text{W}/\text{m}^2\text{K}$]

A = area [m^2]

C_{min} refers to the minimum value of the heat capacitance rate found from comparing the heat capacitance rate of the hot and cold medium.

Parallel Flow Effectiveness

Effectiveness for a parallel flow heat exchanger is defined as follows:

$$\epsilon = \frac{1 - \exp[-NTU(1 + C_r)]}{1 + C_r}$$

Counter Flow Effectiveness

Effectiveness for counter flow heat exchangers is defined as follows:

$$\epsilon = \frac{1 - \exp[-NTU(1 - C_r)]}{1 - C_r \exp[-NTU(1 - C_r)]}$$

Heat Capacitance Rate

C_r refers to the ratio between the minimum and maximum value of heat capacitance rates of the hot and cold mediums.

The minimum and maximum values are determined from:

$$\text{and } C_r = \frac{C_{h, \min}}{C_{c, \max}}$$

Where C_h refers to the hot medium and C_c refers to the cold medium.

$$C_{h, \min} = \dot{m}_h c_{p,h} \Delta T_{h, \min}$$

$$C_{c, \max} = \dot{m}_c c_{p,c} \Delta T_{c, \max}$$

Phase Change

When a medium undergoes a phase change through the heat exchanger, the following variables behave as follows:

in the following equation:

$$h_{fg} = \infty; \Delta T \rightarrow 0$$

Therefore, the following heat equation must be used instead with the use of the latent heat transfer coefficient, h_{fg} :

$$Q = \dot{m} h_{fg} \Delta T$$

Phase Change Cont.

For a phase change:

$$T_1 \rightarrow T_2 \rightarrow \infty \text{!!!!!!} \quad T_1 \neq T_2 \quad \left(\frac{h_1}{T_1} - \frac{h_2}{T_2} \right) = 0$$

$$\frac{h_1}{T_1} - \frac{h_2}{T_2} = 0$$

Phase Change Cont.

Therefore, effectiveness for a phase change is as follows:

Which defines the effectiveness for a condenser and evaporator, parallel or counter flow.

$$\epsilon = 1 - \exp(-NTU)$$

Effectiveness with Constant Specific Heat ($C_r = 1$)

For parallel flow heat exchangers:

$$\epsilon = \frac{1 - e^{-NTU(1+C_r)}}{1 + C_r}$$

For counter flow heat exchangers:

$$\epsilon = 0.5$$

$$\epsilon = \frac{e^{-NTU} + C_r}{1 + C_r}$$

$$\epsilon \gg 0.5$$

Example 1

What is the effectiveness of a counter-flow heat exchanger that has a UA value of 24 kW/K if the respective mass rates of flow and specific heats of the two fluids are 10 kg/s, 2 kJ/(kgK) and 4 kg/s, 4 kJ/(kgK)?

Knowns:

$$UA = 24 \text{ kW/K}$$

$$c_1 = 2 \text{ kJ/kgK}, \dot{m}_1 = 10 \text{ kg/sec}$$

$$c_2 = 4 \text{ kJ/kgK}, \dot{m}_2 = 4 \text{ kg/sec}$$

Example 1 Soln.

$$C_1 = \dot{m}_1 c_1 = 20 \text{ kW/K}$$

$$C_2 = \dot{m}_2 c_2 = 16 \text{ kW/K}$$

$$C_2 < C_1 \quad \rightarrow \quad C_2 = C_{\min}$$

$$C_r = C_{\min}/C_{\max} = 0.8$$

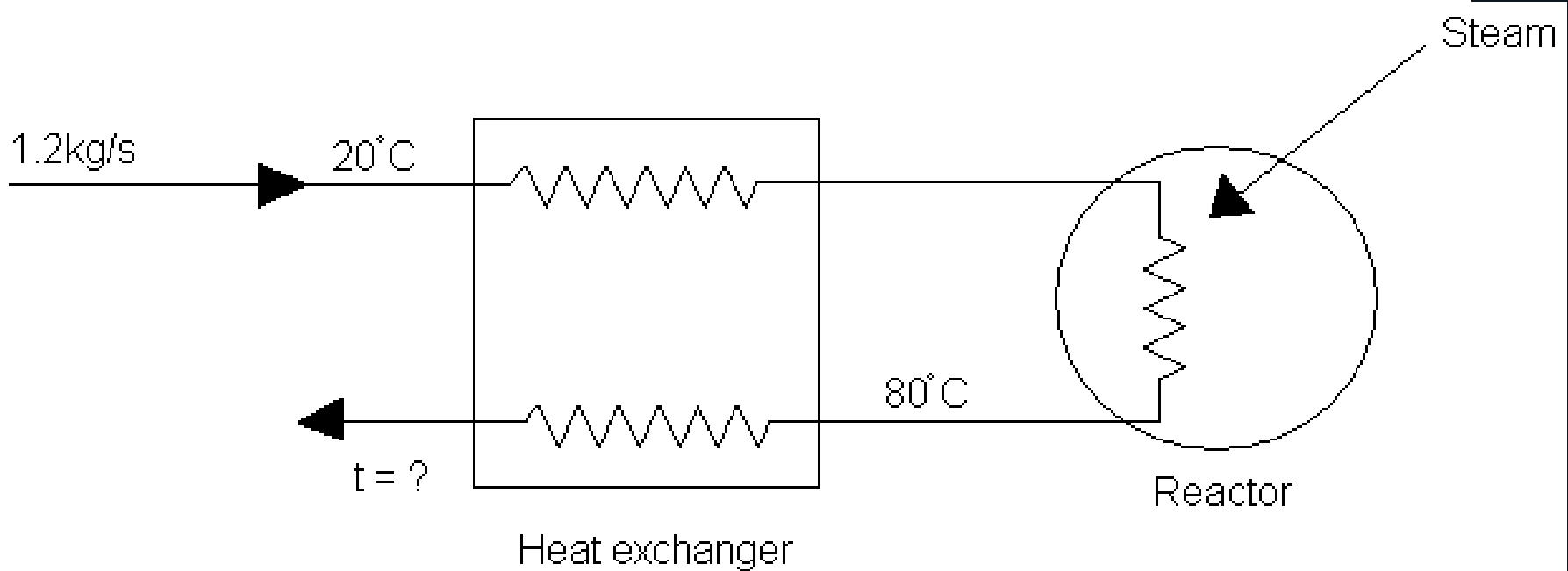
$$NTU = UA/C_{\min} = 1.5$$

$$\varepsilon = \frac{1 - \exp[-NTU(1 - C_r)]}{1 - C_r \exp[-NTU(1 - C_r)]} = 0.636$$

Example 2

In a processing plant a material must be heated from 20 to 80 °C in order for the desired reaction to proceed, whereupon the material is cooled in a regenerative heat exchanger, as shown in the figure below. The specific heat of the material before and after the reaction is 3.0 kJ/ (kgK). If the UA of this counter-flow regenerative heat exchanger is 2.1 kW/K and the flow rate is 1.2 kg/s, what is the temperature T leaving the heat exchanger?

Example 2 Configuration



Example 2 Soln.

Knowns:

$$\dot{m} = 1.2 \text{ kg/sec}$$

$$c_p = 3.0 \text{ kJ/kgK}$$

$$UA = 2.1 \text{ kW/K}$$

$$C_r = 1$$

$$NTU = UA/\dot{m}c_p = 0.583$$

$$\varepsilon = \frac{NTU}{1 + NTU} = 0.368$$

$$\varepsilon = \frac{q}{q_{max}} = \frac{(T_{h_i} - T_{h_o})}{(T_{h_i} - T_{c_i})} = 0.368$$

$$T_{h_o} = -0.368(80 - 20) + 80 = 57.9^\circ\text{C}$$

References

- Professor Jamal Yagoobi (lectures and examples)