Design of a Tubular Heat Exchanger

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We will use the following assumptions:

1. Heat transfer is under steady-state conditions.
2. The overall heat-transfer coefficient is constant throughout the length of pipe.
3. There is no axial conduction of heat in the metal pipe.
4. The heat exchanger is well insulated.

Change in heat energy in a fluid stream, if its temperature changes from T_1 to T_2, is expressed as:

where $\dot{m}$ = mass flow rate of a fluid (kg/s),

c_p = specific heat of a fluid (kJ/kg°C),

temperature change of a fluid is from some inlet temperature T_1 to an exit temperature T_2.

Hot fluid, H, enters the heat exchanger at location (1) and it flows through the inner pipe, exiting at location (2).

Its temperature decreases from $T_{H,\ inlet}$ to $T_{H,exit}$.

Fluid C, is a *cold* fluid that enters the annular space between the outer and inner pipes of the tubular heat exchanger at location (1) and exits at location (2).

Its temperature increases from $T_{C,inlet}$ to $T_{C,exit}$.

Conducting an energy balance, the rate of heat transfer between the fluids is:

$$q = \dot{m}_H c_{pH} (T_{H,inlet} - T_{H,exit}) = \dot{m}_C c_{pC} (T_{C,exit} - T_{C,inlet})$$

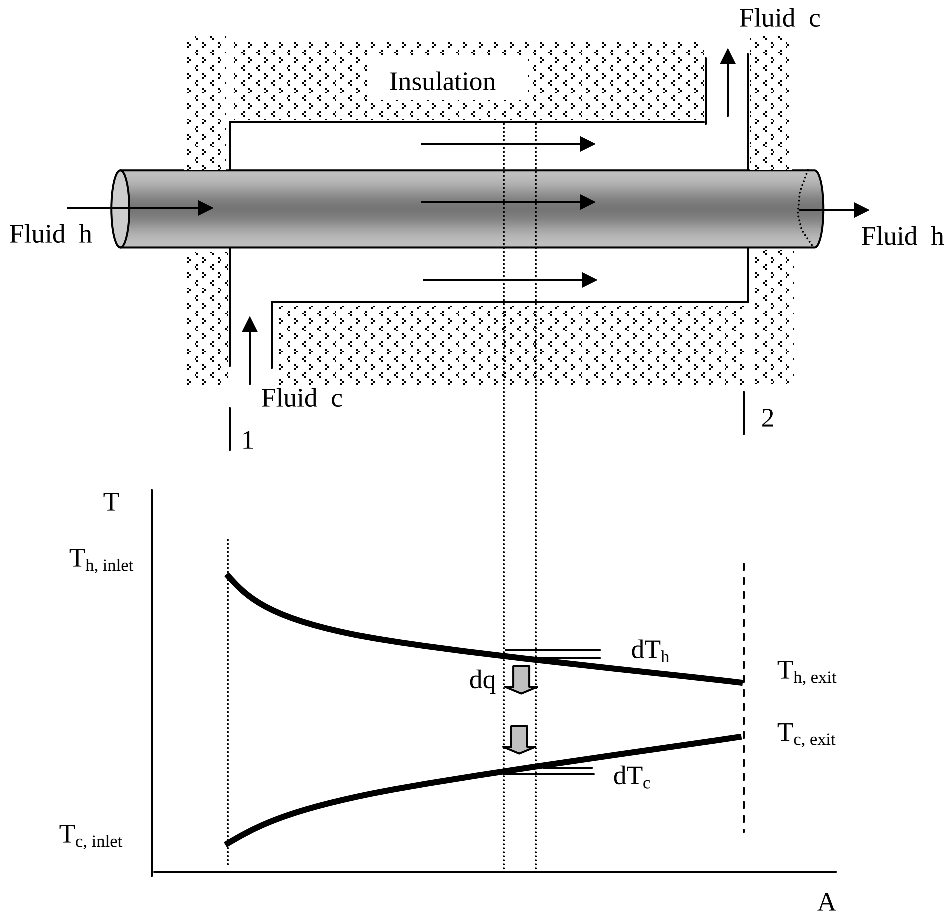
where c_{pH} is the specific heat of the hot fluid (kJ/kg°C),

c_{pC} is the specific heat of the cold fluid (kJ/kg°C),

$\dot{m}_H$ is the mass flow rate of the hot fluid (kg/s),

$\dot{m}_C$ is the mass flow rate of the cold fluid (kg/s).

The preceding equation has limited application



Consider a thin slice of the heat exchanger, the rate of heat transfer, *dq*, from fluid H to fluid C may be expressed as:

where ΔT is the temperature difference between fluid H and fluid C.

The temperature difference, ΔT, between the two fluids H and C is

For a small differential ring element as shown in Figure, using energy balance for the hot stream H

and, for cold stream C

$$dq = \dot{m}_C c_{pC} dT_C$$

In Eq , dT_H is a negative quantity, therefore we added a negative sign to obtain positive value for dq. Solving for dT_H and dT_C, we obtain

$$dT_H = -\frac{dq}{\dot{m}_H c_{pH}}$$

and

$$dT_C = \frac{dq}{\dot{m}_C c_{pC}}$$

Then subtracting

$$dT_H - dT_C = d(T_H - T_C) = -dq\left(\frac{1}{\dot{m}_H c_{pH}} + \frac{1}{\dot{m}_C c_{pC}}\right)$$

or

$$\frac{d(T_H - T_C)}{(T_H - T_C)} = -U\left(\frac{1}{\dot{m}_H c_{pH}} + \frac{1}{\dot{m}_C c_{pC}}\right)dA$$

Integrating

$$\ln\frac{(T_{H,exit} - T_{C,exit})}{(T_{H,inlet} - T_{C,inlet})} = -UA\left(\frac{1}{\dot{m}_H c_{pH}} + \frac{1}{\dot{m}_C c_{pC}}\right)$$

Noting that

we get

$$\ln\frac{\Delta T_2}{\Delta T_1} = -UA\left(\frac{1}{\dot{m}_H c_{pH}} + \frac{1}{\dot{m}_C c_{pC}}\right)$$

Substituting

$$\ln\left(\frac{\Delta T_2}{\Delta T_1}\right) = -UA\left(\frac{T_{H,inlet} - T_{H,exit}}{q} + \frac{T_{C,exit} - T_{C,inlet}}{q}\right)$$

Rearranging terms

$$\ln\left(\frac{\Delta T_2}{\Delta T_1}\right) = -\frac{UA}{q}\left((T_{H,inlet} - T_{C,inlet}) - (T_{H,exit} - T_{C,exit})\right)$$

Rearranging terms,

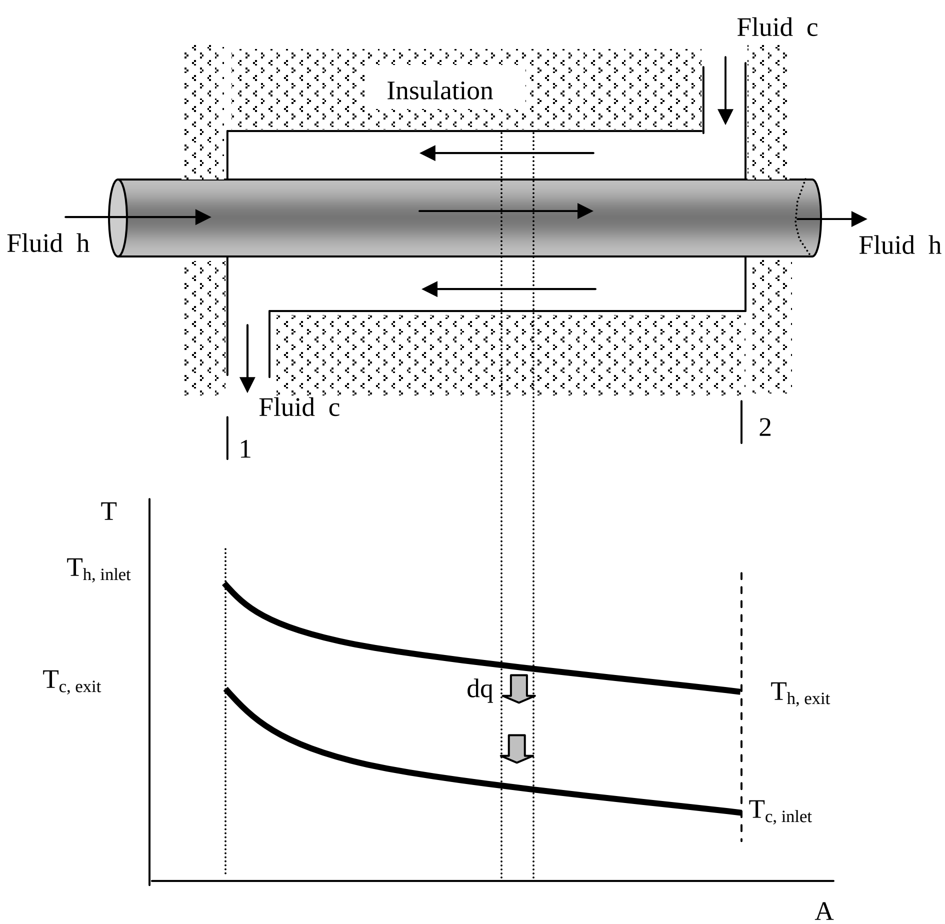
$$q = UA(\Delta T_{lm})$$

where

$$\Delta T_{lm} = \frac{\Delta T_2 - \Delta T_1}{\ln \frac{\Delta T_2}{\Delta T_1}}$$

ΔT_{lm} is called the log mean temperature difference.

A Counter-Current Heat Exchanger



Class Problem

Calculate the log mean temperature difference for a heat exchanger with the following data, the temperature of hot stream decreases from 150°C to 50°C, while the temperature of cold stream increases from 40°C to 80°C.

Consider another case when temperature of hot stream decreases from 150°C to 50°C and cold stream temperature increases from 40°C to 45°C.