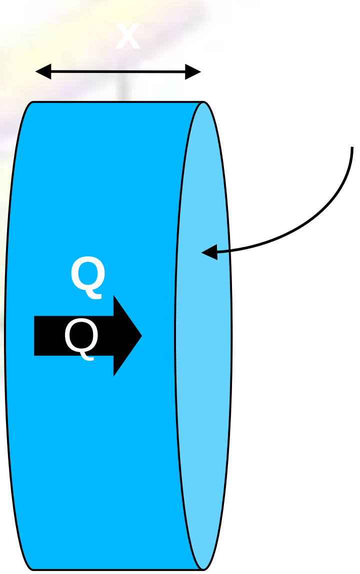
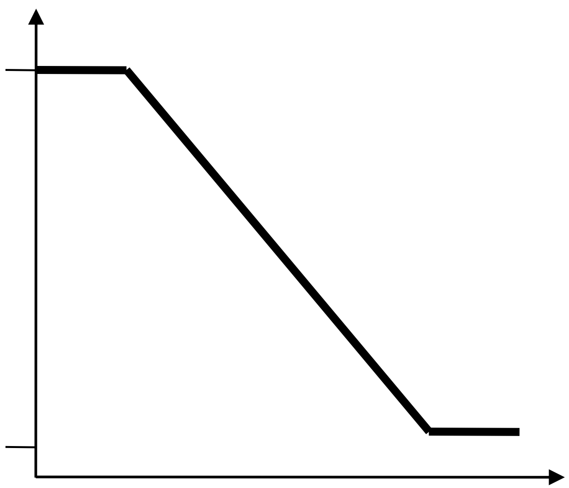
Heat Transfer

- Thermal conduction
- Heat Exchanger Types
  - Parallel / counter/ cross flow
  - Double pipe
  - Shell and tube
  - Plate / Compact
  - Single / multi pass
- Heat Exchanger Analysis
  - Conservation of heat
  - Log mean temperature difference
  - Effectiveness / NTU
  - Fouling
  - Heat Exchanger Design

Thermal Conduction

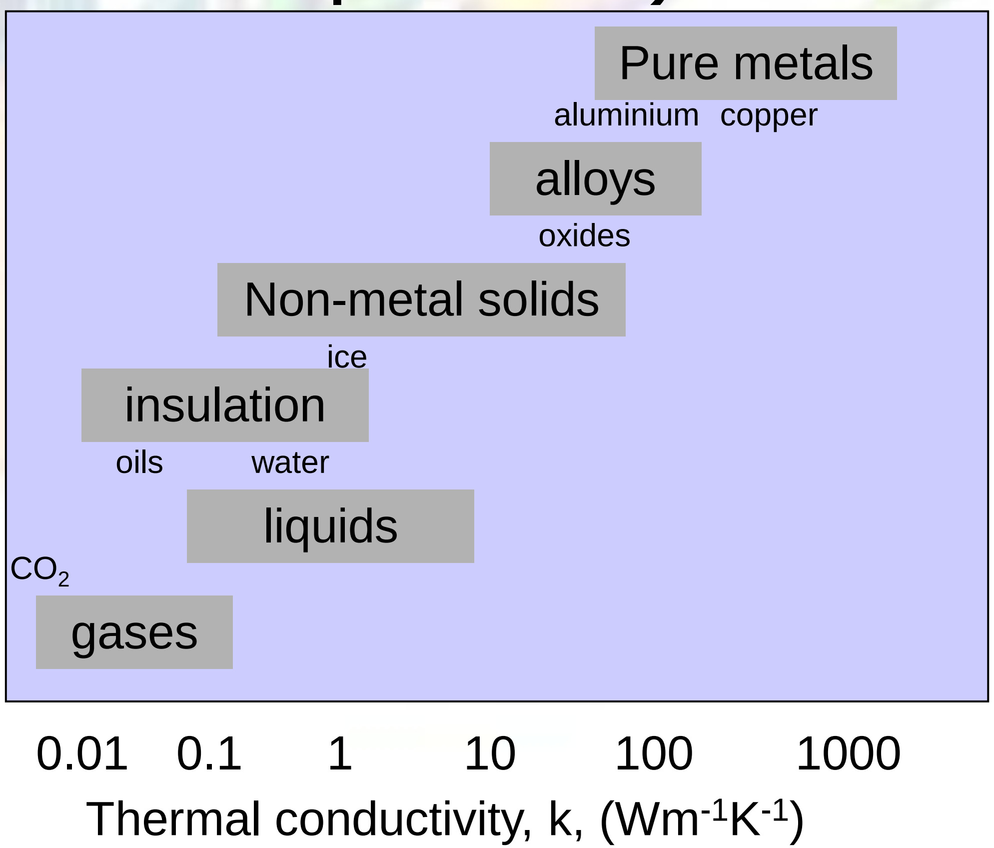
- In all our heat exchangers we have two fluids at different temperatures separated by a wall
- Heat transferred by conduction across the wall
- Remember from 1st year Physics; $Q/t = kA(T_2 - T_1)/x$
- Differential form:
  - $Q/t = kA\, dT/dx$





Thermal Conductivity

- Property of material
- Units: $Wm^{-1}K^{-1}$
- Depends on temperature (decreases for most metals with temperature)



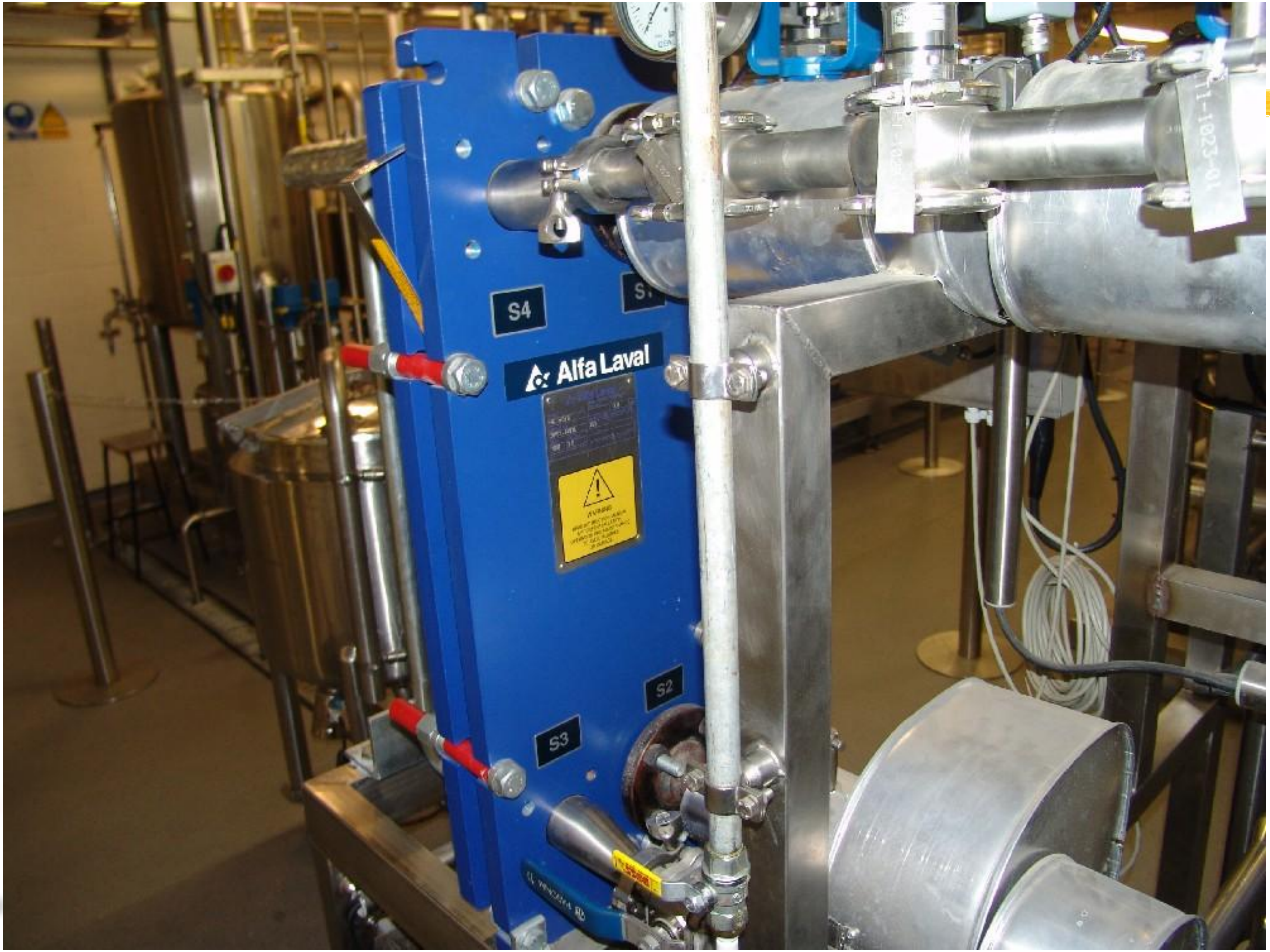
Example

- An aircraft window is $0.1m^2$. It is 10mm thick and made from polycarbonate (k_{pc} = $0.21Wm^{-1}K^{-1}$). The temperature difference across the window is 80^oC. Calculate the heat loss through the window, the total heat loss if there are 200 windows on the plane, and the heating bill on a four hour flight if it costs €1kWhr.

[168W, 33.6kW, €134.4]

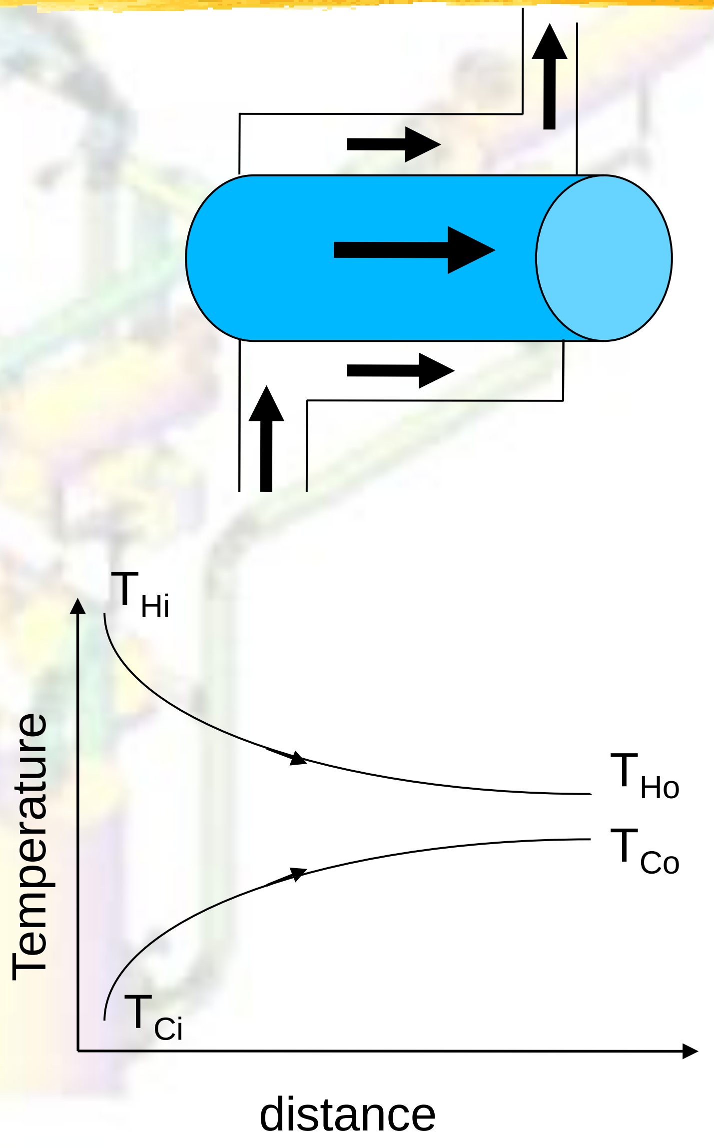
Heat Exchangers

- Two fluids at different temperatures in thermal contact
- Separated by solid wall
- Heat transferred by conduction through the wall and then convection through the fluid
- The convection works best if flow turbulent
  - Specify minimum flow rate (say 3m/s)
- Often used in regeneration mode; hot fluid leaving a reactor vessel heats incoming fluid


S4
Alfa Laval
S2
S3

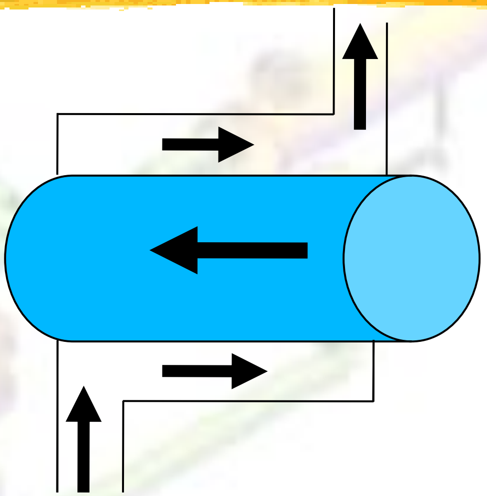
Parallel / Counter / Cross Flow

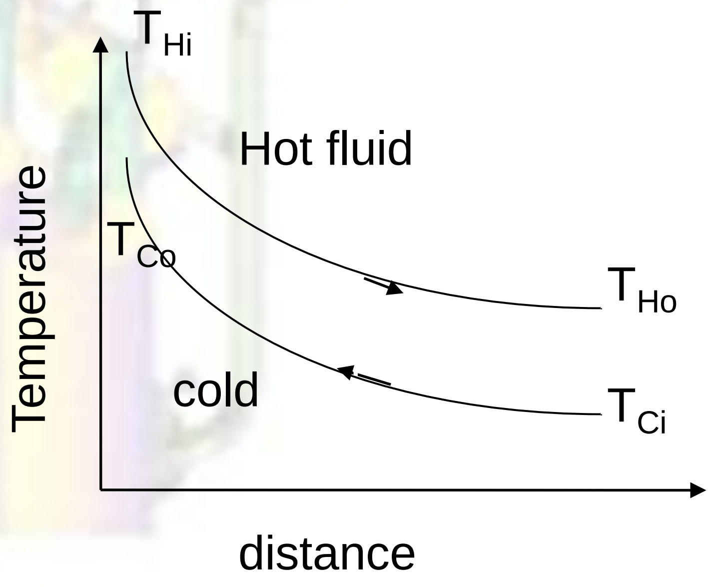
- Parallel Flow
  – two fluids flow in same direction



Parallel / Counter / Cross Flow

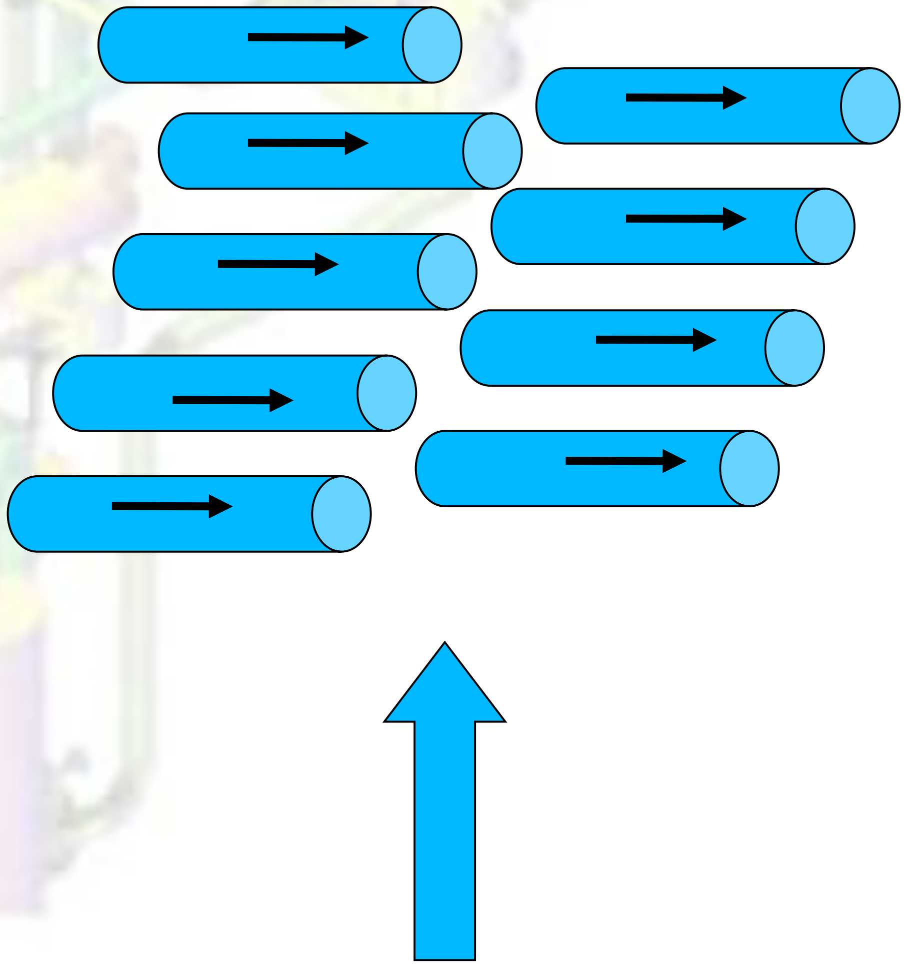
- Counter Flow
  – two fluids flow in opposite directions



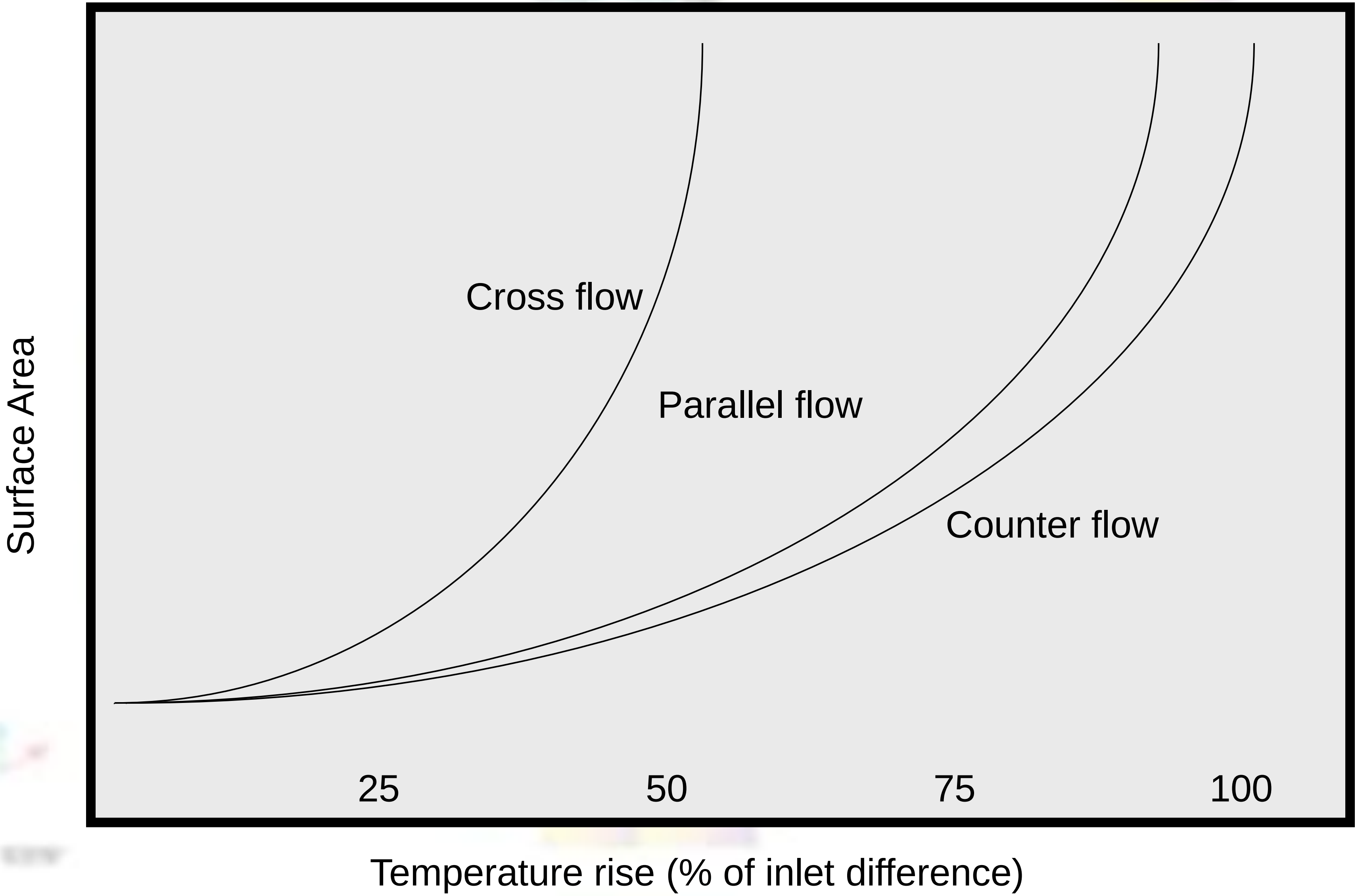


Parallel / Counter / Cross Flow

- Cross Flow – two fluids flow at right angles to each other



How Different Flow Patterns Compare

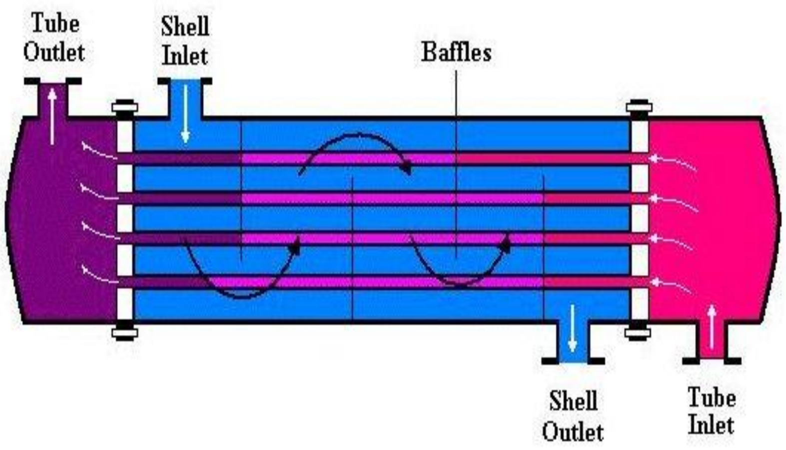


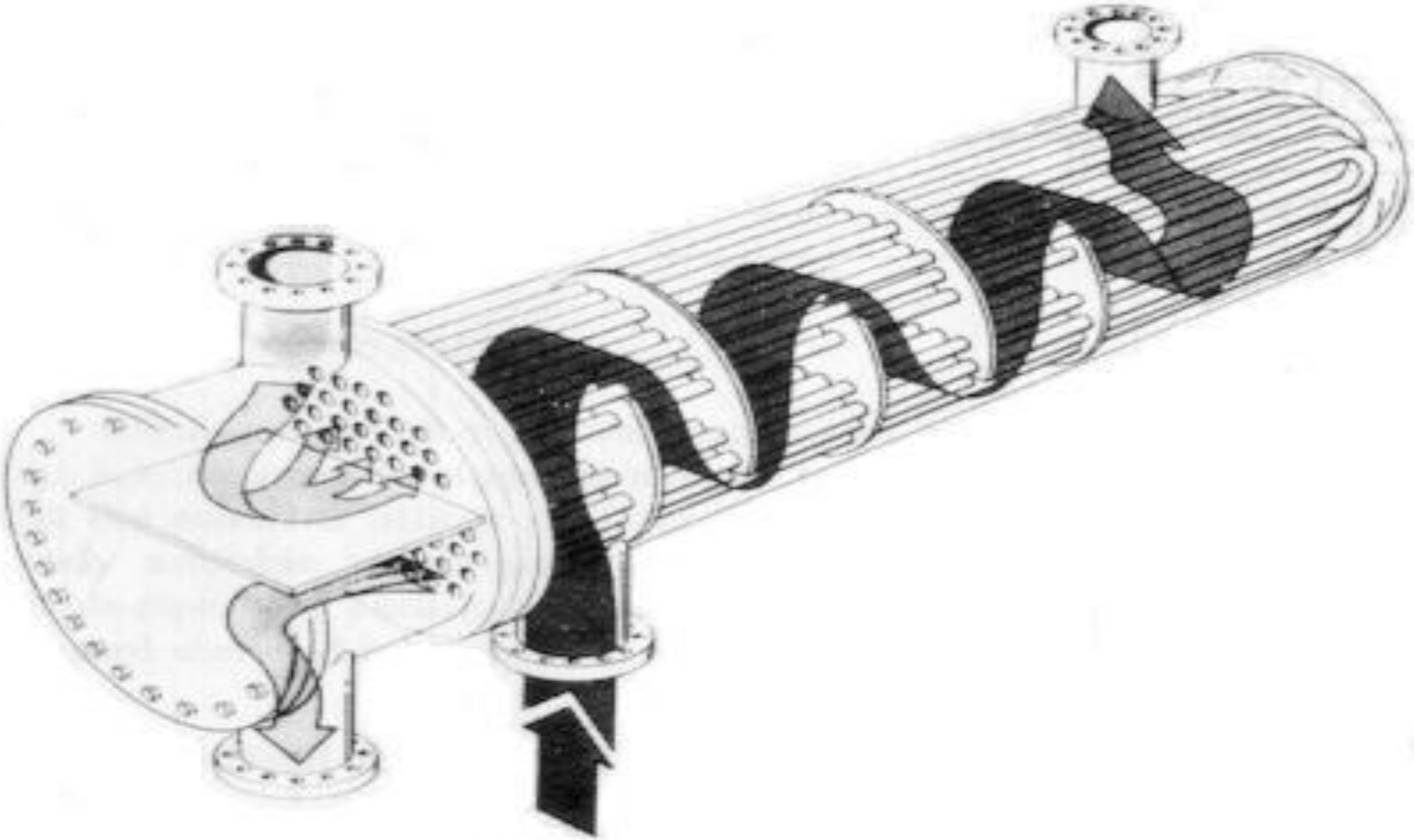
Double Pipe Heat Exchanger

- One pipe located concentrically inside a second, larger one
- Have to be large to be effective

Shell & Tube Exchangers

- Most common HE (80% of market)
- One fluid in network of tubes, second surrounding in shell
- Baffles to complicate flow, improve efficiency (straight, helical)
- If phase change, should be in shell
- Tubes usually doubled or quadrupled back (input and output at same end)
- Tubes ribbed on inner and outer surfaces

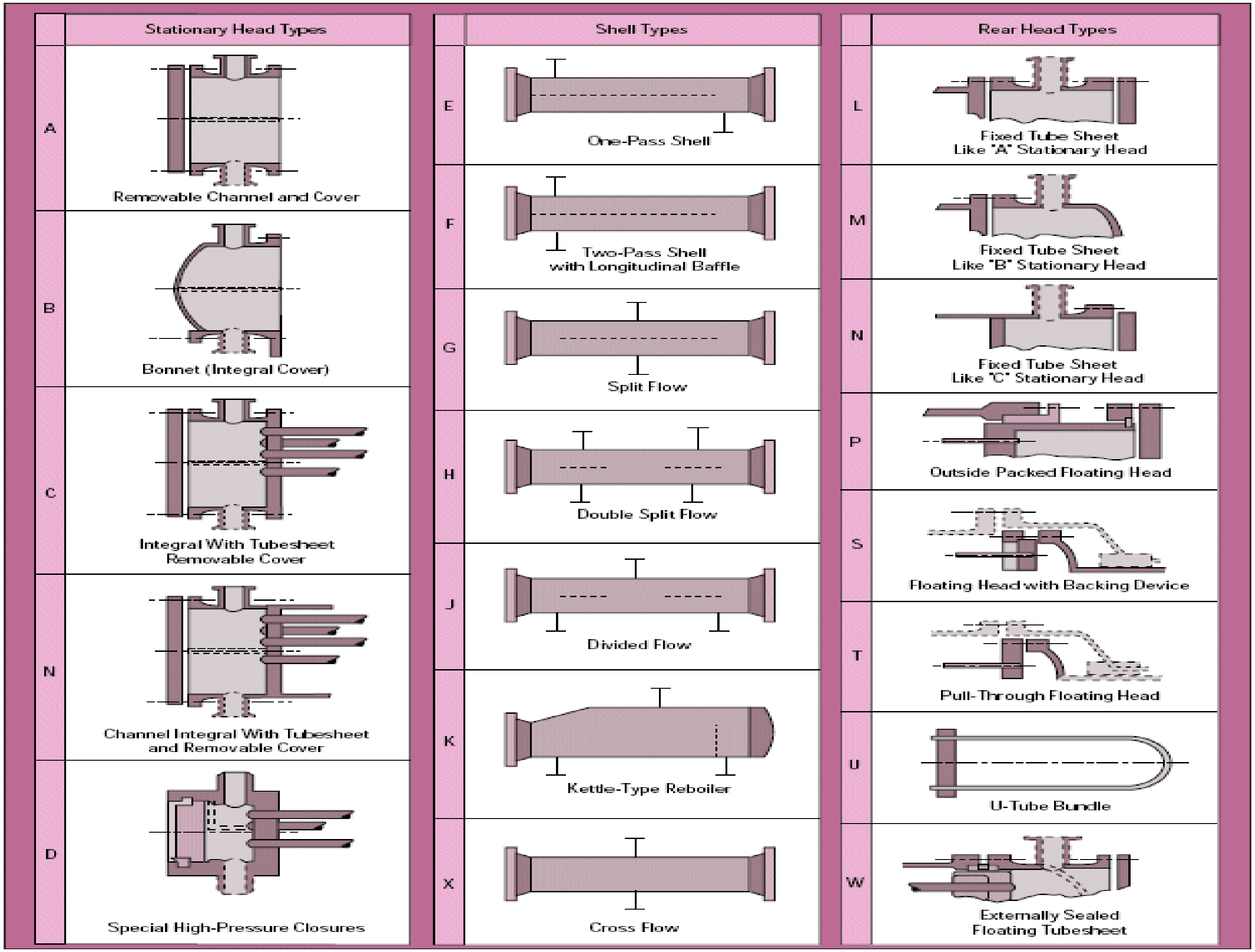




Shell & Tube Exchangers

- Specified by three letter code from TEMA
- Put high pressure (up to 100MPa) or corrosive fluids in tubes
- Put fluids prone to fouling in tubes (higher velocity = less build-up)
- Get lower pressure drop in tubes
- Vibration can be problem – avoid resonance
- Temperature stresses important – U shaped bundles good

3 Letter TEMA Codes



Source:

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Heat Exchanger Analysis

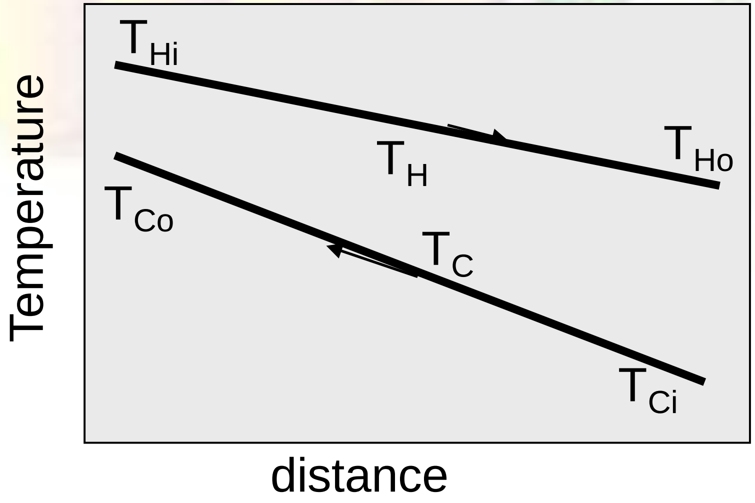
- Four temperatures
- Two flow rates
- Two heat capacities
- Conductivity of separating wall
- Area of separating wall
- Fouling
- Type of flow (cross/parallel/counter)

Conservation of Heat

- Heat lost by hot fluid = heat gained by cold fluid
- Heat change
  - $Q = mc\Delta T$ for change in temperature
  - $Q = mL_{v,f}$ for change of phase
- $mc = C$

Log Mean Temperature Difference

- For conduction – Q/t = UA ΔT where ΔT is the difference in temperatures
- But for a heat exchanger ΔT changes along the length of the device
- For example, for a counter flow the profile is shown below
- So what value of ΔT should we use in the equation?



$$\Delta T_{lm} = \frac{[(T_{H_o} - T_{C_i}) - (T_{H_i} - T_{C_o})]}{\log_e \frac{(T_{H_o} - T_{C_i})}{(T_{H_i} - T_{C_o})}}$$

(counter flow)

- is known as the log mean temperature difference.
- It reflects an average value of the temperature difference across the Heat Exchanger
- For crossflow or multipass heat exchangers we use the same expression but introduce a correction term:
- $$\Delta T_{lm} = F \frac{[(T_{H_o} - T_{C_i}) - (T_{H_i} - T_{C_o})]}{\log_e \frac{(T_{H_o} - T_{C_i})}{(T_{H_i} - T_{C_o})}}$$ (cross flow)
- F usually found from graphs (use F = 0.9 when graphs not available)
- For parallel flow the equation is:

$$\Delta T_{lm} = \frac{[(T_{H_o} - T_{C_o}) - (T_{H_i} - T_{C_i})]}{\log_e \frac{(T_{H_o} - T_{C_o})}{(T_{H_i} - T_{C_i})}}$$

(parallel flow)

- In general get:

$$\Delta T_{lm} = F \frac{\Delta T_2 - \Delta T_1}{\log_e \Delta T_2 / \Delta T_1}$$

- Where ΔT_2 is the temperature difference at one end of the pipe, ΔT_1 is the temperature difference at the other end and F is a correction factor read from tables

Problem on LMTD

- A parallel flow double pipe heat exchanger heats 2.52kg/s of water from 21.1^oC to 54.4^oC using hot water under pressure entering at 110^oC and leaving at 70^oC. The heat exchanger area is A = 4.3m^2 and the heat capacity of water is 4180$Jkg^{-1}{}^oC^{-1}$. Calculate the ΔT_{lm} in the exchanger and the overall heat transfer coefficient U.

  [42.1^oC, 1938$Wm^{-2}K^{-1}$]

- A counter flow double pipe heat exchanger heats water from 15^oC to 74.2^oC using hot water entering at 91.3^oC and leaving at 62.2^oC. The heat exchanger area is A = 8.51m^2 and the overall heat transfer coefficient U = 2500$Wm^{-2}K^{-1}$. Calculate the ΔT_{lm} in the exchanger, q, and the flow rates in both pipes.

  [29.3^oC, 6.25x10^5W, 2.52kg/s for the cold water,5.14kg/s for the hot]

- A parallel flow double pipe heat exchanger heats water from 24^oC to 44.9^oC using hot water entering at 95^oC. The heat exchanger area is A = 4.4m^2. The flow rates are 1.14kg/s for the cold water and 3.1kg/s for the hot water. Calculate the temperature of the hot water leaving the exchanger, the LMTD, and the overall heat transfer coefficient U.

  [83.8^oC, 53.4^oC, 4238$Wm^{-2}K^{-1}$]

Fouling

Fouling

- A €5bn problem (mostly in petrochem industry)
- Estimated to account for 3% of CO_2 emissions
- Problems
  - Reduced heat transfer
  - Reduced throughput
  - Increased pressure drop
  - Replacement costs
  - Cleaning costs and disposal of toxic wastes

Fouling - Causes

- Dirt, soot scale
- Coke from petroleum industry
- Corrosion products
- Algae and other biological growths (prevented by copper)
- Sedimentation – if fluid is a suspension. Self limiting
- Inverse solubility – as fluid cools down
- Chemical reactions

Fouling - Prevention

- Avoid low fluid velocities (less that 1m/s)
- Avoid high fluid velocities (greater than 4m/s for water). Causes errosion
- Avoid big temperature differences