# Homework N$^o$ 4: heat transfer equipments

*a.*

A heat exchanger is required to cool 20 $kg/s$ of water from 360 $K$ to 340 $K$ by means of 25 $kg/s$ water entering at 300 $K$If the overall coefficient of heat transfer is constant at $U = 2\ kW/m^2K$, calculate the surface area required in (a) a countercurrent concentric tube exchanger, and (b) a co-current flow concentric tube exchanger.

*b.*

A furnace is constructed with $\delta_1 = 0.20\ m$ of fiberbrick, $\delta_2 = 0.10\ m$ of insulating brick, and $\delta_3 = 0.20\ m$ of building brick. The inside temperature is 1200 $K$ and the outside temoerature is 330 $K$. Thermal conductivities are $k_1 = 1.4\ W/mK$, $k_2 = 0.21\ W/mK$ and $k_3 = 0.7\ W/mK$.

1. Estimate the heat loss per unit area;
2. calculate the temperature profile across the multilayered wall;
3. discuss possible solutions to halve the heat loss maintaing the same overall thickness for the wall layer ($\delta = \sum \delta_i$, $I = 1, 3$).

*c.*

A steel tube 55 $mm$ inner diameter and 60 $mm$ outer diameter ($k_0 = 16\ W/mK$) is insulated with a $\delta_1 = 50\ mm$ layer of silica foam, for which the conductivity is $k_1 = 0.055\ W/mK$, followed with a $\delta_2 = 40\ mm$ layer of cork with a conductivity of $k_2 = 0.05\ W/mK$.

1. Calculate the thermal resistance of each layer of the pipe (steel pipe, silica foam and cork). Which one is controlling?
2. If the temperature of the fluid inside the pipe is $150^oC$ and the outer surface of the cork is $30^oC$, calculate the temperature profile across the layers and the heat loss in Watts per meter of pipe.

*d.*

14.4 $t/h$ of nitrobenzene (thermal capacity $C_p = 2380\ J/kg\ K$, conductivity $k = 0.15\ W/mK$, viscosity $\mu = 0.70 \cdot 10^{-3} Pa \cdot s$) is to be cooled from 400 $K$ to 315 $K$ by heating a stream of benzene from 305 $K$ to 345 $K$.

1. Can we use a single pass, co-current heat exchaanger to cool the flow?
2. Two tubular heat exchangers are available each with 0.44 $m$ internal diameter shell fitted with 166 tubes, 19 $mm$ outer diameter and 15 $mm$ inner diameter, each 5 $m$ long. The tubes are arranged in two passes on 25 $mm$ square pitch with a baffle spacing of 150 $mm$. There are two passes on the shell side and operation is to be countercurrent. With benzene passing through the tubes, the anticipated film coefficient on the tube side is 1000 $W/m^2K$. Calculate tube side coefficient based on outside area;
3. Assuming true cross-flow prevails in the shell, calculate shell side coefficient and overall heat transfer coefficient.
4. What value of scale resistance could be allowed if these units were used?

*e.*

Flue gases produced by a steal plant (flow rate 110 $m^3/s$ at $T = 1000\ K$ and atmspheric pressure) contain iron oxides particles iof small size which should be removed using a fabric filter. Since the temperature of flue gases is too high for any filtering material, a preecooling system should be designed to cool down the flue gases below the operating limits of available fabric materials (e.g. Teflon, $T_{max} = 505\ K$). Assuming the waste gases behave like air ($C_p = 1.08\ kJ/kgK$, $M = 29\ kg/kmol$), calculate

1. the amount of air required to cool down the flue gases by dilution with ambient air ($T_{env} = 25^oC$) up to $0.9T_{max}$;
2. the amount of water which should be sprayed and evaporated inside the waste gases to cool down waste gases to $0.9T_{max}$;
3. the thermal heat which can be recovered using a properly sized heat exchanger;
4. the plant engineer suggests to install a serpentine ($D = 2\ cm$) of copper ($K = 398\ W/mK$, thickness $\delta = 3\ mm$) at the wall of the duct ($D_{gas} = 0.80\ m$) conveying the waste gases (i) to cool down the pipe wall and (ii) to recover the heat from flue gases; considering that diathermic oil ($Q = 0.5\ l/s$, $C_p = 2.5\ kJ/kgK$, $\nu = 6 \cdot 10^{-7} m^2/s$, $\rho = 820 \cdot kg/m^3$, and $K = 0.105\ W/mK$) can be circulated inside the serpentine, calculate the overall heat transfer coefficient between waste gases and oil;
5. calculate which should be the surface area of the serpentine to recover all the heat available before waste gases enter the fabric filter. Calculate the power of the pump necessary to circulate the diathermic oil along the serpentine.