# Process Systems Engineering

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## Exercise # 6

Calculate the economic potential of fourth level by applying the following correlations, whereas the total cost of the column is given by the installed cost, and the fillers cost.

❖ **Pressure vessels, Columns, Reactors**

See Exercise #4.

❖ **Distillation Tray-Columns**

Installed cost: $C.I._{trays} = \left(\frac{M\,\&\,S}{280}\right) 4.7 \cdot D^{1.55} \cdot H_{TOT} \cdot F_c$ [equipment cost + installation cost]

with $D$ and $H_{TOT}$ in [ft]. $H_{TOT}$ is the total height of the column:

$H_{TOT} = \left(N_{trays} - 1\right) H_{Spacing\,between\,trays} + H_{Top-Bottom}$

with $H_{Top-Bottom} \cong 4-5\ \text{m}$.

The factor $F_c$ is calculated as the sum of three factors: $F_c = F_s + F_t + F_m$.

| Tray spacing [in] | 24 | 18 | 12 |
|---|---|---|---|
| $F_s$ | 1.0 | 1.4 | 2.2 |

| Tray type | No down-comer | Sieve | Valve | Bubble cap | "Koch Kaskade" |
|---|---|---|---|---|---|
| $F_t$ | 0.0 | 0.0 | 0.4 | 1.8 | 3.9 |

| Tray Material | Carbon Steel | Stainless Steel | Monel |
|---|---|---|---|
| $F_m$ | 0.0 | 1.7 | 8.9 |

❖ **Heat exchangers**

Installed cost: $C.I. = \left(\frac{M\,\&\,S}{280}\right) 101.3 A^{0.65} \left(2.29 + F_c\right)$ [equipment cost + installation cost]

with $A$ = Area of heat transfer in [ft$^2$], e $F_c = \left(F_d + F_p\right) F_m$

The so called "installed cost" is the sum of the purchase cost and the installation cost.

| Material $\frac{Shell}{Tube}$ | $\frac{CS}{CS}$ | $\frac{CS}{Brass}$ | $\frac{CS}{Mo}$ | $\frac{CS}{SS}$ | $\frac{SS}{SS}$ | $\frac{CS}{Monel}$ | $\frac{Monel}{Monel}$ | $\frac{CS}{Ti}$ | $\frac{Ti}{Ti}$ |
|---|---|---|---|---|---|---|---|---|---|
| $F_m$ | 1 | 1.3 | 2.15 | 2.81 | 3.75 | 3.1 | 4.25 | 8.95 | 13.05 |

N.B.: Brass = Brass, Mo = Molybdenum, Ti = Titanium

| Pressure [psi] | ≤ 150 | 300 | 400 | 800 | 1000 |
|---|---|---|---|---|---|
| $F_p$ | 0 | 0.1 | 0.25 | 0.52 | 0.55 |

| Heat exchanger type | Kettle | Floating Head | U-tube | Fixed tube |
|---|---|---|---|---|
| $F_d$ | 1.35 | 1.00 | 0.85 | 0.8 |

For the calculation of heat exchange area, the heat exchanged in the condenser is:

$$Q_c = U_c A_c \Delta T_{ml} = W_{H_2O} c_{p,H_2O} \left(T_{out} - T_{in}\right) = \Delta H_{ev}\left(T_{cond}\right)\overline{V}$$

where $U_c$ is the global heat transfer coefficient, $A_c$ is the exchange area of the condenser, $\Delta T_{ml}$ is the logarithmic mean temperature difference, $W_{H_2O}$ is the flowrate of cooling water, $T_{in}$ and $T_{out}$ are the temperatures in inlet and outlet to the condenser (generally, $T_{in} = 30°C$ e $T_{out} = 50°C$), $\overline{V}$ is the condensing flowrate at the column head. In the case of stabilizer we recommend $T_{out} \cong 38°C$.

The logarithmic mean temperature difference is calculated as:

$$\Delta T_{ml} = \frac{\left(T_{cond} - T_{out}\right) - \left(T_{cond} - T_{in}\right)}{\log \dfrac{T_{cond} - T_{out}}{T_{cond} - T_{in}}}$$

Consider $U_c \cong 580\ W/m^2K$. Use condenser duty and $T_{cond}$ from Unisim.

For the calculation of the heat exchange area of the reboiler, the heat exchanged in the reboiler is:

$$Q_r = U_r A_r \Delta T_r = W_{steam} \Delta H_{ev}^{steam} = \Delta H_{ev}\left(T_{reb}\right)\bar{V}$$

in which $W_{steam}$ is the flow rate of steam to the reboiler, $\bar{V}$ is the evaporating flow rate in the reboiler (process side).

Consider $U_r \Delta T_r = 11250\,\mathrm{Btu/h\,ft^2}$. Use reboiler duty from Unisim.

The operating costs related to the reboilers can be calculated considering that the cost of 30 bar steam is 1.65€/1000lb, while that of the 70 bar steam is 2.25€/1000 lb. The cost of cooling water to calculate the operating costs related to the condensers is 0.06€/1000 gal.

## ❖ Antoine Equation - Water coefficients

$$P_i^0(T) = \exp(C_1 + {C_2}/{T} + C_3\ln(T) + C_4 T^{C_5}) \qquad [Pa], [K]$$

| $C_1$ | $C_2$ | $C_3$ | $C_4$ | $C_5$ |
|---|---|---|---|---|
| 73.649 | -7258.2 | -7.3037 | 4.17e-6 | 2 |