Process System Engineering

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Exercise 6

Calculations of the economic potential of fourth level (EP4)

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Defining EP_4

The economic potential of the fourth level is defined as:

$$EP_4 = EP_3 - \left(CAPEX + OPEX\right)_{separation\ section}$$

where EP_4 is in [M€/y].

- If the potential of the fourth level is greater than zero, the process may be economically attractive; *vice versa*, the process is definitely not economically interesting.

- **Remarks**: usually, the cost of the flash is considered to be negligible, because it is much lower than that of a distillation column.

- To calculate EP4, we must design all the pieces of equipment for the separation of the products from light and heavy by-products.

Cost

Equipment costs are the sum of two contributions:

- CAPEX = the fixed costs of investment;
- OPEX = operating expenditures/costs.

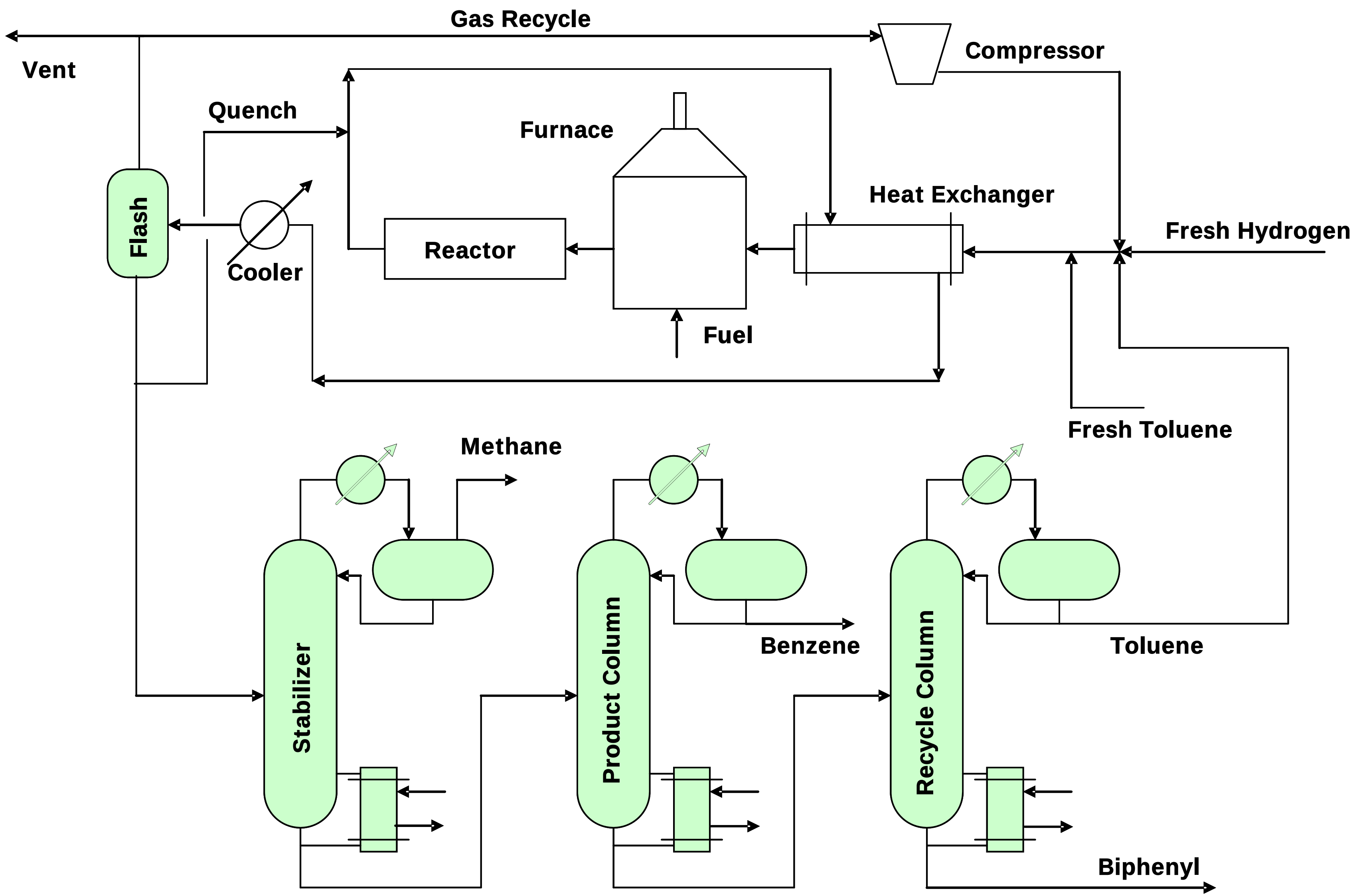
In the calculation of EP4, the cost of columns and heat exchangers (*i.e.* reboilers and condensers, but also the furnace and other important process to process heat exchangers) is taken into account.

For the sake of simplicity, we will assume the same depreciation period for all the process units which is the one assumed for the EP3 evaluation (*i.e.* 5 years due to the mechanical and thermal stresses on the compressor).

The CAPEX are the sum of the physical costs of the material used for the construction of the equipment and processing costs (*i.e.* welds, ...).

The OPEX depend on the operating conditions such as the consumption of electrical energy and utilities (*i.e.* compressed air, oil, ...).

HDA -Separation Section



Column Costs

Column costs depend on two different contributions:

- Installation costs (CAPEX);
- Operating costs (OPEX).

Regarding columns, operating costs are **null**, because those pieces of equipment can be schematized through a pressure tank model (as seen in the calculation of EP2 for the reactor). In order to guarantee the proper working, the duties are supplied by two auxiliary units: the **condenser** and the **reboiler**.

Installation costs consist of two factors:

- The column purchase cost (pressure vessel);
- The internals cost (*e.g.*, trays), as a function of their typology, their building material, and the space between two adjacent trays.

Column purchase cost

The purchase cost of a column is evaluated through the following expression (with D,H in [ft] and M&S = 1110):

$$C.I._{column} = 101.9 \frac{M\,\&\,S}{280} D^{1.066} H_{TOT}^{0.802} \left(2.18 + F_P F_M\right) \qquad [€]$$

Evaluating the cost requires the design of the column, in order to find its diameter (D), and height (H).

The total height of a column (H_{TOT}) is defined thought the following expression, as a function of the trays number, and the top and bottom spacing, in order to guarantee a liquid holdup both in the bottom of the column and in the reboiler, and to collect the vapor phase to be sent to the condenser:

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

where $H_{Top-Bottom} \cong 4-5\ \mathrm{m}$

Internals (trays) cost

The trays cost of a column is evaluated through the following expression (with D,H in [ft] and M&S = 1110):

$$C.I._{trays} = \left(\frac{M \& S}{280} \right) 4.7 D^{1.55} H_{TOT} F_c$$

Where F_c is the sum of three different contributions:

$$F_c = F_s + F_t + F_m$$

- F_s is a function of the spacing between the trays;
- F_t is a function of the tray typology;
- F_m is a function of the tray building material.

Hint

The only column that works with a rather high hydrogen concentration is the stabilizer: the suggested building material for such a piece of equipment is stainless steel; on the other hand, carbon steel (cheaper!) is used for the other columns.

Heat exchanger costs

Heat exchanger costs derive from three different terms:

- Purchase costs (CAPEX);
- Installation costs (CAPEX);
- Operating costs (OPEX).

Purchase and installation costs are evaluated as a function of the heat exchanger dimensions, its typology, building material, and working pressure. Their sum is called **installed cost**. The parameter that characterizes the heat exchanger dimensions is the **exchange area**.

Operating costs depend on the duty supplied that process unit to work correctly. OPEX term can be evaluated by means of the utility flowrate, its typology (*e.g.*, 30 bar steam, 70 bar steam, cold water), and its mass cost.

Condenser - exchange area

The heat exchanged in the condenser can be evaluated with the following expression:

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

Where U_c is the overall exchange coefficient (normally, $U_c \approx 580\ W / m^2\ K$), A_c is the exchange area, ΔT_{ml} is the average logarithmic temperature difference, W_{H2O} is the cooling water flowrate, T_{out} and T_{in} are the inlet, and outlet coolant temperatures (normally, T_{in} = 30°C and T_{out} = 50°C), V is the head vapor flowrate.

The latent heat of condensation is evaluated with the following expression:

$$\Delta H_{ev} \left(T_{cond} \right) = \sum_{i=1}^{NC} x_i \Delta H_{ev}^{i} \left(T_{cond} \right)$$

Condenser – exchange area

The average logarithmic temperature difference is:

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

N.B.:

- With reference to the stabilizer column, T_{out} must be lower than the condensate temperature (T ≈ 50°C). A good approximation for this temperature is T_{out} ≈ 38°C.
- It is not so common to design heat exchangers with active areas greater than 500 m^2. If this is the case, it is recommended to design a battery of two or more heat exchangers in series!

Reboiler - exchange area

The heat exchanged in the reboiler can be evaluated with the following expression:

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

Where W_{steam} is the steam (utility) flowrate and $\bar{V}$ is the evaporating flowrate.
It is possible to assume $U_r \Delta T_r = 11250\,\mathrm{Btu/h\,ft^2}$

The average logarithmic temperature difference is:

$$\boxed{\Delta T_{ml} = T_{steam} - T_{reb}}$$

Heat exchanger investment costs

- **Purchased cost**

$$C.A. = \left(\frac{M\&S}{280}\right)101.3A^{0.65}F_c$$

as a function of the exchange area A [ft^2] and F_c factor, this depends on the exchanger typology, the shell and tube building material, and the working pressure.

$$F_c = \left(F_d + F_p\right)F_m$$

- **Installed cost (purchased cost + installation cost)**

$$C.A. = \left(\frac{M\&S}{280}\right)101.3A^{0.65}\left(2.29 + F_c\right)$$

Heat exchanger operating cost

Heat exchanger operating cost can be evaluated with the following expression (accordingly to its function, *i.e.* condenser or reboiler):

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

$$Q_r = U_r A_r \Delta T_{ml} = W_{steam} \Delta H_{ev}^{steam}$$

Once the duty, the utility inlet, and outlet temperature (or latent heat of evaporation) are known, it is possible to compute the optimal utility flowrate.

The cost of utilities is the following:

- 30 bar steam = 1.65 €/ 1000 lb;
- 70 bar steam = 2.25 €/ 1000 lb;
- Cooling water = 0.06 € / 1000 gal.