Process Systems Engineering
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Exercise 4

Assessing the economic potential of level-3 (EP3)

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Definitions EP_3

Economic potential for the third level is defined as:

$$EP_3 = EP_2 - €_{reatt} - €_{compr}$$

With EP_3 in [M€/y].

If the potential of third level is greater than zero, the process may be economically attractive, if the potential of the third level is less than zero, the process is definitely not economically interesting.

Remark: the cost of the pumps is negligible compared to the cost of the compressors.

To calculate the EP3 it is mandatory to find the dimensions of the reactor and the compressor.

Cost

Equipment cost is the sum of the following two components:

- Fixed cost of investment;
- Operative cost.

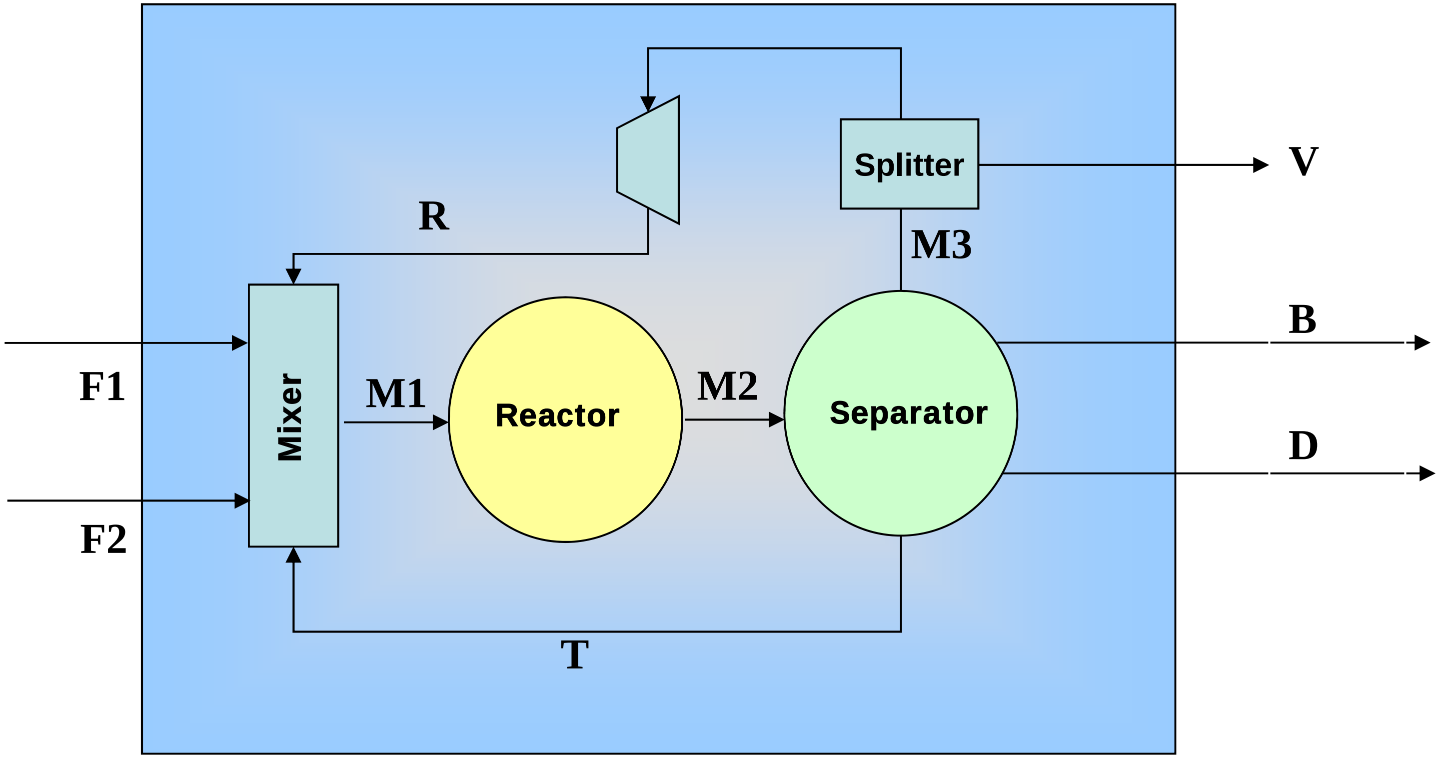
In the evaluation of EP3, its is taken into account the cost of the reactor and compressor. The **depreciation period** for the compressor and the reactor is equal to 5 years.

The investment cost is the sum of the physical costs of the material used for the construction of the equipment and processing costs (welds, ...).

The operating costs are dependent on the operating conditions, by the consumption of electrical energy and utilities (compressed air, oil, ...).

Material Balance

- Identification of streams:



Cost of reactor

The reactor does not require the use of a catalyst, and then the investment costs do not include costs of preparation of the catalyst and its support. The reactor is also **virtually** isothermal and then operated adiabatically. Accordingly, it does not require a system of heating / cooling. The cost of the reactor will be the only investment costs. The reactor is then equivalent to a pressurized empty pipe, operating at high temperature. The reactor will then be assimilated to a pressure tank for the calculation of investment costs.

The investment costs are calculated using the following formula (with D,H in [ft] e M&S = 1110) of the **installed cost**:

$$€_{reatt} = 101.9 \frac{M\&S}{280} D^{1.066} H^{0.802} \left(2.18 + F_P F_M\right) \qquad [€]$$

The calculation of costs therefore requires the sizing of the reactor in terms of diameter (D) and length (H). Knowing the contact times and the circulating flow of the reactor is possible to determine its volume. For the economic optimum ratio **H /D** the reactor must be between **6 and 10**.

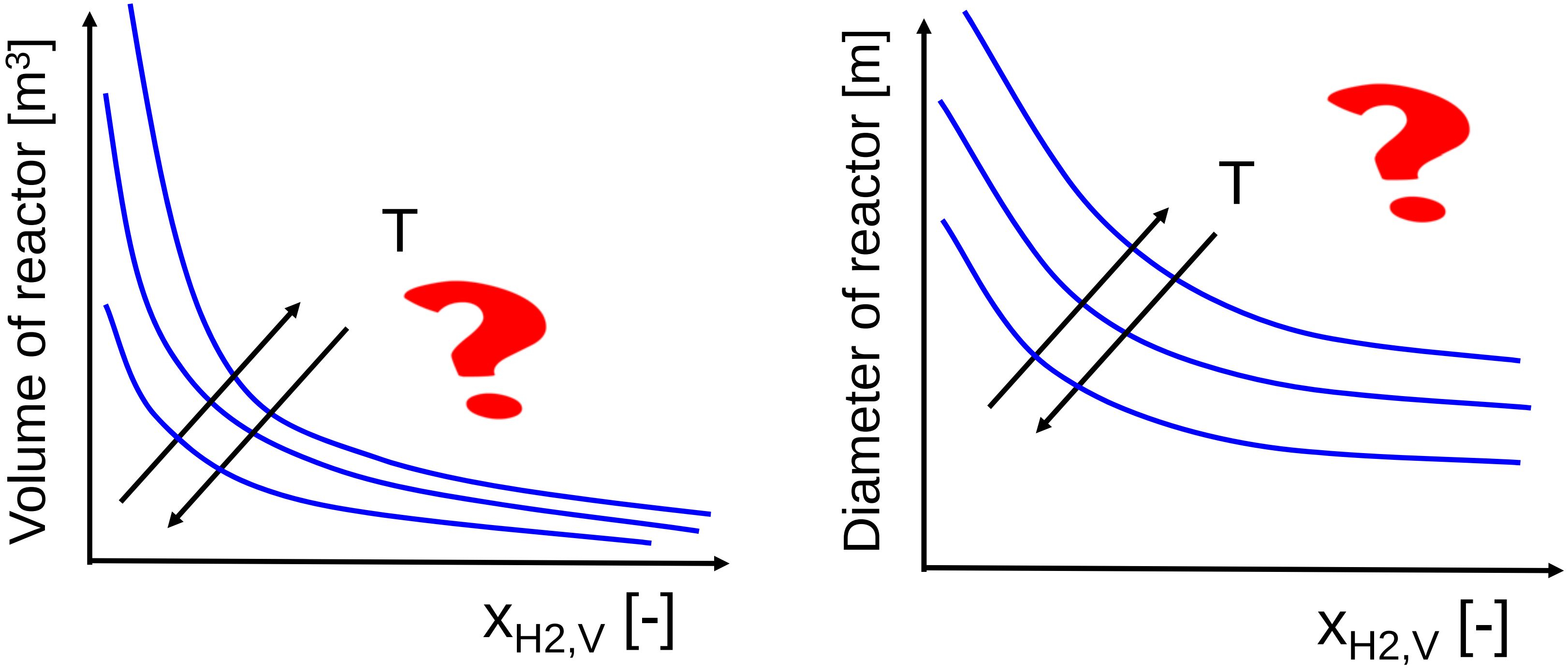
Costs of the reactor

The terms Fp and Fm allow us to consider the influence of pressure and the material of construction.

Since it works at high temperature, the reactor must be insulated. This investment increases the installed cost by 15%.

Temperature [°C]	**Residence Time[s]**
600	458.12
650	82.16
700	17.68
750	4.68

Dimensions of the reactor

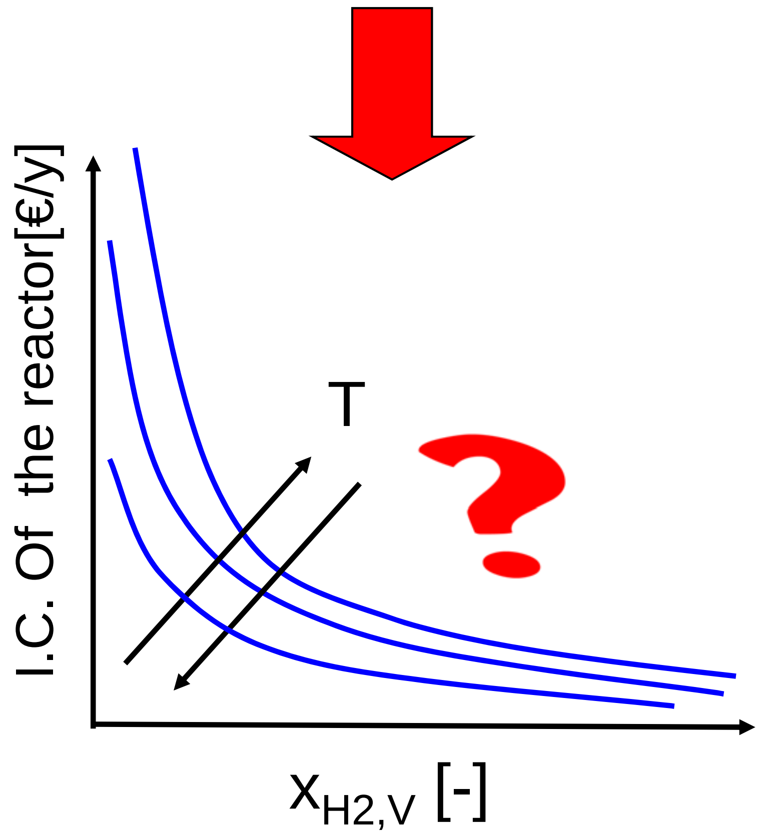


Hint: at elevated temperatures correspond low volume of the reactor.

The volume of the reactor is directly proportional to the flow of reagents entering the reactor.

Cost of reactor

The costs of the reactor are proportional to:
D (1.066 +0.802)
Thus since for each temperature the diameter of the reactor decreases as the molar fraction of hydrogen in the vent, also the costs related to the reactor will have the same trend.



Costs of the compressor

For the compressor must be considered both the costs of installation and operation:

- **Installed cost**:

$$€_{compr,inst} = 517.5 \frac{M\,\&\,S}{280} (bhp)^{0.82} (2.11 + F_c) \qquad [€]$$

with M&S = 1110; *bhp* is the power to the motor shaft in [hp]

- **Operating costs** : assumes a real transformation efficiency equal to 0.9 and a shaft efficiency equal to 0.9. The cost of electricity is 0.061095 € / kWh. To calculate the costs you have to calculate the consumption of the compressor.

Consumption of the compressor

The specific work is defined as [J/mol]:

$$L = RT_1 \frac{\beta^{\gamma} - 1}{\gamma}$$

where,

- The compression ratio is defined as:

$$\beta = \frac{P_2}{P_1}$$

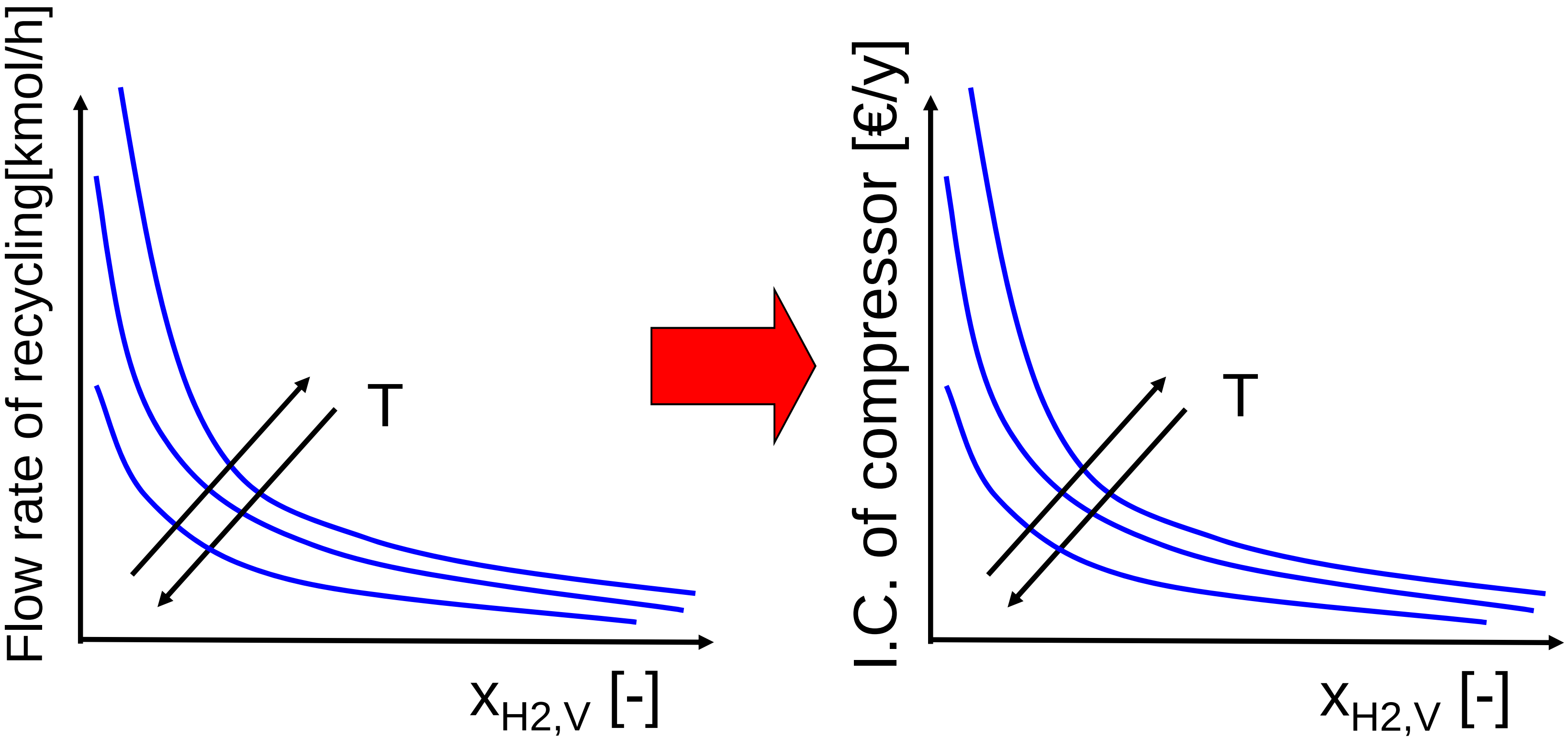
- The adiabatic coefficient is evaluated as following:

$$\gamma_{mix} = \sum_{i=1}^{NC} x_i \gamma_i$$

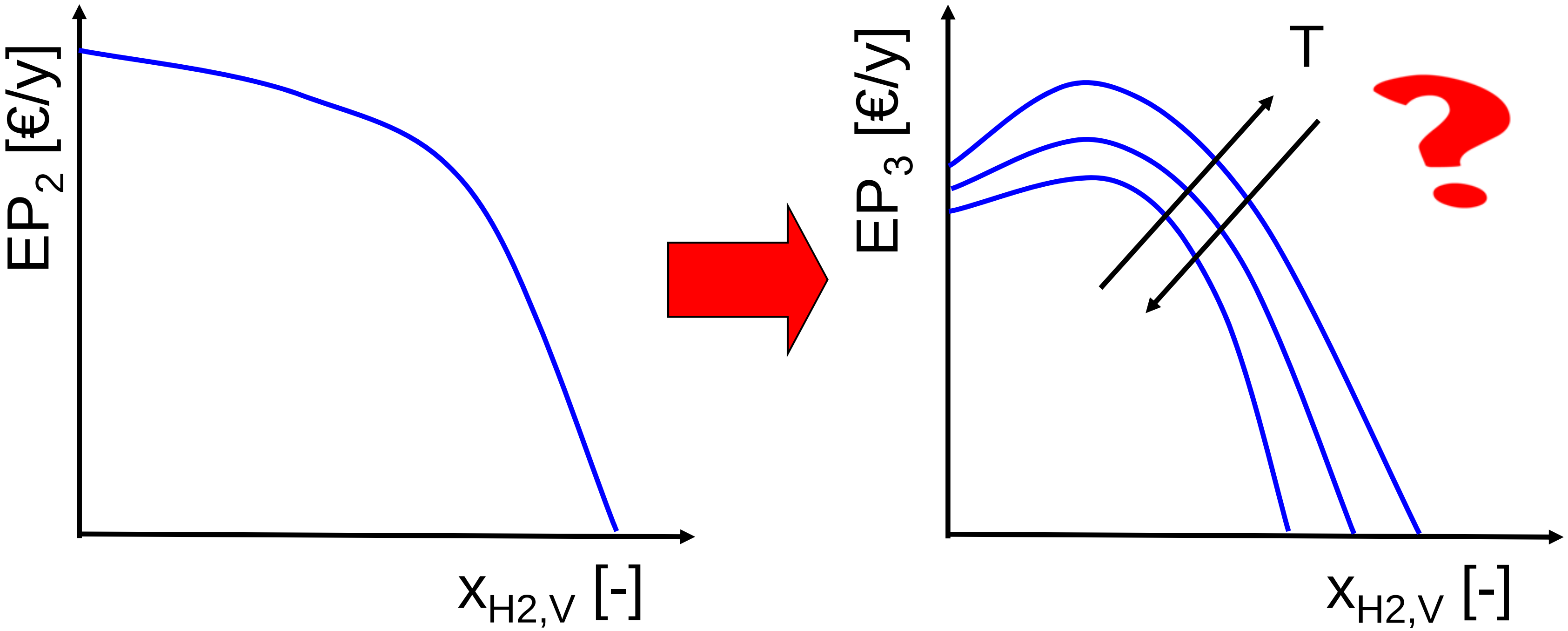
$$\gamma_i = \frac{c_{p,i} - c_{v,i}}{c_{p,i}}$$

Investment costs of the compressor

Since both the investment costs depend on the operating power used and this power depends on the flow rate of recycling in the gas phase, the costs related to the compressor will have the same trend as that of the flow rate of recycling:



EP_2 VS EP_3



Requirements

Provide the following plots:

- molar fraction of hydrogen in the vent / Reactor volume;
- molar fraction of hydrogen in the vent / Reactor diameter;
- molar fraction of hydrogen in the vent / Reactor I.C.;
- molar fraction of hydrogen in the vent / Recycle flowrate;
- molar fraction of hydrogen in the vent / Compressor I.C.;
- molar fraction of hydrogen in the vent / Compressor O.C.;
- molar fraction of hydrogen in the vent / EP3;

Comment on the differences between the EP3 and EP2 trends.