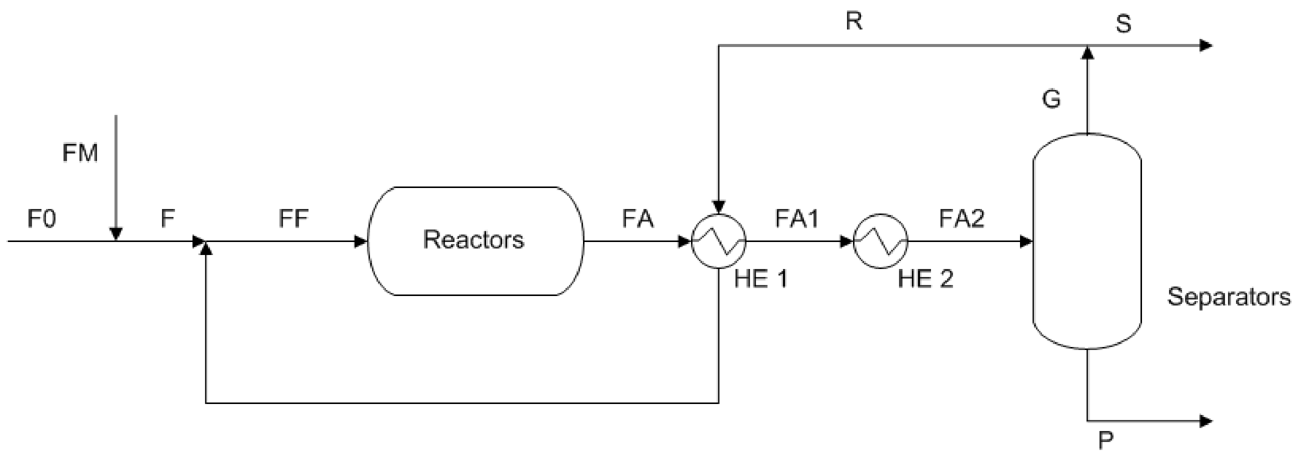
Methanol synthesis: design of recycle



Methanol is produced in a multi-stage adiabatic reactor where the following reactions take place:

$$CO + 2H_2 \rightarrow CH_3OH \qquad (1)$$

$$CO_2 + H_2 \rightarrow CO + H_2O \qquad (2)$$

A make-up flowrate of CO_2 (FM) is added to the fresh feed (F0), to guarantee the modulus $M = \frac{H_2-CO_2}{CO_2+CO} = 3$ in the stream entering in the reactor (FF). The effluent stream (FA) is fed to the methanol separator. The gas stream leaving the separator is recycled to the reactor after being purged. The liquid stream (P) is sent to the distillation trains. The separator works with recovery efficiencies ($\varphi_i = P_i/FA_i$) equal to 0.88, 0.95 and 0.0095 for methanol, water and carbon dioxide, respectively. Methane, hydrogen, carbon monoxide and nitrogen can be assumed to be present only in the G stream. The CO conversion and the carbon yield to methanol per passage inside the reactor are equal to 0.42 and to 0.30, respectively.

By defining the recycle fraction as $\xi = R/G$, evaluate:

a) The recycle fraction required to achieve an overall conversion of CO equal to 98%
b) The flowrate and the composition of all the stream in the process
c) The recycle ratio ($\beta = R/F$)
d) The overall CO conversion, the concentration of the inert in the recycle stream and the recycle ratio as a function of ξ
e) The temperature of the stream R and FA1 after the first heat exchanger (HE – 1)
f) The heat duty to HE – 2 to obtain that stream FF entering in the reactor is at 245 °C

DATA:

The feed stream F0 consists of:

Species	CO	CO_2	H_2	CH_4	CH_3OH	H_2O	N_2
F0 [kmol/h]	148.57	75.42	696.72	24.79	0.00	1.77	3.17

Temperatures:

Stream/Unit	F0	FM	FF	FA	FA2	Separator
T [°C]	550	550	245	264	110	40

Heat capacity:

Specie	a	b	c	d
CO	29.556	-6.5807e-3	2.0130e-5	-1.2227e-8
CO2	27.437	4.2315e-2	-1.9555e-5	3.9968e-9
H2	25.399	2.0178e-2	-3.8549e-5	3.1880e-8
CH4	34.942	-3.9957e-2	1.9184e-4	-1.5303e-7
CH3OH	40.046	-3.8287e-2	-2.4529e-4	-2.1679e-7
H2O	33.933	-8.4186e-3	2.9906e-5	-1.7825e-8
N2	29.342	-3.5395e-3	1.0076e-5	-4.3116e-9

$$Cp_i(T) = a_i + b_i \cdot T + c_i \cdot T^2 + d_i \cdot T^3 \text{ [J/mol/K], T [K]}$$