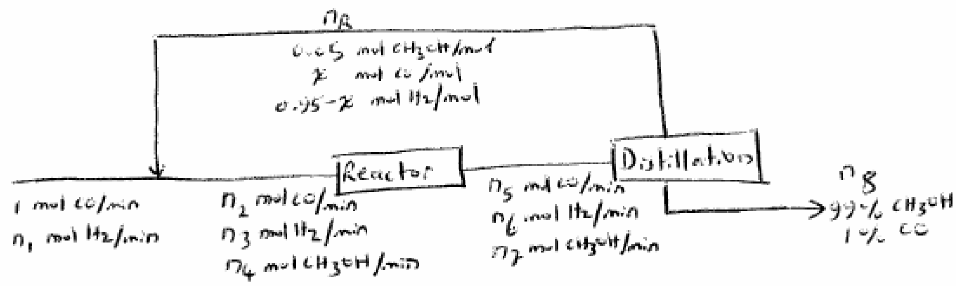
Consider the combination of a continuous steady state catalytic reactor followed by distillation with recycle of the unreacted products in which the following reaction takes place:

$$CO + 2H_2 \rightarrow CH_3OH$$

Assume that 50% of the reactants are consumed in each pass through the reactor (i.e. the reactants enter the reactor in stoichiometric ratio). The molar composition of the bottom stream of the distillation column is 99% methanol and 1% CO. The top stream is recycled and it contains 5 mol% methanol. The fresh feed to the process (not the reactor) is composed of CO and H_2 and the flow rate of CO is maintained at 1 mol/min.

a) Draw a flow diagram for the process and label all streams.
b) What is the flow rate of hydrogen in the feed stream?
c) What is the molar flow rate of the total feed stream to the reactor at steady state?
d) What is the molar flow rate of the output from the reactor at steady state?
e) What is the composition of the recycle stream coming from the distillation column?

a)



b) System: Overall

C Balance: $1 = (0.99)n_8 + (0.01)n_8 \Rightarrow \boxed{n_8 = 1 \text{ mol/min}}$

H Balance: $n_1 \frac{2}{1} = (0.99)n_8 \frac{4}{1} \Rightarrow \boxed{n_1 = 1.98 \text{ mol } H_2/\text{min}}$

We need to make balances around two of the tree systems (choose the two physical systems) and use the additional information (two equations) to solve 8 unknowns $(n_2, n_3, n_4, n_5, n_6, n_7, n_R, x)$

System: Distillation Column

CH3OH Balance: $n_7 = (0.99)\cdot 1 + (0.05)n_R$ ------- (1)

H2 Balance: $n_6 = (0.95 - x)\, n_R$ ------- (2)

CO Balance: $n_5 = 0.01 + x n_R$ ------- (3)

System: Mixing Point

CH3OH Balance: $(0.05)\, n_R = n_4$ ------- (4)

CO Balance: $1 + x n_R = n_2$ ------- (5)

H2 Balance: $1.98 + \underbrace{(0.95 - x)n_R}_{n_6 \text{ from (2)}} = n_3$ ------- (6)

Additional Information

50% conversion on both reactants: $\frac{n_3 - n_6}{n_3} = 0.50$ or $n_6 = \frac{1}{2}n_3$ ----- (7)

$\frac{n_2 - n_5}{n_2} = 0.5$ or $n_5 = \frac{1}{2}n_2$ ---- (8)

{or instead of Eq. (8) we could use $n_3 = 2n_2$ or $n_6 = 2n_5$}

Solution of 8 equations for 8 unknowns

From (2), (6) & (7) $\Longrightarrow$ $\boxed{n_3 = 3.06 \text{ mol/min}}$ & $\boxed{n_6 = 1.98 \text{ mol/min}}$

From (3), (5) & (8) $\Longrightarrow$ $\boxed{x\, n_R = 0.98 \text{ mol CO/min in Recycle}}$

$\boxed{n_5 = 0.99 \text{ mol/min}}$

$\boxed{n_2 = 1.98 \text{ mol/min}}$

From (2) knowing n_6 & $x\, n_R$ $\Longrightarrow$ $\boxed{n_R = 3.116 \text{ mol/min}}$

From (3) knowing n_R & n_5 $\Longrightarrow$ $\boxed{x = 0.315 \text{ mol CO/mol}}$

& $\boxed{0.95 - x = 0.635 \text{ mol } H_2\text{/mol}}$

From (1) knowing n_R $\Longrightarrow$ $\boxed{n_7 = 1.146 \text{ mol/min}}$

From (4) knowing n_R $\Longrightarrow$ $\boxed{n_4 = 0.156 \text{ mol/min}}$

So,

c) Feed to the reactor $= n_2 + n_3 + n_4 = 6.096$ mol/min

d) Output from the reactor $= n_5 + n_6 + n_7 = 4.116$ mol/min

e) Composition of the Recycle: 0.05 mol CH_3OH/mol (5% CH_3OH)

0.315 mol CO/mol (31.5% CO)

0.635 mol H_2/mol (63.5% H_2)