

§ 4.3 d, e, 4.4 Multi-unit Processes

Most processes require multiple steps and combinations of vessels (e.g. PET recycling, any CHE 200 topic)

- each of the ^{units or} vessels / ~~requires a separate~~ degrees of freedom analysis

- the overall process / ~~requires a degrees of freedom~~ analysis, but as for the overall material balance, ^{on a single vessel,} the overall balance for the plant is a combination of the units: it is dependent

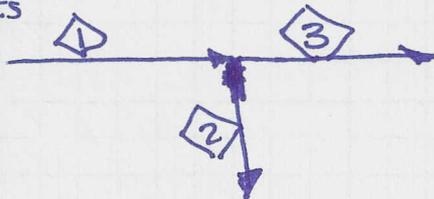
* insert examp^t pg 1a → There are also 4 special things we will do with streams which combine and/or split:

1) Split: one stream divides into 2 streams

In this case, the compositions are

the same for all three streams:

eg: 3 comp^s



IN = OUT (SS, no rxn)

	1	2	3
A	x_{A1}	x_{A1}	x_{A1}
B	x_{B1}	x_{B1}	x_{B1}
C	x_{C1}	x_{C1}	x_{C1}
	F_1	F_2	F_3

1) $F_1 = F_2 + F_3$

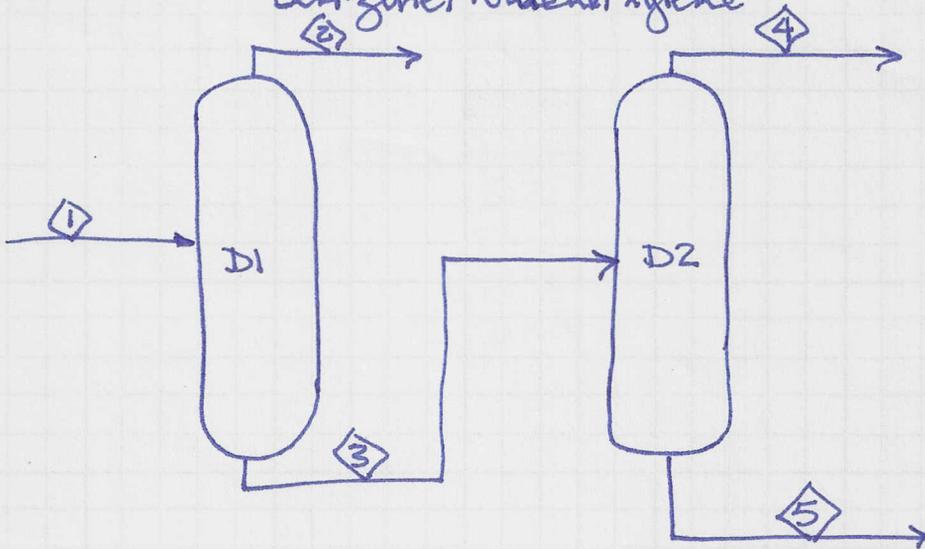
2) N/A

3) $x_{A1} + x_{B1} + x_{C1} = 1.0$

Need basis or process spec's to complete the equations.

NOTE: component balances all reduce to the same equation, so they are ~~not used~~ irrelevant at a SPLIT

EXAMPLE 2 distillation columns in series: separation of benzene/toluene/xylene



MOLAR BASIS

COMP T	1	2	3	4	5
benzene (B)	0.20	x_{B2}	0.025	0.08	—
toluene (T)	0.30	x_{T2}	0.35	0.92	x_{T5}
xylene (X)	0.50	—	0.625	—	x_{X5}
Flow (mol/hr)	1000	F_2	F_3	F_4	F_5

Degrees of freedom analysis:

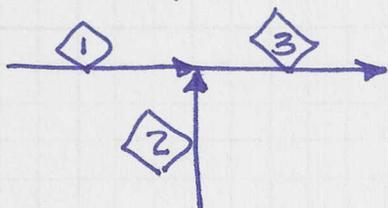
	<u>D1</u>	<u>D2</u>	<u>PROCESS</u>
<u>Streams</u>	Streams 1, 2, 3	Streams 3, 4, 5	Streams 1, 2, 4, 5
<u>Unknowns</u>	$(x_{B2}, x_{T2}, F_2, F_3)$ (4)	(5)	(not 3) (7)
<u>material balances:</u>	(3)	(3)	(3)
$\sum x_{i,j}$	$j=2$ (1)	$j=5$ (1)	$j=2,5$ (2)
<u>process spec's</u>	(0)	(0)	(0)
<u>degrees of freedom</u>	<u>0</u>	<u>1</u>	<u>2</u>

NOTE: on solving D1, F_3 is known which reduces the degrees of freedom on D2 to 0. In this case, the overall balance is the wrong place to start!

2) Combine or mix streams: 2 streams meet and are combined without reaction.

In this case, all of the compositions are different.

eg. 4 comp'ts



IN = OUT (SS, no rxn permitted)

	1	2	3
A	x_{A1}	x_{A2}	x_{A3}
B	x_{B1}	x_{B2}	x_{B3}
C	x_{C1}	x_{C2}	x_{C3}
D	x_{D1}	x_{D2}	x_{D3}
Flows	F_1	F_2	F_3

① • Overall balance:

$$F_1 + F_2 = F_3$$

② • Component balances: $n = 4 \Rightarrow n - 1 = 3$ balances are independent of overall \Rightarrow pick A, B, C

A-balance

$$x_{A1} F_1 + x_{A2} F_2 = x_{A3} F_3$$

B-balance and C-balance

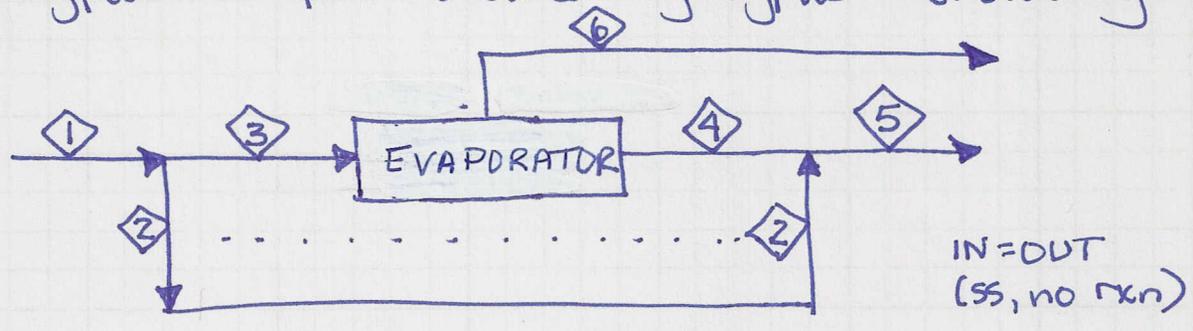
similar - you write

③ • $\sum x_i$ in streams 1, 2, 3 e.g. $x_{A1} + x_{B1} + x_{C1} + x_{D1} = 1.0$

\Rightarrow 15 unknowns; $(1 + 3 + 3 = 7)$ equations

\Rightarrow must specify 8 variables through process spec. or other means.

3) Bypass : split followed by bypass followed by mix.



	1	2	3	4	5	6
water	0.90	0.90	0.90	0.20	x_{W5}	1.0
other stuff (Q)	0.10	0.10	0.10	0.80	x_{Q5}	-
Flow (kg/hr)	100	F_2	F_3	F_4	F_5	F_6

Degrees of Freedom analysis:

Now it is necessary to define a system and find the degrees of freedom for the system.

Degrees of Freedom

	Split	Evap	Mix	Process
streams	1, 2, 3	3, 4, 6	2, 4, 5	1, 5, 6
unknowns unknowns	F_2 F_3 (2)	F_3 F_6 F_4 (3)	F_2 F_4 F_5 x_{W5} x_{Q5} (5)	F_5 F_6 x_{W5} x_{Q5} (4)
MB	1	2	2	2
$\sum x_i$	0	0	1	1
Process spec	0	0	0	0
d.f.	1	1	2	1

There must

be at a point in the process where $d.f. = 0$,
so that the solution can proceed, so a process
spec is needed.

• SPLIT : set the ratio for $F_2 : F_3$

OR • EVAPORATOR : set F_6

OR • MIX : no. two degrees of freedom here

OR • OVERALL : set F_6 , x_{w5} , x_{q5}

objective is evaporation, so set $x_{w5} = 0.3$

Back to overall:

$$x_{q5} = 0.7$$

$$90 = F_6 + 0.3(100 - F_6)$$

$$F_6 = \frac{60}{1-0.3} = 85.7 \frac{\text{kg}}{\text{hr}}$$

$$F_5 = (100 - 85.7) \frac{\text{kg}}{\text{hr}} = 14.3 \frac{\text{kg}}{\text{hr}}$$

Check with Q balance:

$$0.10(100) = 0 + 0.7(14.3)$$

$$10 = 10 \quad \checkmark$$

Back to MIX : now x_{q5} , x_{w5} , F_5 are known.

unknowns: F_2 , F_4

$$\text{eqns: } F_2 + F_4 = 14.3$$

overall

$$0.2F_4 + 0.9F_2 = 0.3(14.3) \quad \text{water}$$

$df = 0$ so solve F_2 , F_4

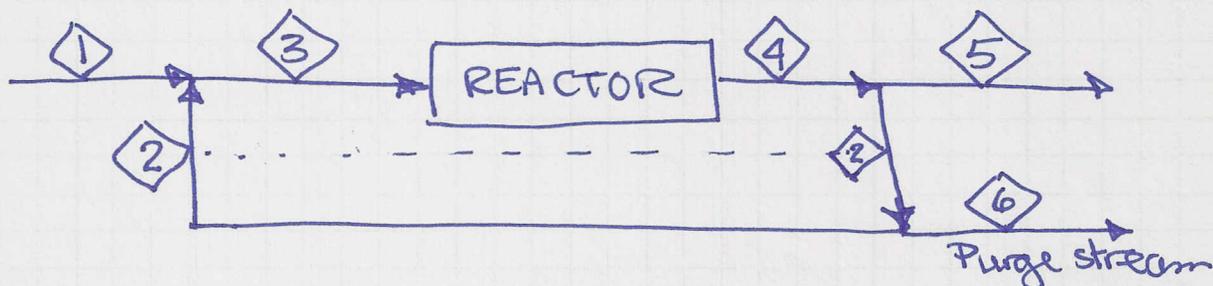
Back to EVAPORATOR : unknowns: F_3

equations: overall is all we need.
solve F_3

Back to SPLIT : unknowns: none.

done #

4) Last trick with streams is a RECYCLE stream. This is a mix, followed by a vessel, followed by a split:



The approach for the degrees of freedom analysis is identical to the BYPASS approach, but these streams are usually motivated by a reactor, so we leave further analysis for the time being.

Note the PURGE stream. This prevents traces of impurities from building up in the system. We will return to it later as well.