E82

Recycle and Bypass

E82 – Techniques in Process Flow Diagrams

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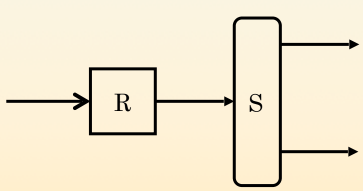
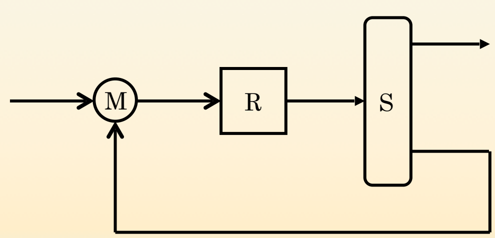
Recycle

- No reactors go to completion.
- No separators have perfect separation.
- Wasted reagents are wasted money.
- Recycle (like feedback) can improve performance.



No Recycle



Recycle

Recycle Example

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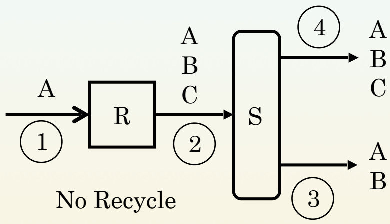

$$C_3H_8 \rightarrow C_3H_6 + H_2$$

$$A \rightarrow B + C$$

Given: Feed 100 mol/s A

Reactor: $f_A = 0.10$ (10%)

Separator: $t_{A3} = 0.995$, $t_{B4} = 0.950$, $t_{C4} = 1$

Recycle Example (continued) Material Balances

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Reactor

$$\dot{\xi} = (100)(0.10) = 10 \text{ mol/s}$$

$$\dot{n}_{A2} = 100 - 10 = 90 \text{ mol/s}$$

$$\dot{n}_{B2} = 0 + 10 = 10 \text{ mol/s}$$

$$\dot{n}_{C2} = 0 + 10 = 10 \text{ mol/s}$$

Separator

$$\dot{n}_{A3} = (0.995)(90) = 89.55 \text{ mol/s}$$

$$\dot{n}_{B3} = (0.05)(10) = 0.5 \text{ mol/s}$$

$$\dot{n}_{C3} = (0)(10) = 0 \text{ mol/s}$$

$$\dot{n}_{A4} = \dot{n}_{A2} - \dot{n}_{A3} = 0.45 \text{ mol/s}$$

$$\dot{n}_{B4} = \dot{n}_{B2} - \dot{n}_{B3} = 9.5 \text{ mol/s}$$

$$\dot{n}_{C4} = \dot{n}_{C2} - \dot{n}_{C3} = 10 \text{ mol/s}$$

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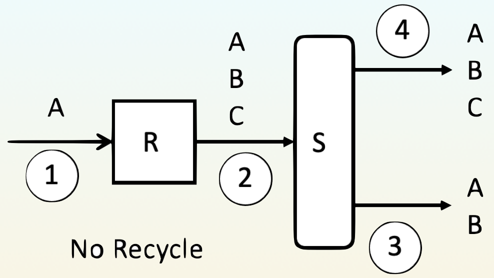

$$C_3H_8 \rightarrow C_3H_6 + H_2$$

$$A \rightarrow B + C$$

	Stream 1	Stream 2	Stream 3	Stream 4
n_A	100	90	89.55	0.45
n_B	0	10	0.5	9.5
n_C	0	10	0	10
n	100	110	90.05	19.95
x_A	1	0.8182	0.9944	0.0226
x_B	0	0.0909	0.0056	0.4762
x_C	0	0.0909	0.0000	0.5013

Flows in mol/s

Reactor		
f_A	0.1	
ν_A	-1	
ν_B	1	
ν_C	1	
ν	1	
ξ	10	mol/s

Separator	
t_{A3}	0.995
t_{B4}	0.950
t_{C4}	1.000

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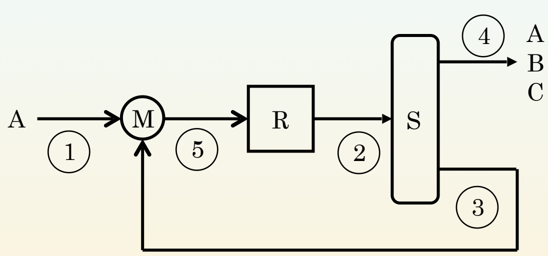
Recycle Example (continued) Same System with Recycle



Separator

$$\dot{n}_{A3} = 0.995\dot{n}_{A2}$$

$$\dot{n}_{A4} = 0.005\dot{n}_{A2}$$

Reactor

$$\dot{\xi} = 0.10\dot{n}_{A5} \text{ mol/s}$$

$$\dot{n}_{A2} = \dot{n}_{A5} - 0.10\dot{n}_{A5} = 0.90\dot{n}_{A5}$$

Mixer

$$\dot{n}_{A5} = 100 + \dot{n}_{A3}$$

Material balance for component A

Recycle Example (continued) Same System with Recycle

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Successive substitution for solution

$$\dot{n}_{A2} = 0.90\dot{n}_{A5}$$

$$\dot{n}_{A3} = 0.995\dot{n}_{A2} = 0.995\left(0.90\dot{n}_{A5}\right)$$

$$\dot{n}_{A5} = 100 + \dot{n}_{A3} = 100 + 0.995\left(0.90\dot{n}_{A5}\right)$$

$$\dot{n}_{A5}\left[1 - 0.995\left(0.90\right)\right] = 100$$

$$\dot{n}_{A5} = \frac{100}{\left[1 - 0.995\left(0.90\right)\right]} = 956.9$$

Recycle Example (continued)

HARVEY MUDD COLLEGE

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Four equations in four unknowns

Solution

$\dot{n}_{A2} = 861$ mol/s

$\dot{n}_{A3} = 857$ mol/s

$\dot{n}_{A4} = 4.3$ mol/s

$\dot{n}_{A5} = 957$ mol/s

Similar approach for B and C

$\dot{n}_{B2} = 101$ mol/s

$\dot{n}_{B3} = 5.0$ mol/s

$\dot{n}_{B4} = 96$ mol/s

$\dot{n}_{B5} = 5.0$ mol/s

$\dot{n}_{C2} = 96$ mol/s

$\dot{n}_{C3} = 0$ mol/s

$\dot{n}_{C4} = 96$ mol/s

$\dot{n}_{C5} = 0$ mol/s

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Recycle Example (continued)

What did recycle buy us?

Overall fractional conversion $= \dfrac{\dot{n}_{A1} - \dot{n}_{A4}}{\dot{n}_{A1}}$

$$f_A = \frac{100 - 4.3}{100} = 0.957 \text{ vs. } 0.10$$

Overall extent of reaction

$$\dot{\xi}_O = 100 - 4.3 = 95.7 \text{ mol/s vs. } 10 \text{ mol/s}$$

What did it cost?

$$\dot{n}_2 = 1058 \text{ mol/s vs. } 110 \text{ mol/s}$$

$$\dot{n}_3 = 862 \text{ mol/s vs. } 90 \text{ mol/s}$$

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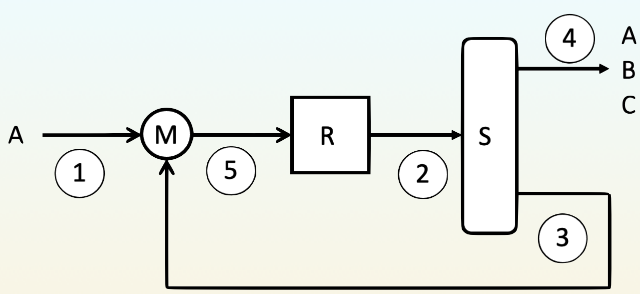

	Stream 1	Stream 2	Stream 3	Stream 4	Stream 5
n_A	100	861.2	856.9	4.3	956.9
n_B	0	100.7	5.0	95.7	5.0
n_C	0	95.7	0.0	95.7	0.0
n	100	1057.7	862.0	195.7	962.0
x_A	1	0.8143	0.9942	0.0220	0.9948
x_B	0	0.0952	0.0058	0.4890	0.0052
x_C	0	0.0905	0.0000	0.4890	0.0000

Flows in mol/s

Reactor		
f_A	0.1	
ν_A	-1	
ν_B	1	
ν_C	1	
ν	1	
ξ	95.7	mol/s

Overall		
f_{AO}	0.957	
ξ_O	95.7	mol/s

Separator	
t_{A3}	0.995
t_{B4}	0.950
t_{C4}	1.000

Bypass

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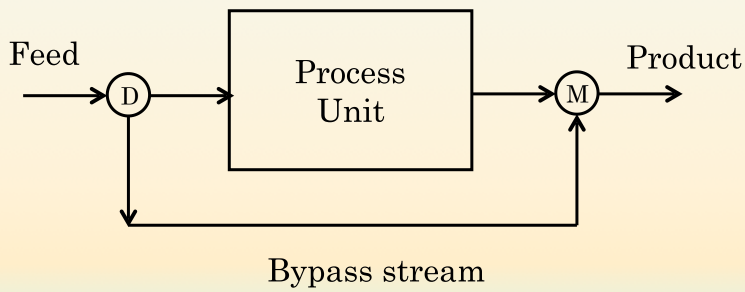
- Less common than recycle.
- Common example is fruit juice concentrator.



Purge

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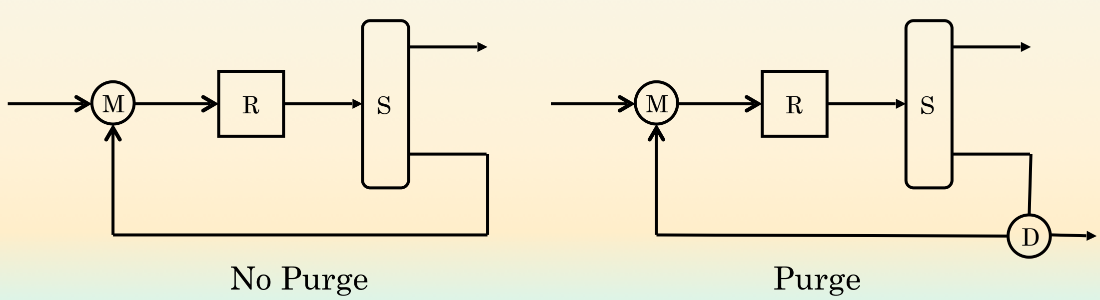
- Often necessary to remove trace species in the feed.
- Used with recycle when the separator has a split fraction of 0 on a trace species.
- Less expensive than an additional separator.



Actual PFD

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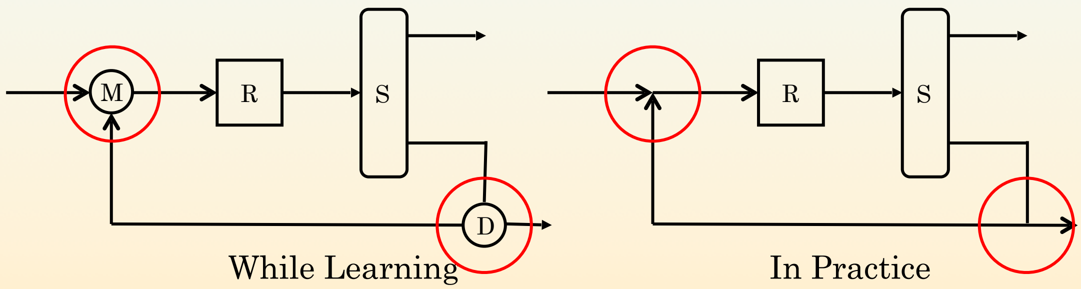
Mixers and dividers are almost never shown on actual PFD's.



Simplifying PFDs

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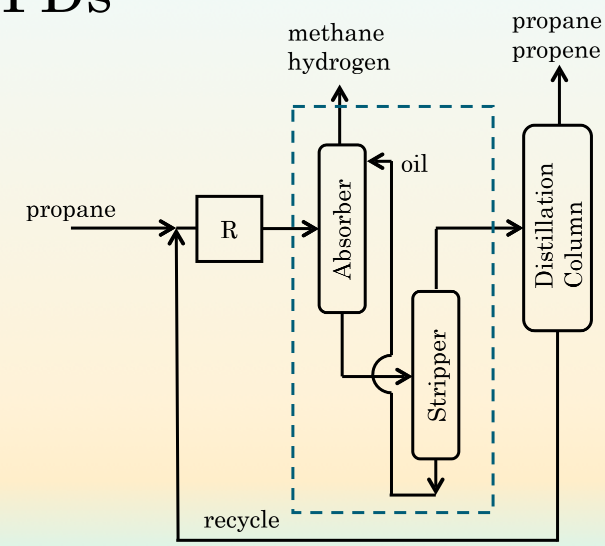
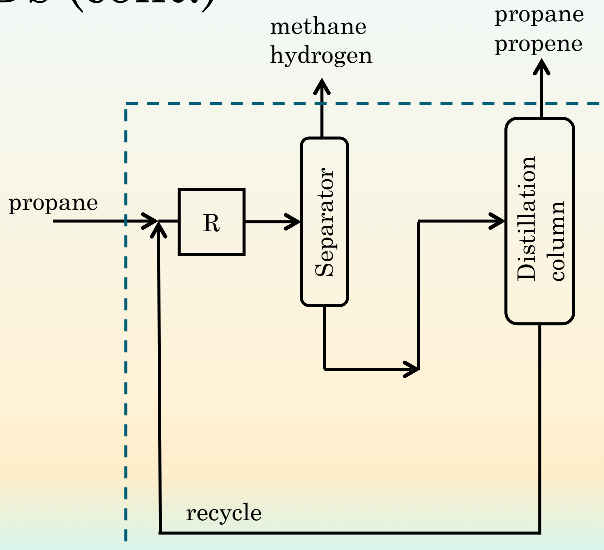
Flowsheets can be simplified by drawing a surrounding box and only dealing with the inputs and outputs. For example, the process flowsheet for the dehydrogenation of propane to propene.



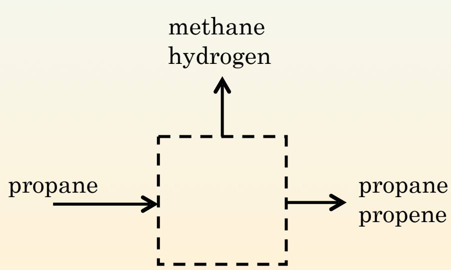
Simplifying PFDs (cont.)

The absorber and stripper can be combined into one separator for calculation purposes



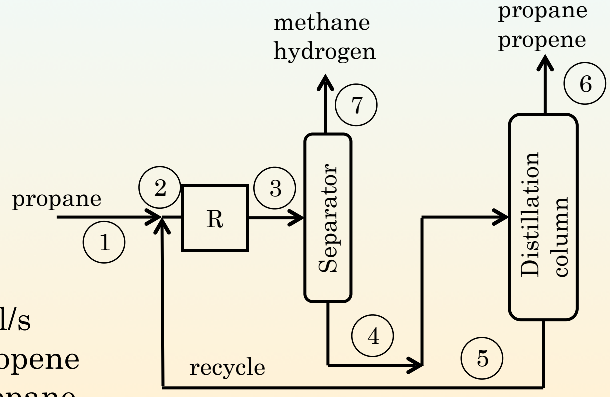
Simplifying PFDs (cont.)

The reactor, separator, distillation column, and recycle loop can be combined into an overall process block for calculation purposes.



Application

Let's look at the calculations for this slightly more realistic dehydrogenation process.



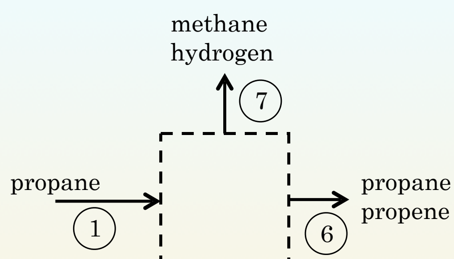
C_3H_8 – A
C_3H_6 – B
CH_4 – C
H_2 – D

Product flow rate – 100 mol/s
Product stream 6 – 98% propene
Recycle stream 5 – 97% propane

$C_3H_8 \rightarrow C_3H_6 + H_2$ $\quad f_{C_3H_8} = 0.35$ (in reactor)

$C_3H_8 + 2H_2 \rightarrow 3CH_4$ $\quad \text{Sel} = \dfrac{\dot{n}_{C_3H_6-\text{gen}}}{\dot{n}_{CH_3-\text{gen}}} = 2$ (in reactor)

Application (cont.)



Propene is produced by reaction 1 only, so

$$\dot{\xi}_1 = (0.98)(100 \text{ mol/s}) = 98 \text{ mol/s}$$

$$\dot{n}_{B-\text{gen}} = \dot{n}_{B6} - \dot{n}_{B1} = \dot{n}_{B6}$$

$$\dot{n}_{C-\text{gen}} = \dot{n}_{C7} - \dot{n}_{C1} = \dot{n}_{C7}$$

$$\text{Sel} = \frac{\dot{n}_{B-\text{gen}}}{\dot{n}_{C-\text{gen}}} = \frac{\dot{n}_{B6}}{\dot{n}_{C7}} = \frac{\nu_{B,1}\dot{\xi}_1}{\nu_{C,2}\dot{\xi}_2} = \frac{\dot{\xi}_1}{3\dot{\xi}_2} = 2$$

$$\dot{\xi}_2 = \frac{\dot{\xi}_1}{6} = \frac{98}{6}$$

Application (cont.)

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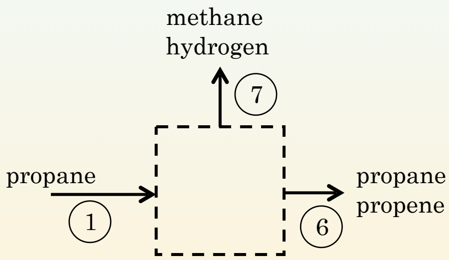
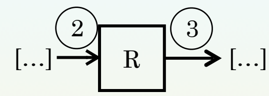


Mole balance on A

$$\dot{n}_{A6} = \dot{n}_{A1} + \nu_{1A}\dot{\xi}_1 + \nu_{2A}\dot{\xi}_2$$

$$2 = \dot{n}_{A1} - 98 - 16.3$$

$$\Rightarrow \dot{n}_{A1} = 116.3 \text{ mol/s}$$



$$f_A = \frac{\dot{n}_{A2} - \dot{n}_{A3}}{\dot{n}_{A2}}$$

$$\Longrightarrow \dot{n}_{A3} = \dot{n}_{A2}(1 - f_A)$$

$$\dot{n}_{A3} = \dot{n}_{A2} + \nu_{A1}\dot{\xi}_1 + \nu_{A2}\dot{\xi}_2 = \dot{n}_{A2} - \dot{\xi}_1 - \dot{\xi}_2$$

$$\dot{n}_{A2}(1 - f_A) = \dot{n}_{A2} - \dot{\xi}_1 - \dot{\xi}_2$$

$$\dot{n}_{A2} = \frac{\dot{\xi}_1 + \dot{\xi}_2}{f_A} = \frac{98 + \frac{98}{6}}{0.35} = 326.7$$

Application (cont.)

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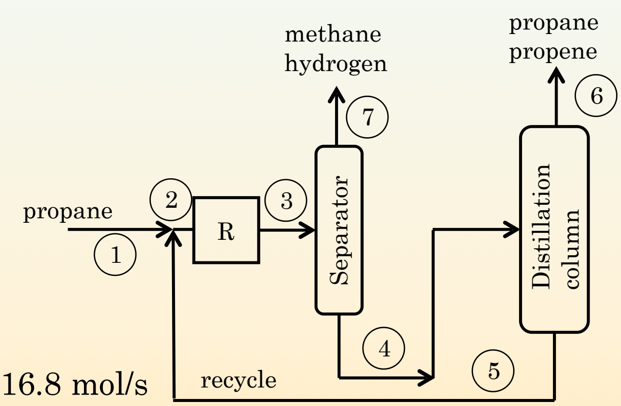
Material balance on A around each element

M $\dot{n}_{A2} = 116.3 + \dot{n}_{A5}$

R $\dot{n}_{A3} = 0.65\dot{n}_{A2}$

S1 $\dot{n}_{A4} = \dot{n}_{A3} - \dot{n}_{A7} = \dot{n}_{A3}$

S2 $2 = \dot{n}_{A4} - \dot{n}_{A5}$



Solution

$\dot{n}_{A2} = 326.6$ mol/s

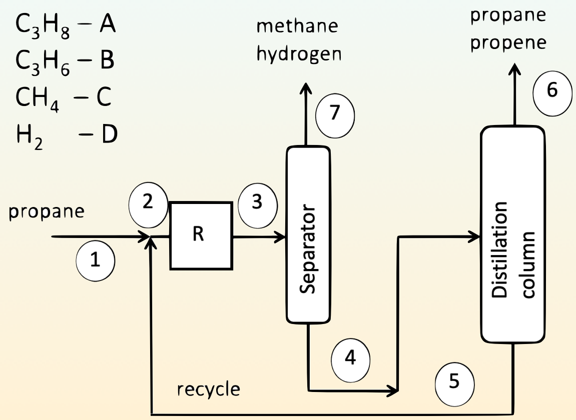
$\dot{n}_{A3} = 212.3$ mol/s

$\dot{n}_{A4} = 212.3$ mol/s

$\dot{n}_{A5} = 210.3$ mol/s

Recycle 97% A

$$\therefore \dot{n}_5 = \frac{210.3}{0.97} = 216.8 \text{ mol/s}$$



	Stream 1	Stream 2	Stream 3	Stream 4	Stream 5	Stream 6	Stream 7
n_A	116.3	326.7	212.3	212.3	210.3	2	0
n_B	0	6.51	104.5	104.5	6.51	98	0
n_C	0	0	49	0	0	0	49
n_D	0	0	65.3	0	0	0	65.3
n	116.3	333.2	431.2	316.8	216.8	100	114.3
x_A	1	0.980	0.492	0.670	0.970	0.020	0
x_B	0	0.020	0.242	0.330	0.030	0.980	0
x_C	0	0	0.114	0	0	0	0.429
x_D	0	0	0.152	0	0	0	0.571

Flows in mol/s

Reactor			
f_A	0.35		
Sel	2	**R1**	**R2**
	ν_A	-1	-1
	ν_B	1	0
	ν_C	0	3
	ν_D	1	-2
	ν	1	0
	ξ (mol/s)	98	16.33