EngrD 2190 – Lecture 9

Concept: Process Analysis – Mass Balances with Chemical Reactions

Context: Options for Unreacted Reactants, cont'd
Recycle with Purge?
Partial Separation with Recyle?

Defining Question: How to convert the 'rate created' term in a mass balance to an equation?

Read Chapter 3 pp. 110-117 (informal mass balances)

Homeworks 1 and 2 - Common Style Errors

Streams

- Streams should touch both the originating unit and the destination unit.
- Every stream should have exactly one arrowhead.
- Extend all purges and product/reactant streams to the edge of the page.

Separators

- Streams should enter the separator only from the sides and exit only from the top and bottom.
- Gases should leave from the top and liquids and/or solids should leave from the bottom.

Stream Labels

- If streams leaving a separator are *not* drawn logically (gas out the top and liquids out the bottom), you must indicate the phases leaving separators.
- Label contents of *all* streams, even short streams.

Reactors

- A reactor should have exactly one stream in and one stream out.

Career Fair Suggestions (From Professor Kathleen Vaeth – 2019)

1. Start with a positive fit statement of your experience (transferable skills) to the company's needs. Don't start with "I realize my background does not match your requirements, but…"
2. Listen intently!
3. Be adaptive with questions to the discussion. It is critical to have a good list of questions specific to the company that you can use to <u>lead the conversation</u> with the recruiter. However, you must also build your skill to listen intently and think of good leading questions 'on your feet' as your talk with the recruiter.
4. Have multiple questions lined up to keep the conversation going as long as required…think ahead to what your next question will be
5. Tailor your elevator pitch to the deep research you do on the company you about to talk with. Be flexible with your elevator pitch – adapt and simplify depending on the situation and what the recruiter is saying.
6. Having a prepared pitch helps, but be ready to be interrupted in your pitch – have bullet points that you can go back to.
7. Make sure the pitch is comfortable and natural for you.
8. Come prepared for not only the elevator pitch but also the closer…"Thank you for your time (name of recruiter)", firm handshake and eye contact as you leave.
9. Practice with a couple "non-target" companies prior to approaching your target company(s). And you may learn something new from a company you thought you were not interested in.
10. Use the resume as a prop (point to the area of your topic) during your discussion.
11. The conversations become easier with practice.

Oil Spill in California

Los Angeles Times, October 2, 2021.

Crews raced to contain the damage from a major oil spill off the Orange County coast that left crude spoiling beaches, killing fish and birds and threatening local wetlands.

The spill originated from a pipeline off the coast of Huntington Beach connected to an offshore oil platform. The failure caused 126,000 gallons of crude to spill into coastal waters creating a slick that spanned about 8,320 acres.

Originally reported by the pipeline folks as "about 3000 barrels."

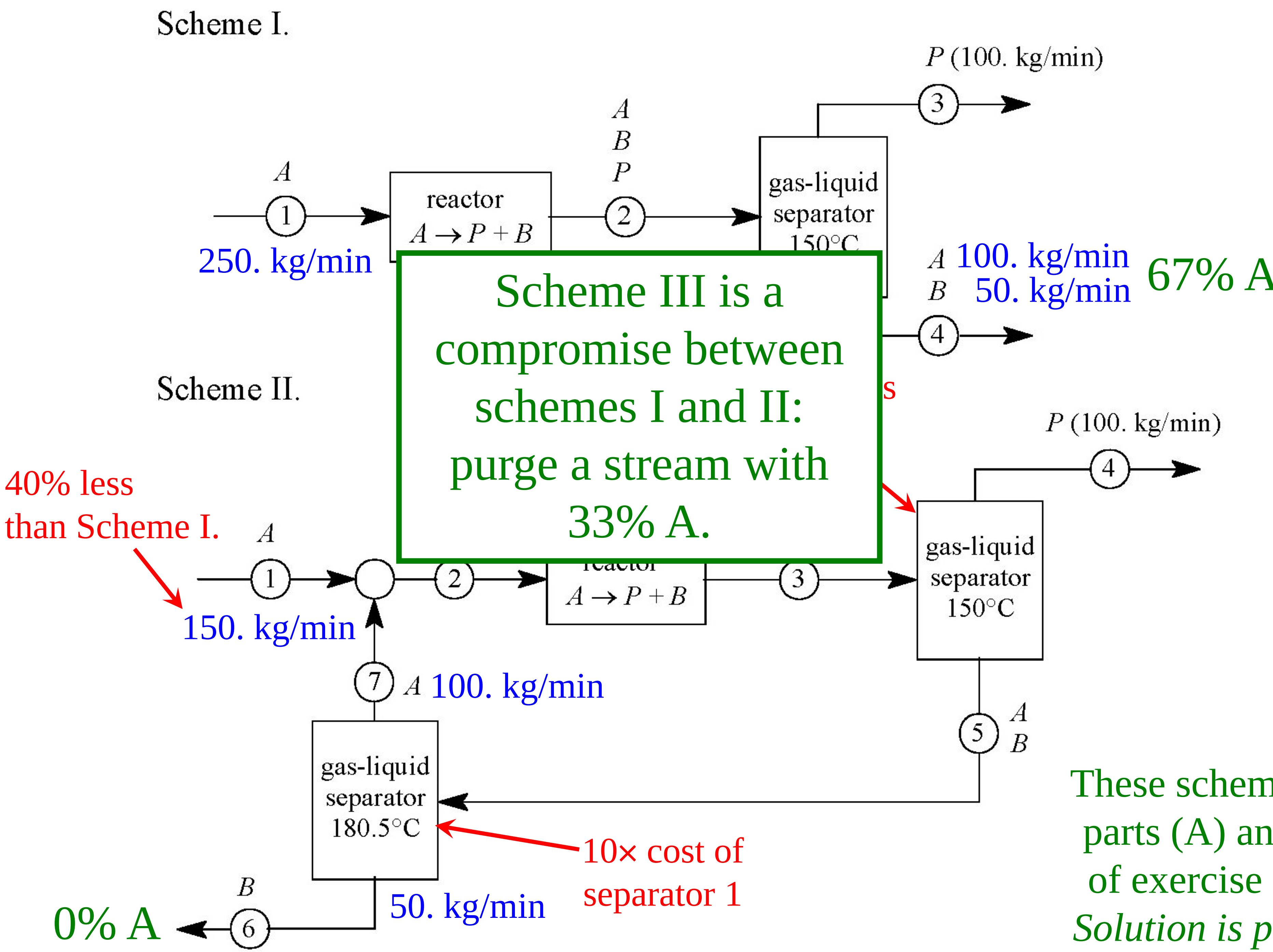
1 barrel = 42 gallons so 3000 barrels = 126,000 gallons.

Originally reported by the pipeline folks as "about 13 square miles."

1 square mile = 640 acres so 13 square miles = 8320 acres.

Never use 'about' or 'approximately' with a number that has 3 significant figures.

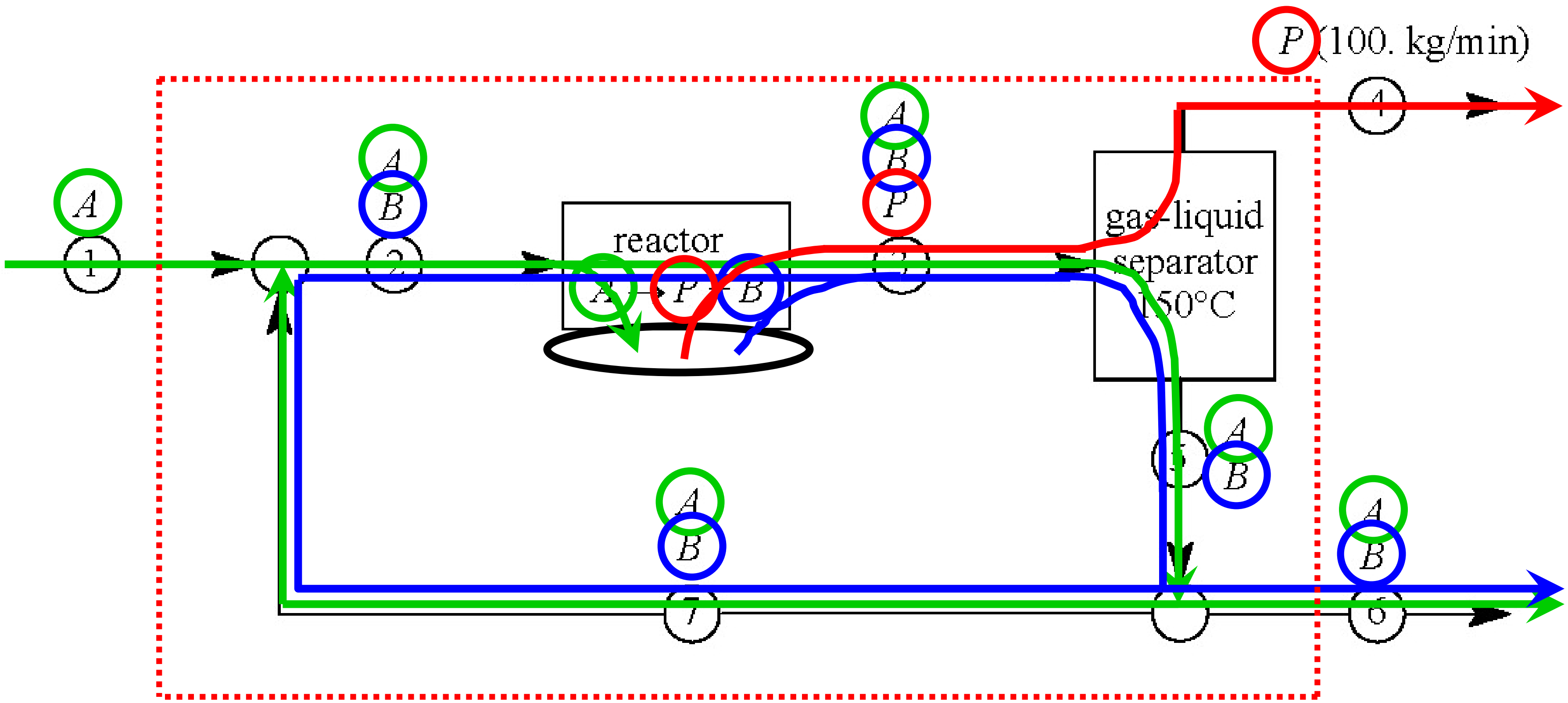
Summary of Schemes I and II.



These schemes are parts (A) and (B) of exercise 3.44. *Solution is posted.*

Scheme III

Scheme III. Recycle unreacted *A* (with some by-product *B*) and remove the by-product in a purge stream (with some unreacted *A*.). The recycle purge (stream 6) is arbitrarily set such that the ratio *A*:*B* is 1:2.



Calculate the flow rates of streams 1 and 6, in kg/min. Calculate the flow rate and composition of stream 3.

Model 1: (3 streams) × (3 parameters/stream) = 9 parameters

Model 1 of Scheme III – Mathematical Model

Apply the Conservation of Mass. Write a total mass balance.

rate of A in + rate of B in + rate of P in = rate of A out + rate of B out + rate of P out

$$F_{A,1} + F_{B,1} + F_{P,1} = F_{A,4} + F_{A,6} + F_{B,4} + F_{B,6} + F_{P,4} + F_{P,6} \quad (1)$$

Process Specifications: stream 1: $F_{B,1} = F_{P,1} = 0$ (2), (3)

stream 4: $F_{A,4} = F_{B,4} = 0$, $F_{P,4} = 100.$ (4), (5), (6)

stream 6: $F_{P,6} = 0$ (7)

33 wt% of stream 6 is A. $\Rightarrow$ 67 wt% of stream 6 is B.

$\Rightarrow$ The A:B ratio in stream 6 is 1:2.

$$\frac{F_{A,6}}{F_{B,6}} = \frac{1}{2} \quad \Rightarrow \quad F_{A,6} = \tfrac{1}{2} F_{B,6} \quad (8)$$

9 parameters, 8 equations $\Rightarrow$ need 1 more equation.

Model 1 of Scheme III – Mathematical Model, cont'd

Recall the analysis of the reaction in Schemes I and II: $A \rightarrow P + B$

P and B are created at equimolar rates.

P and B are involved in no subsequent reactions.

$$\text{molar rate P is created} = \text{molar rate B is created}$$

$$\text{mol wt P} = 2 \times (\text{mol wt B})$$

$$\Rightarrow \quad \text{mass rate P is created} = 2 \times (\text{mass rate B is created})$$

Write a mass balance on P around the entire process.

$$\text{rate of P in} + \text{rate P is created} = \text{rate of P out} + \text{rate P is consumed}$$

$$F_{P,1} + \text{rate P is created} = F_{P,4} + F_{P,6} + \text{rate P is consumed}$$

Substitute process specifications $F_{P,1} = 0$, $F_{P,6} = 0$, and rate P consumed = 0.

$$\text{rate P is created} = F_{P,4}$$

Substitute process specification $F_{P,4} = 100.$

$$\text{rate P is created} = 100.\ \text{kg/min}$$

Now consider B …

Model 1 of Scheme III – Mathematical Model, cont'd

Write a mass balance on B around the entire process.

rate of B in + rate B is created = rate of B out + rate B is consumed

$$F_{B,1} + \text{rate B is created} = F_{B,4} + F_{B,6} + \text{rate B is consumed}$$

Substitute process specifications $F_{B,1} = 0$, $F_{B,4} = 0$, and rate B consumed = 0.

$$\text{rate B is created} = F_{B,6}$$

Substitute deduction "mass rate P is created = 2 × (mass rate B is created)"

$$F_{B,6} = \text{rate B is created} = \tfrac{1}{2}(\text{rate P is created}) = \tfrac{1}{2}(100) = 50 \text{ kg/min}$$

$$F_{B,6} = 50 \text{ kg/min}$$

Model 1 of Scheme III – Mathematical Model, cont'd

Stream 3: Analysis of reaction A $\rightarrow$ P + B

$$\text{rate A is consumed} = \text{rate P is created} + \text{rate B is created}$$

$$\text{rate A is consumed} = 100 + 50 = 150 \text{ kg/min}$$

Reactor Specification: 60% of A entering the reactor = rate A is consumed.

$$0.6F_{\mathrm{A},2} = \text{rate A is consumed} = 150 \text{ kg/min}$$

$$F_{A,2} = \frac{150}{0.6} = 250 \text{ kg/min}$$

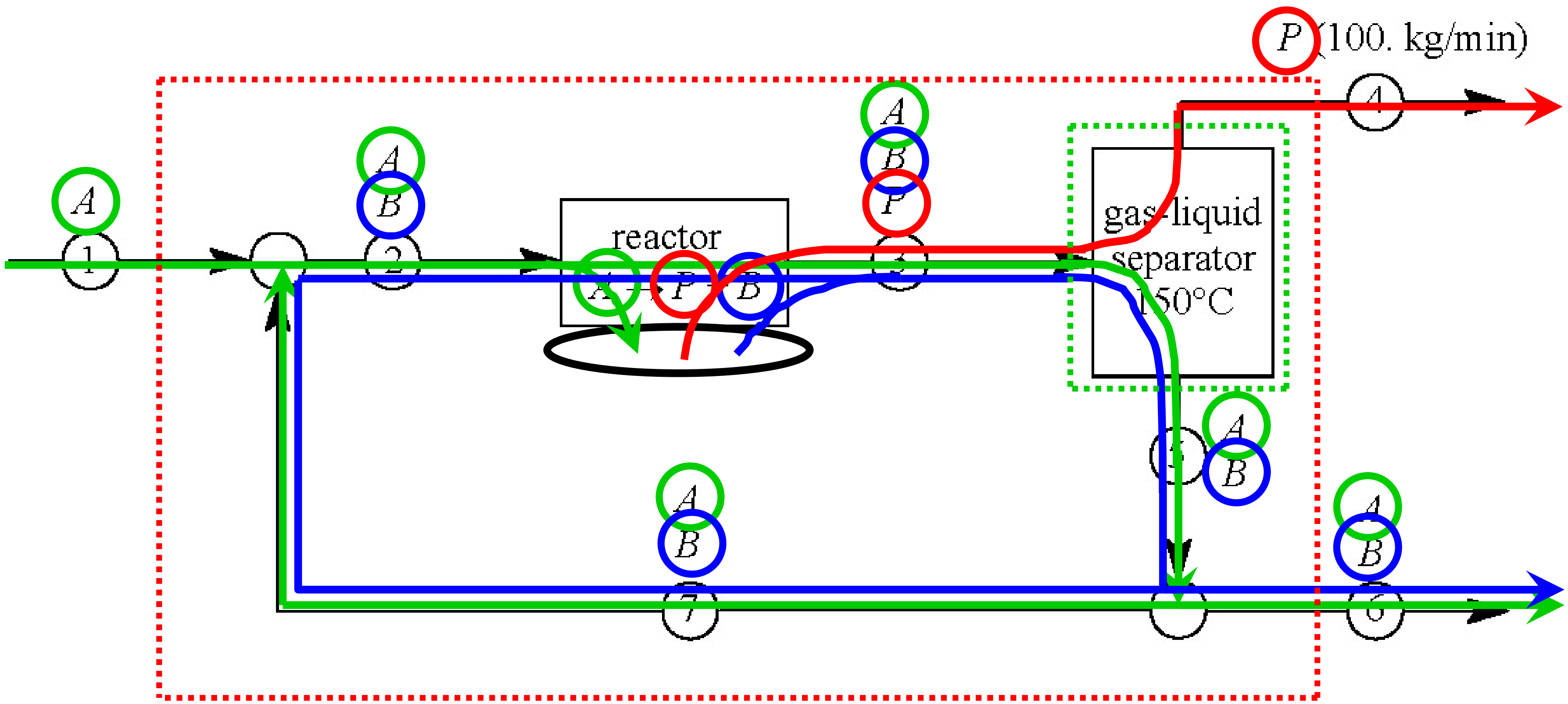
Reactor Specification: 40% of A entering the reactor does not react.

$$F_{\mathrm{A},3} = 0.4F_{\mathrm{A},2} = 0.4(250) = 100. \text{ kg/min}$$

We need to relate $F_{\mathrm{A},3}$ to $F_{\mathrm{A},5}$. Draw system borders around the separator.

Scheme III

Scheme III. Recycle unreacted *A* (with some by-product *B*) and remove the by-product in a purge stream (with some unreacted *A*.). The recycle purge (stream 6) is arbitrarily set such that the ratio *A*:*B* is 1:2.



Calculate the flow rates of streams 1 and 6, in kg/min. Calculate the flow rate and composition of stream 3.

Model 1: (3 streams) × (3 parameters/stream) = 9 parameters

Model 2: (3 streams) × (3 parameters/stream) = 9 parameters

Model 2 of Scheme III – Mathematical Model

Mass balance on A in separator. (no chemical reaction)

rate of A in = rate of A out

$$F_{A,3} = \cancelto{0}{F_{A,4}} + F_{A,5} \quad \text{(informal)}$$

$$F_{A,5} = F_{A,3} = 100 \text{ kg/min}$$

Process Specification:

stream composition leaving a splitter = stream composition entering a splitter

For streams 5, 6, and 7, $\dfrac{F_{A,6}}{F_{B,6}} = \dfrac{F_{A,7}}{F_{B,7}} = \dfrac{F_{A,5}}{F_{B,5}} = \dfrac{1}{2}$

$$F_{B,5} = 2F_{A,5} = 2(100) = 200 \text{ kg/min}$$

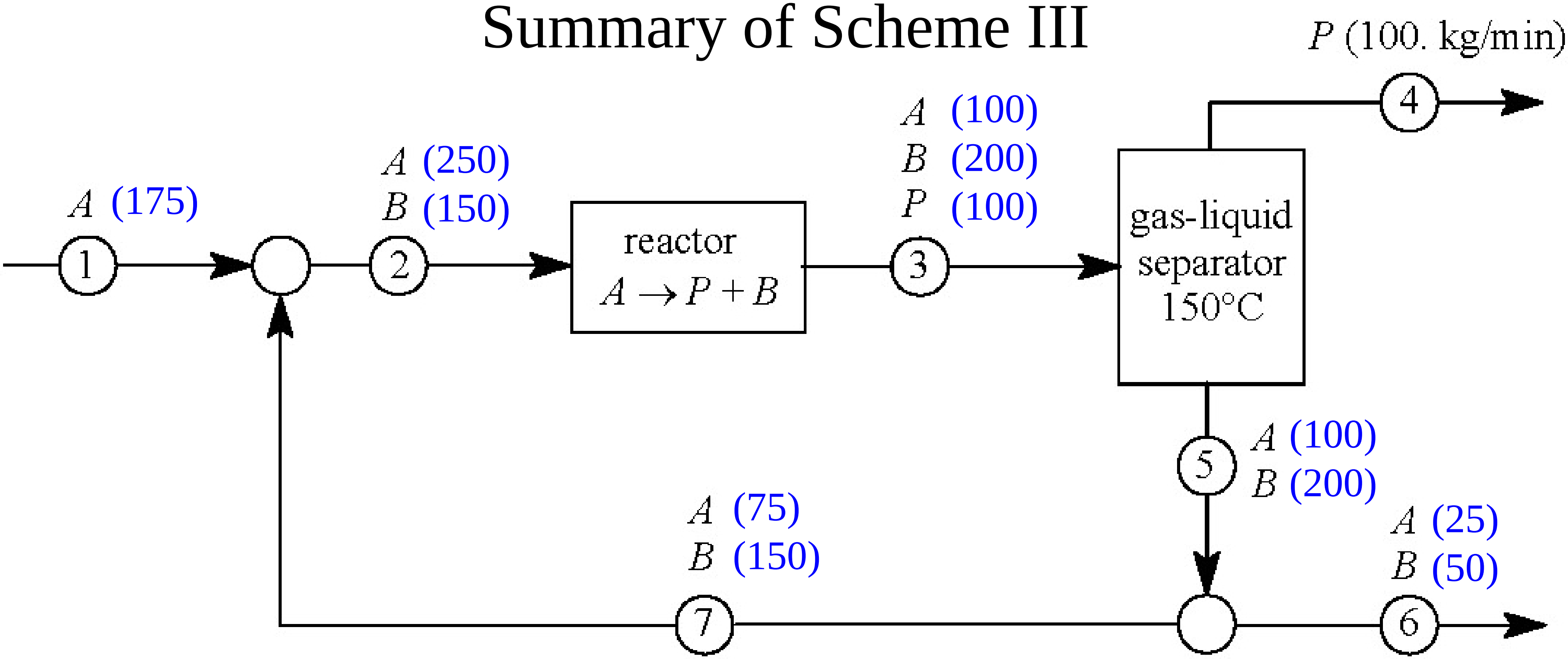
Mass balance on B in separator. (no chemical reaction)

rate of B in = rate of B out

$$F_{B,3} = \cancelto{0}{F_{B,4}} + F_{B,5} \quad \text{(informal)}$$

$$F_{B,3} = F_{B,5} = 200 \text{ kg/min}$$

Summary of Scheme III



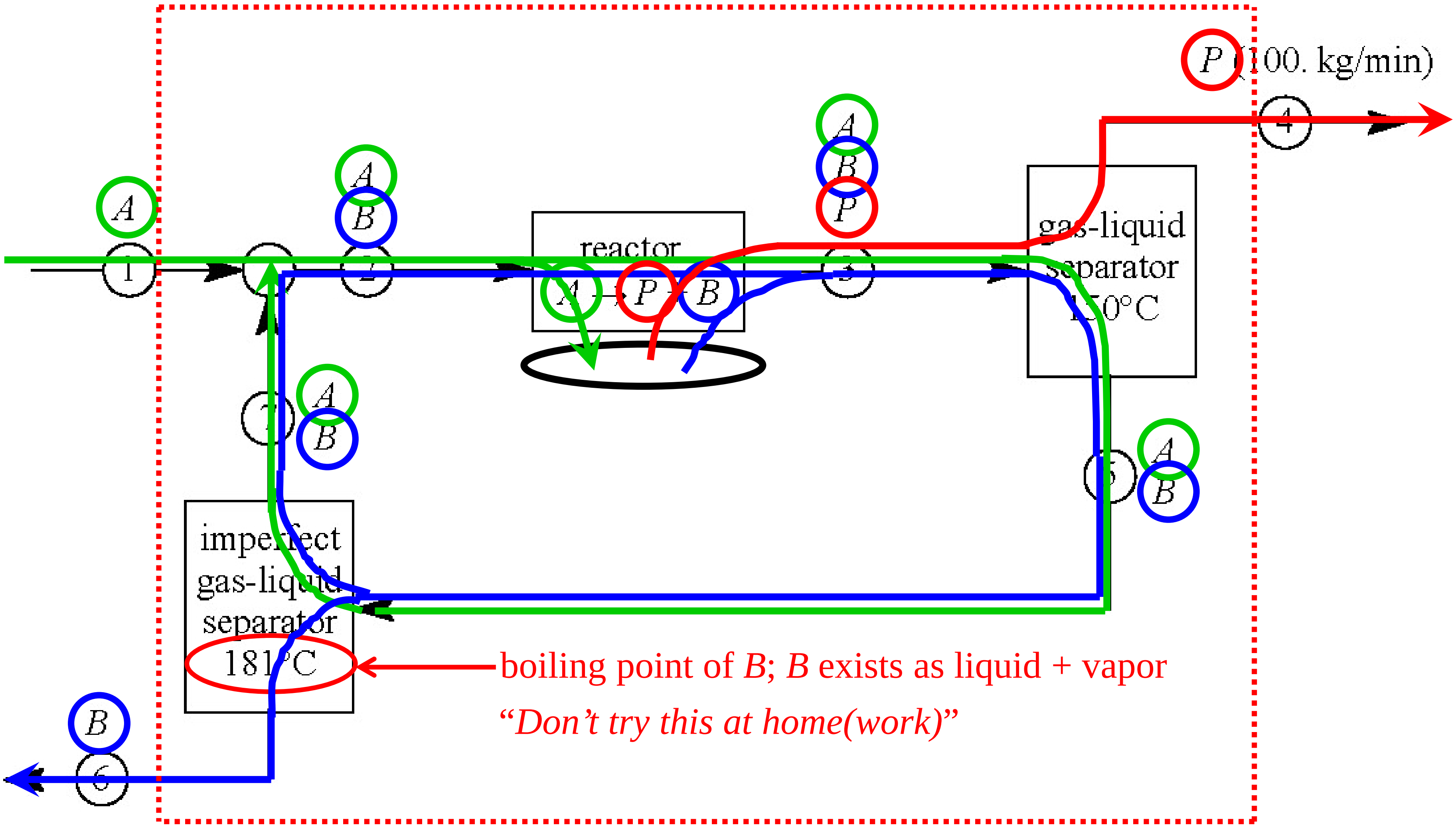
Process Specification:

stream composition leaving a splitter = stream composition entering a splitter

This process specification is often essential, but is most likely to be overlooked because the specification is inherent in the splitter, not explicit.

Scheme III is part (E) of exercise 3.44.
Solution is posted.

Scheme IV. Use an imperfect separator to remove pure by-product *B* and recycle a mixture of *A* and *B*. The imperfect separator operates at the boiling point of by-product *B*, so the by-product *B* exists in the imperfect separator as both liquid and gas. The imperfect separator is arbitrarily designed such that the flow rate of liquid *B* out (in stream 6) equals the flow rate of gas *B* out (in stream 7).



Model 1: (3 streams) × (3 parameters/stream) = 9 parameters

Calculate the flow rates of streams 1 and 6, in kg/min. Calculate the flow rate and composition of stream 3.

Model 1 of Scheme IV – Mathematical Model

Apply the Conservation of Mass. Write a total mass balance.

rate of A in + rate of B in + rate of P in = rate of A out + rate of B out + rate of P out

$$F_{A,1} + F_{B,1} + F_{P,1} = F_{A,4} + F_{A,6} + F_{B,4} + F_{B,6} + F_{P,4} + F_{P,6} \quad (1)$$

Process Specifications: stream 1: $F_{B,1} = F_{P,1} = 0$ (2), (3)

stream 4: $F_{A,4} = F_{B,4} = 0,\; F_{P,4} = 100.$ (4), (5), (6)

stream 6: $F_{A,6} = F_{P,6} = 0$ (7), (8)

Like in Scheme III,

rate of P out = rate P is created = $F_{P,4}$ = 100 kg/min

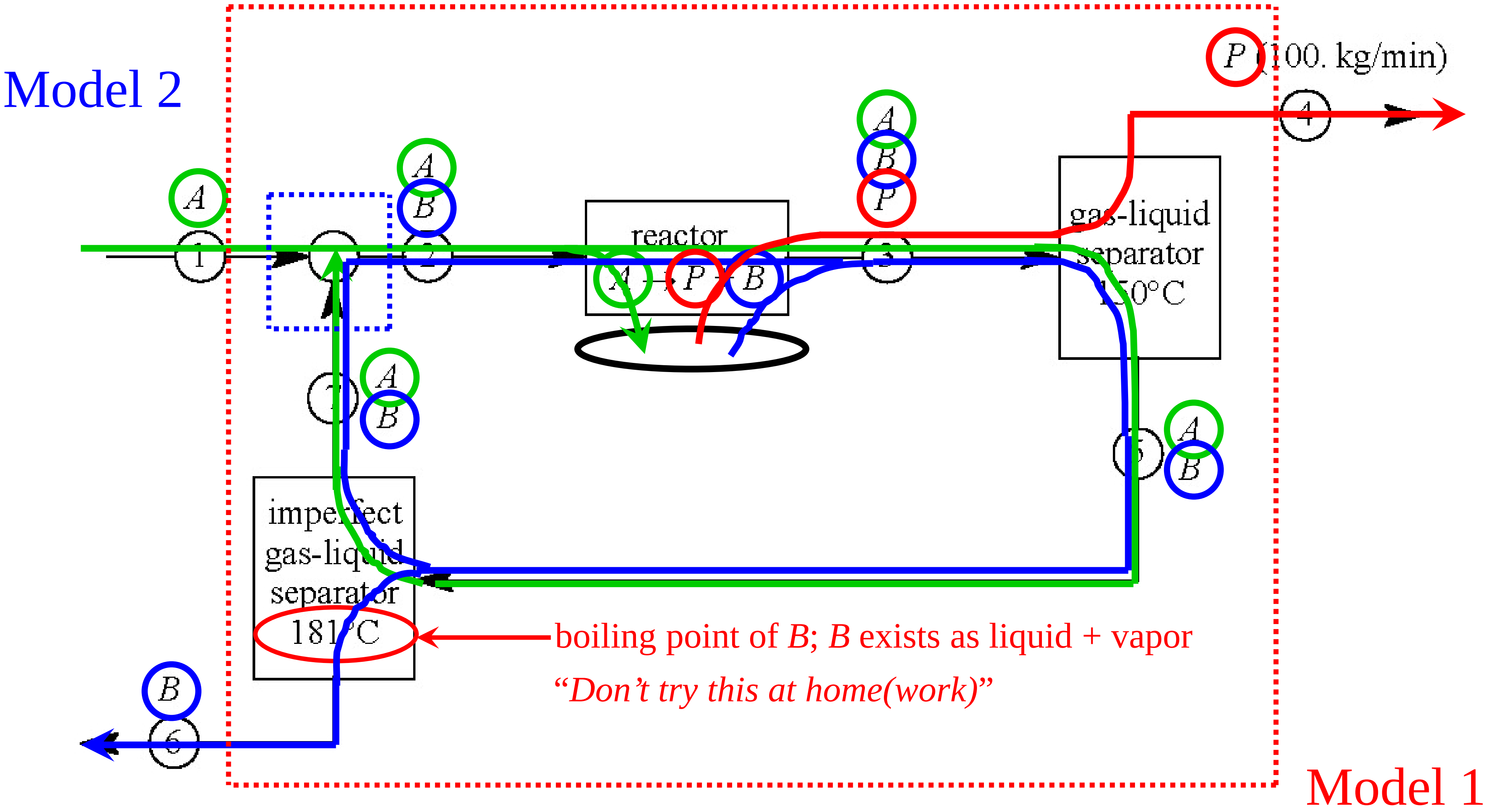
½(rate P is created) = rate B is created = ½(100) = 50 kg/min

$$F_{B,6} = 50 \text{ kg/min} \quad (9)$$

9 equations, 9 parameters. Solvable! $\Rightarrow F_{A,1} = 150$ kg/min

Reactor size? We need system borders that cross internal streams.

Scheme IV. Use an imperfect separator to remove pure by-product *B* and recycle a mixture of *A* and *B*. The imperfect separator operates at the boiling point of by-product *B*, so the by-product *B* exists in the imperfect separator as both liquid and gas. The imperfect separator is arbitrarily designed such that the flow rate of liquid *B* out (in stream 6) equals the flow rate of gas *B* out (in stream 7).



Calculate the flow rates of streams 1 and 6, in kg/min. Calculate the flow rate and composition of stream 3.

Model 2 of Scheme IV – Mathematical Model

Like in Scheme III,

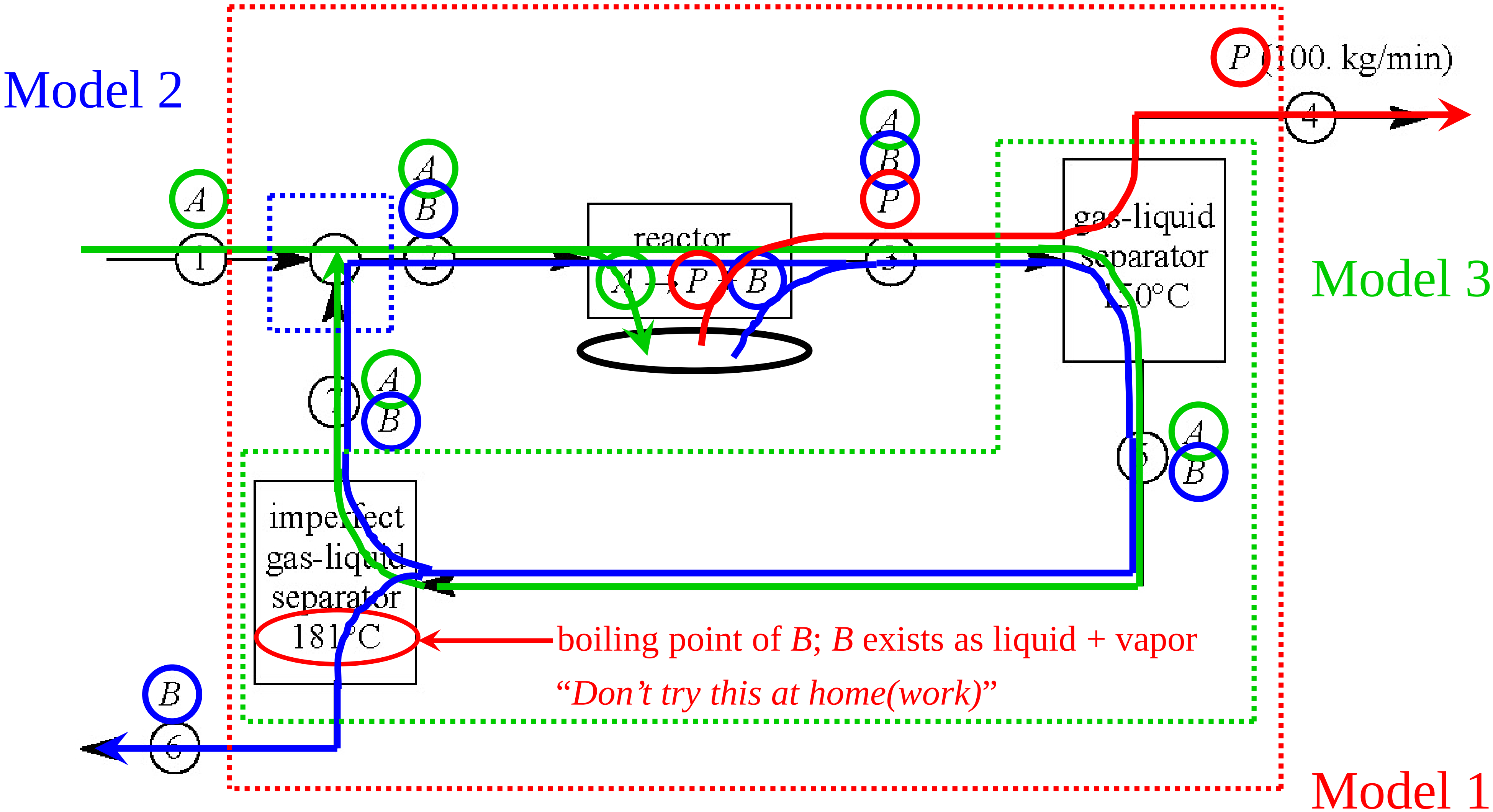
$$\text{rate A is consumed} = \text{rate P is created} + \text{rate B is created}$$
$$= \quad 100 \quad + \quad 50$$
$$= 150 \text{ kg/min}$$

$$F_{\text{A},2} = \text{rate of A into reactor} = \frac{\text{rate A is consumed}}{0.6} = \frac{150}{0.6} = 250 \text{ kg/min}$$

Mass balance around combiner:

$$\text{rate of A in} = \text{rate of A out}$$
$$F_{\text{A},1} + F_{\text{A},7} = F_{\text{A},2}$$
$$F_{\text{A},7} = F_{\text{A},2} - F_{\text{A},1} = 250 - 150 = 100 \text{ kg/min}$$

Scheme IV. Use an imperfect separator to remove pure by-product *B* and recycle a mixture of *A* and *B*. The imperfect separator operates at the boiling point of by-product *B*, so the by-product *B* exists in the imperfect separator as both liquid and gas. The imperfect separator is arbitrarily designed such that the flow rate of liquid *B* out (in stream 6) equals the flow rate of gas *B* out (in stream 7).



Calculate the flow rates of streams 1 and 6, in kg/min. Calculate the flow rate and composition of stream 3.

Model 3 of Scheme IV – Mathematical Model

Mass balance around the two separators:

rate of A in = rate of A out

$$F_{A,3} = F_{A,4} + F_{A,6} + F_{A,7}$$

Process Specification: $F_{A,4} = F_{A,6} = 0 \quad \Rightarrow \quad F_{A,3} = F_{A,7} = 100$ kg/min

Mass balance around the two separators:

rate of B in = rate of B out

$$F_{B,3} = F_{B,4} + F_{B,6} + F_{B,7}$$

Process Specification: $F_{B,4} = 0, \; F_{B,6} = F_{B,7} = 50$ kg/min

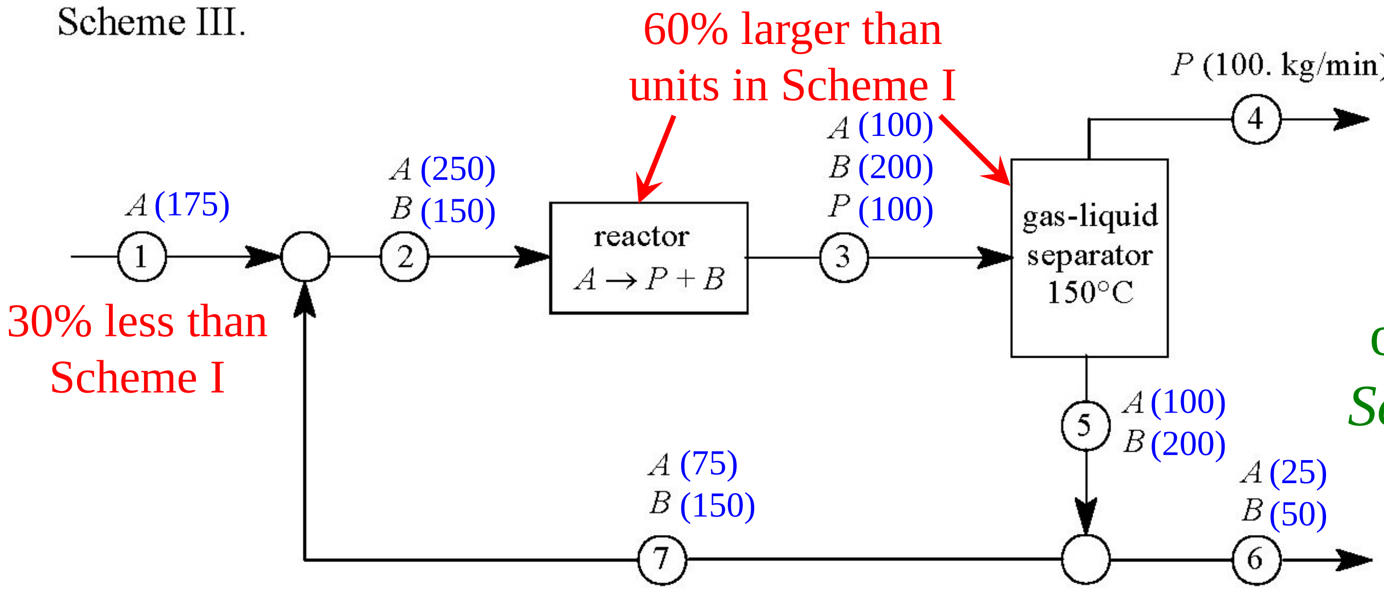
Substitute into mass balance on B.

$$F_{B,3} = F_{B,4} + F_{B,6} + F_{B,7}$$

$$F_{B,3} = 0 + 50 + 50 = 100 \text{ kg/min}$$

Summary of Schemes III and IV

Scheme III.



Scheme III is part (E) of exercise 3.44. *Solution is posted.*

Scheme IV.