Process Integration for Resource Conservation 1st edition Foo Solutions Manual

SKU: 9781439860489-SOLUTIONS

SOLUTION FOR PROBLEMS IN CHAPTER 3

Problem 3.1 (tire-to-fuel process)

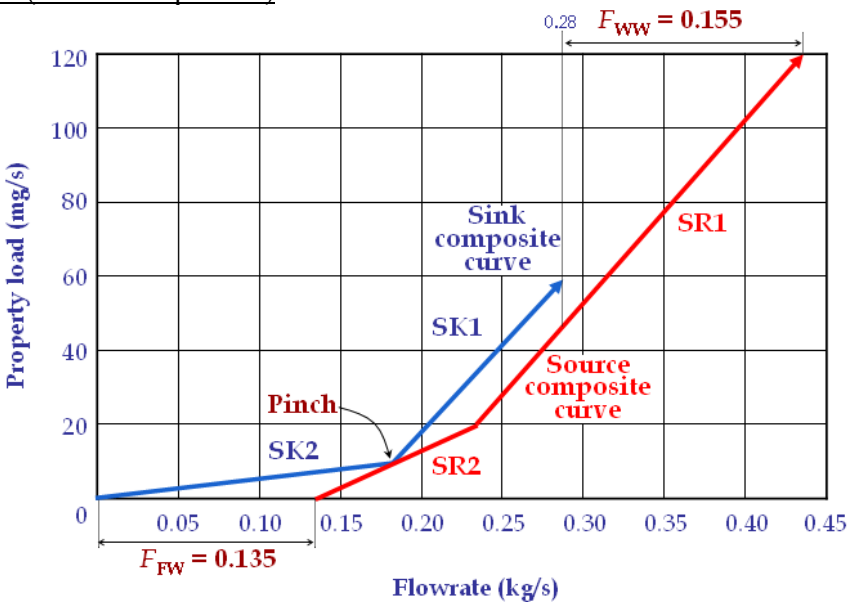


Figure S3.1 MRPD for Problem 3.1

Minimum flowrates for fresh water (F_{FW}) = 0.135 kg/s; and wastewater (F_{WW}) = 0.155 kg/s.

Problem 3.2 (textile plant)

Note: When plotting the sink composite curve, please note that sink SK3 has lower concentration than SK2, and hence is plotted prior to the latter.

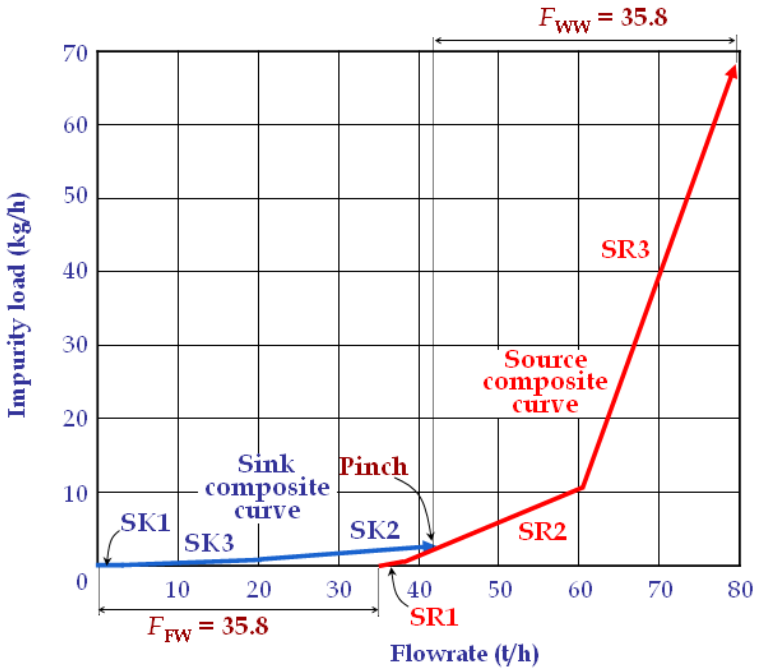


Figure S3.2 MRPD for Problem 3.2

Minimum flowrates for fresh water (F_{FW}) = 35.8 t/h; and wastewater (F_{WW}) = 35.8 t/h.

Problem 3.3

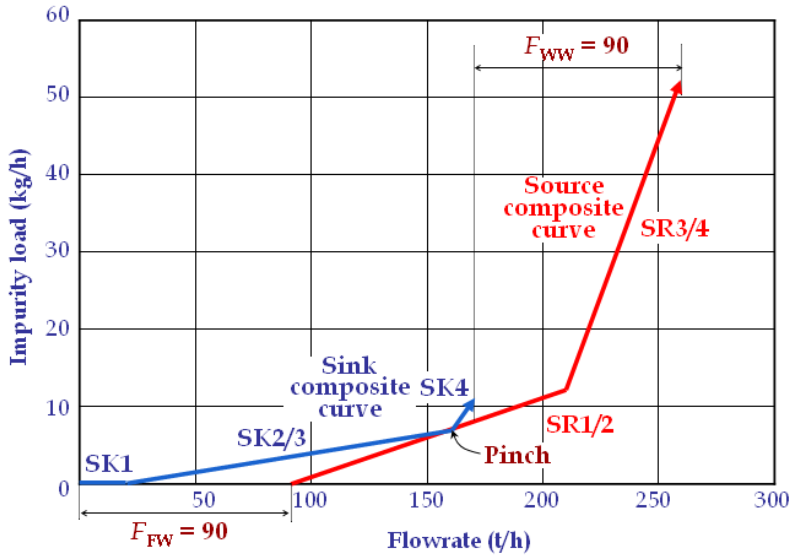


Figure S3.3 MRPD for Problem 3.3

Minimum flowrates for fresh water (F_{FW}) = 35.8 t/h; and wastewater (F_{WW}) = 35.8 t/h.

Problem 3.4 (Polley and Polley, 2000)

(a) Pure fresh water feed

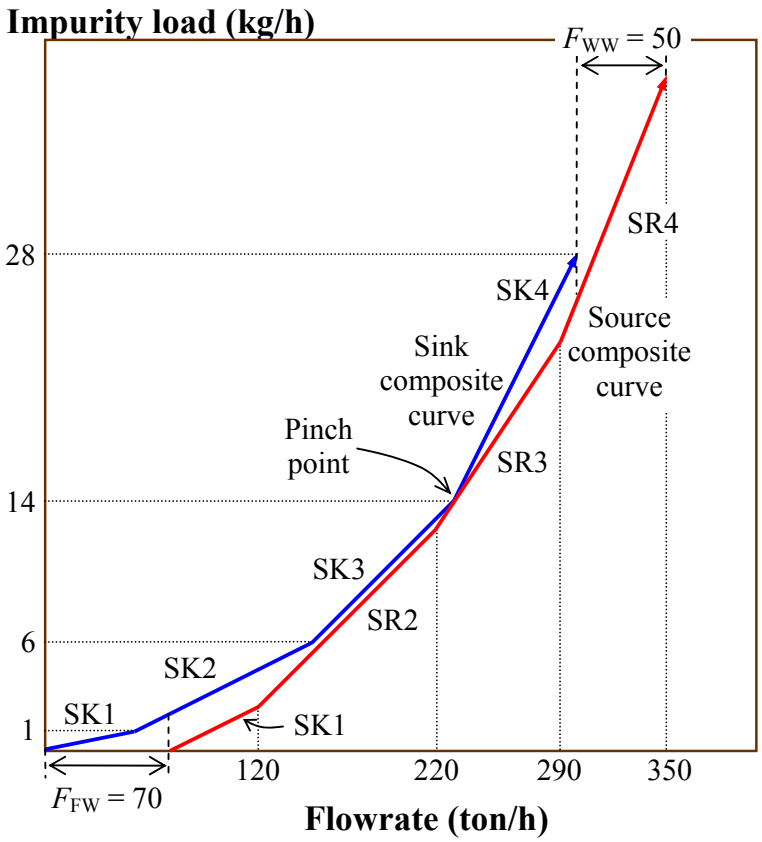


Figure S3.4 MRPD for Problem 3.4(a) (Foo, 2009)

Minimum flowrates for fresh water (F_{FW}) = 70 t/h; and wastewater (F_{WW}) = 5 t/h.

(b) Single impure fresh water feed, with 10 ppm impurity content

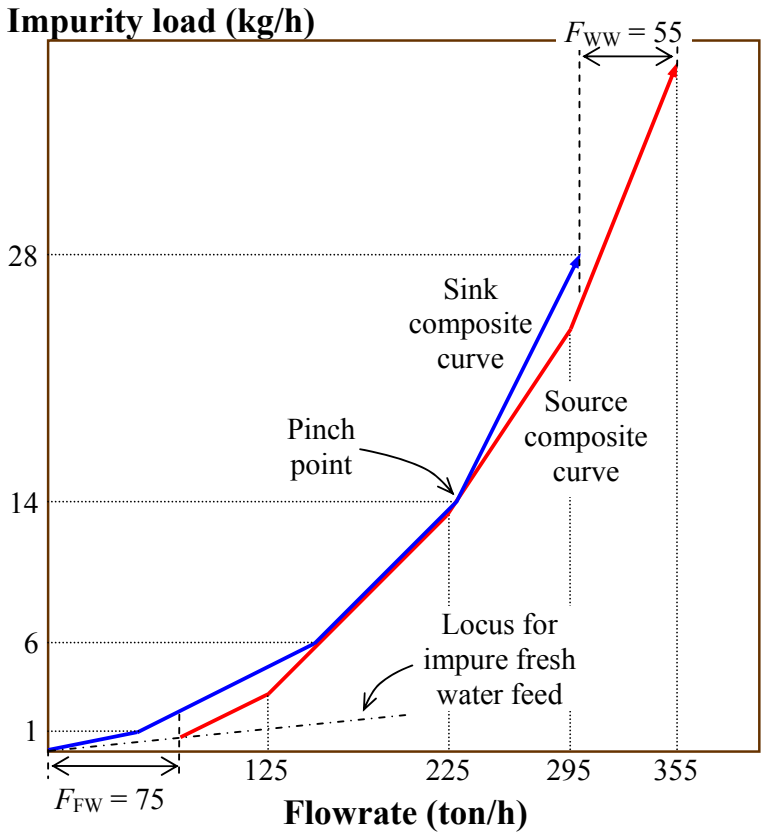


Figure S3.5 MRPD for Problem 3.4(b) (Foo, 2009)

Minimum flowrates for fresh water (F_{FW}) = 75 t/h; and wastewater (F_{WW}) = 55 t/h.

(c) Pure (0 ppm, \$1/ton) and impure fresh water feeds (80 ppm, \$0.2/ton).

In (a), the pinch concentration (when pure fresh water feed is used) for this problem is identified as 150 ppm. Hence, the prioritised cost for pure ($CT_{P,\,FW1}$) and impure fresh water sources ($CT_{P,\,FW2}$) are determined using **Equation 3.3** as:

$$CTP_{FW1} = \frac{\$1/\text{ton}}{(150-0)\,\text{ppm}} = \frac{\$6.667}{\text{kg impurity}};$$

$$CTP_{FW2} = \frac{\$0.2/\text{ton}}{(150-80)\,\text{ppm}} = \frac{\$2.857}{\text{kg impurity}}$$

Since the prioritised cost of the impure fresh water source is much lower than that of the pure fresh water source, the use of former should be maximised prior to the latter. Targeting using MRPD is shown in **Figure S3.6**. The fresh water flowrates for pure (F_{FW1}) and impure fresh water sources (F_{FW2}) are identified as 56.25 and 43.75 t/h respectively.

Operating cost for fresh water feeds are then calculated as:

$$56.25\ (1) + 43.75\ (0.2) \ = \ \$65/\text{h}$$

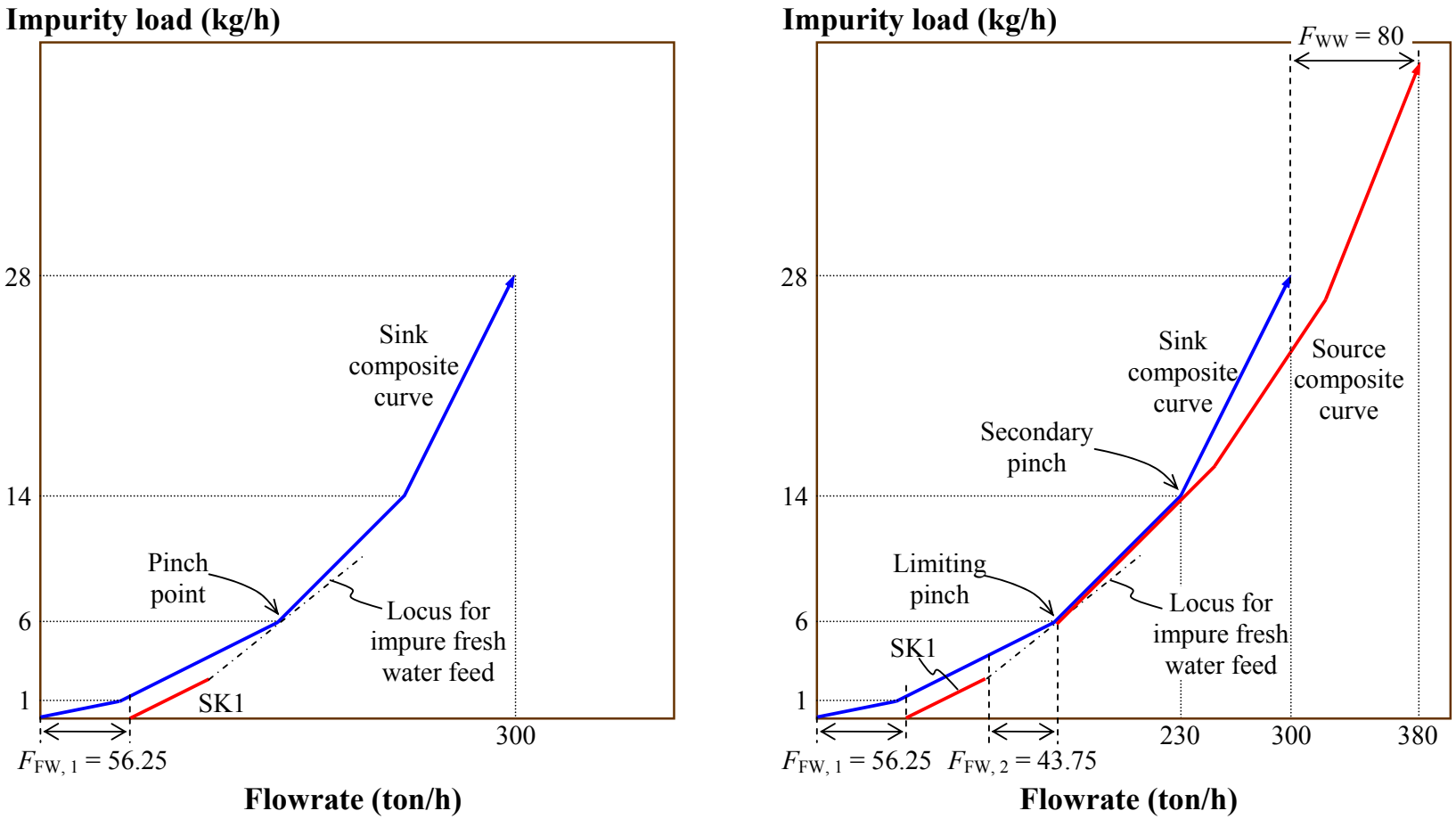


Figure S3.6 MRPD for Problem 3.4(c): (a) targeting for pure fresh fresh water feed; (b) targeting for impure fresh water feed (Foo, 2009)

Problem 3.5

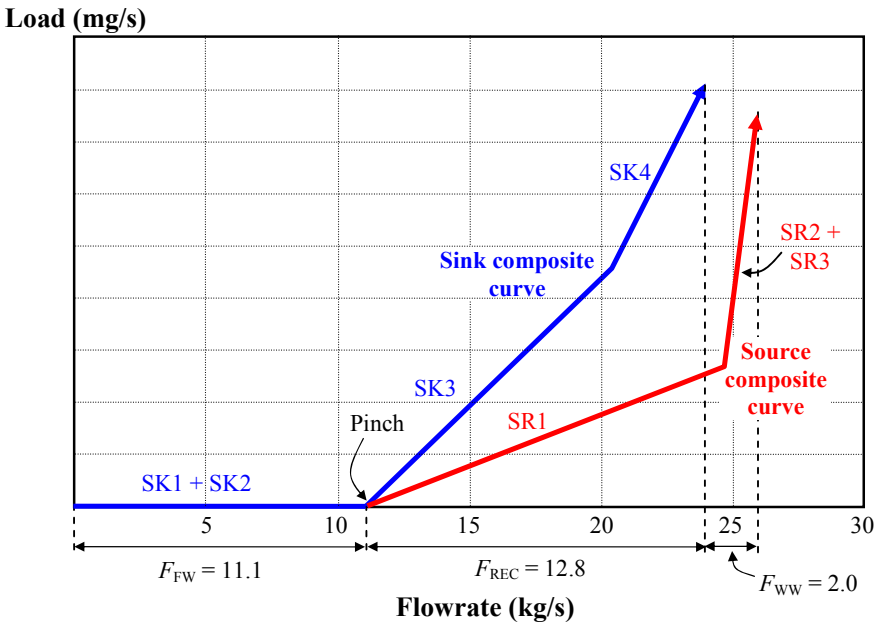


Figure S3.7 MRPD for Problem 3.5 (Foo, 2012)

Minimum flowrates for fresh water (F_{FW}) = 11.1 kg/s; and wastewater (F_{WW}) = 2.0 kg/s.

Problem 3.6

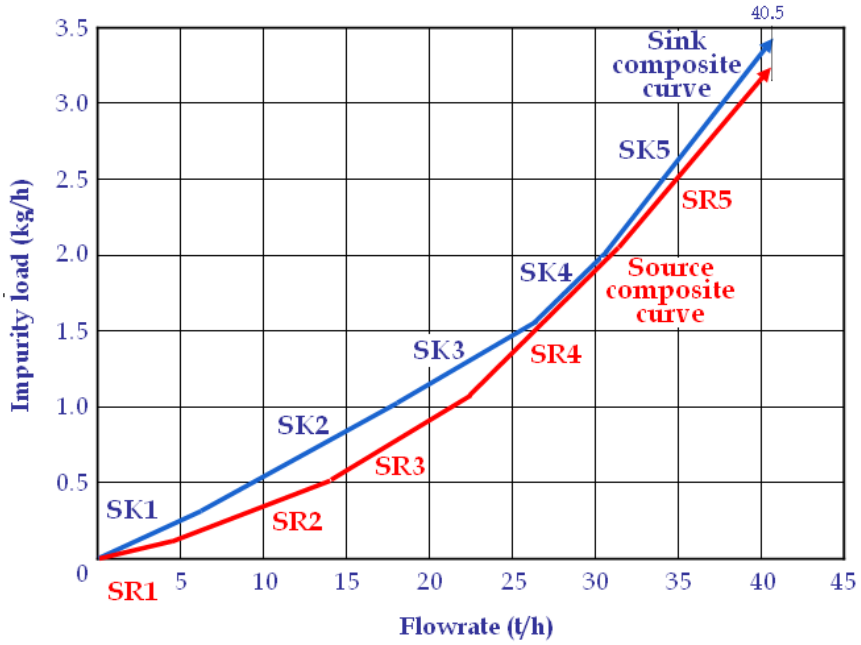
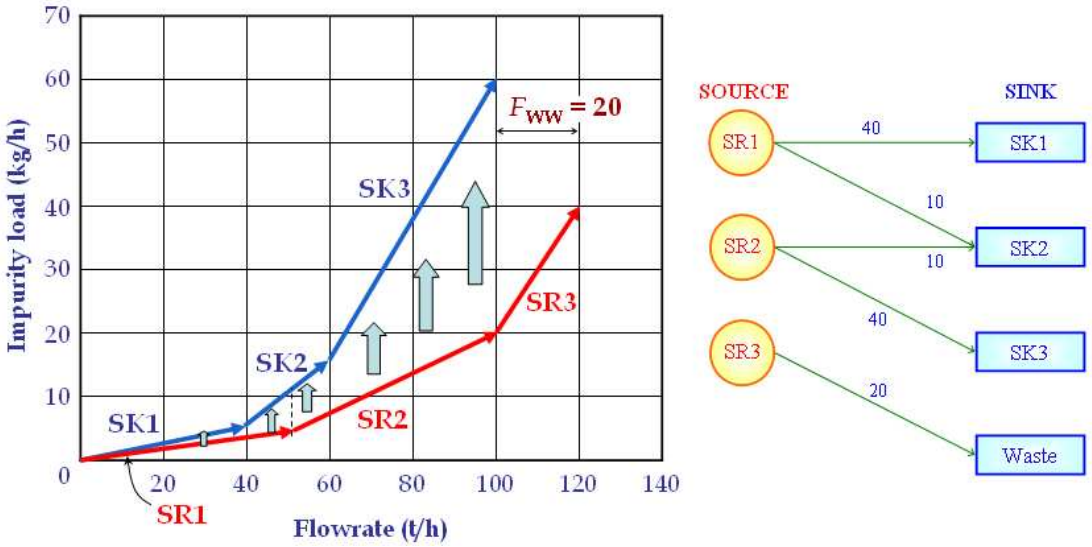


Figure S3.8 MRPD for Problem 3.6

Zero fresh resource and zero discharge network, i.e. no fresh water and wastewater flowrates.

Problem 3.7

Flowrate allocation for each water sink can be determined based on the horizontal distance of the segment. For instance, sink SK1 is allocated fully by source SR1; while SK2 receives water from both SK1 and SK2, with flowrate of 10 t/h respectively (see **Figure S3.9**). Similar approach is used for other sinks in **Examples 3.5** and **3.6** (see **Figure S3.10**).



(a) (b)

Figure S3.9 RCN for **Examples 3.5 -** zero fresh resource network

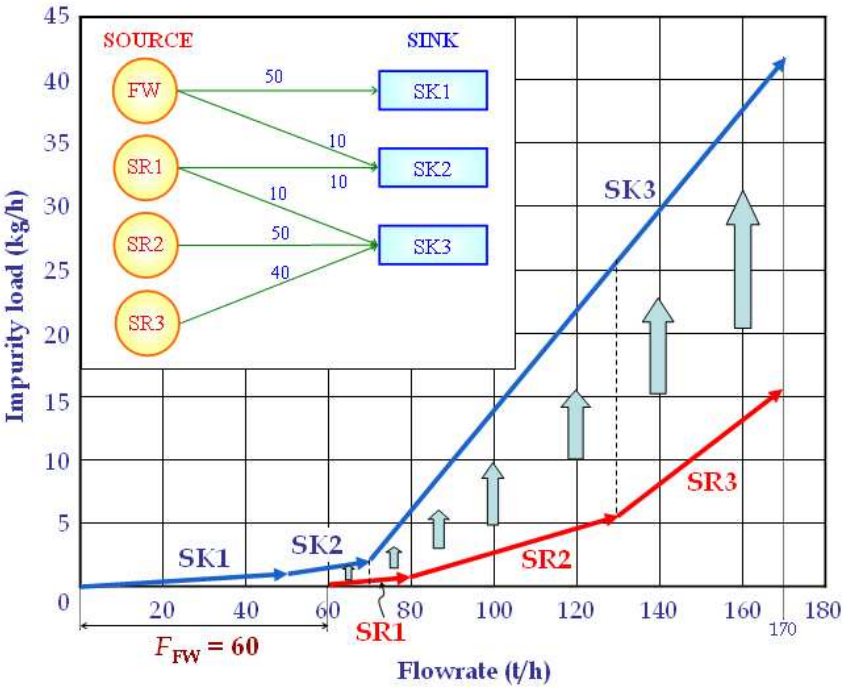


Figure S3.10 RCN for **Examples 3.6 -** Zero discharge network

Problem 3.8

Note: When plotting the sink composite curve, please note that source SR2 has lower concentration than SR1, and hence is plotted prior to the latter.

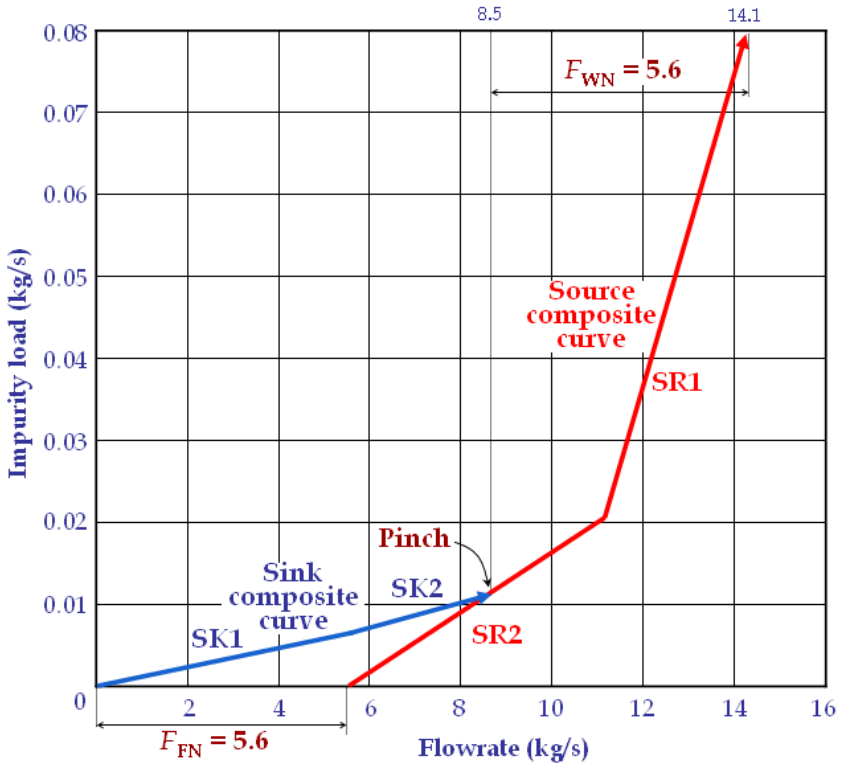


Figure S3.11 MRPD for Problem 3.8

Minimum flowrates for fresh nitrogen (F_{FN}) = 5.6 kg/s; and waste gas (F_{WN}) = 5.6 kg/s.

Problem 3.9

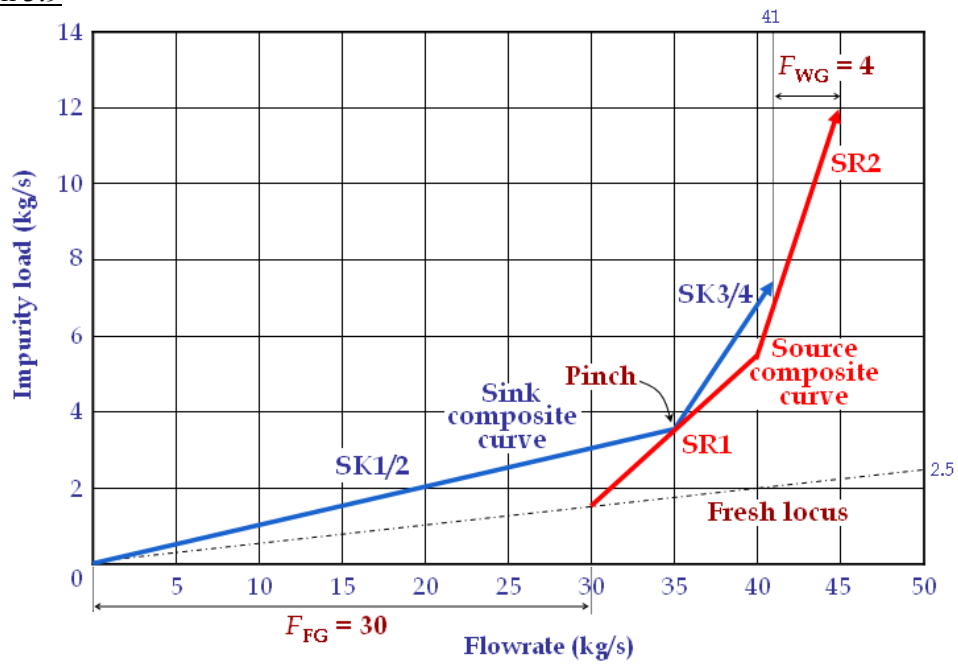


Figure S3.12 MRPD for Problem 3.9

Minimum flowrates for fresh oxygen gas (F_{FW}) = 30 kg/s; and waste gas (F_{WG}) = 4 kg/s.

Problem 3.10

Note: When plotting the sink composite curve, please note that source SR2 has lower concentration than SR1, and hence is plotted prior to the latter.

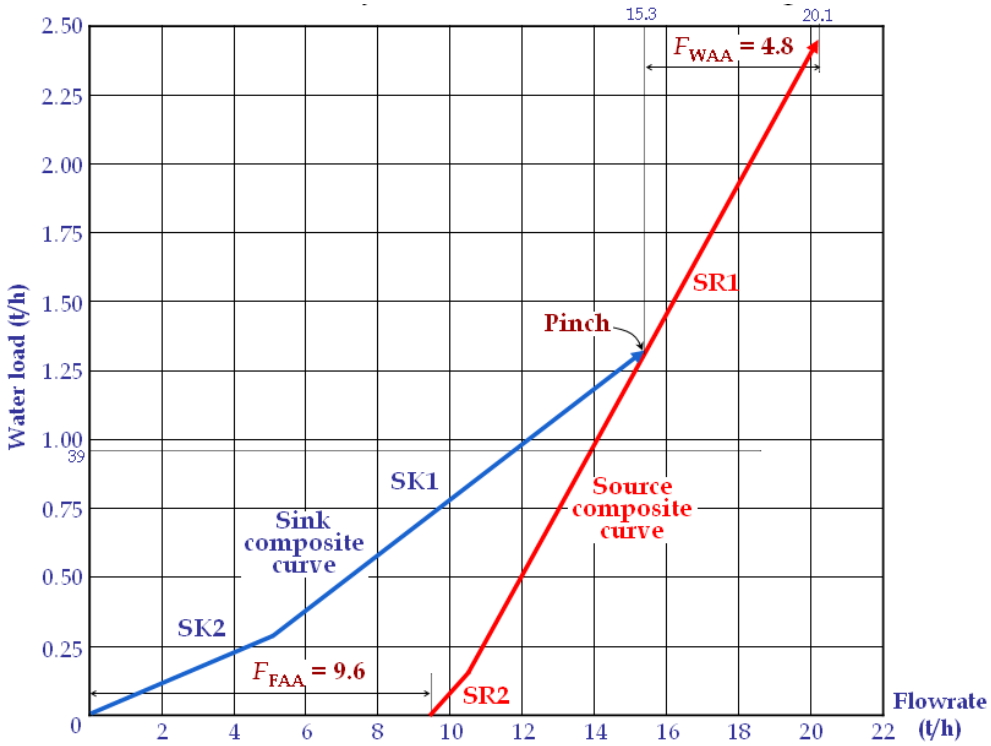


Figure S3.13 MRPD for Problem 3.10

Minimum flowrates for fresh acetic acid (F_{FAA}) = 9.6 t/h; and waste (F_{WAA}) = 4.8 t/h.

Problem 3.11

Since UPW has a resistivity of 18,000 kΩ/cm, which translates into the operator value of 0.000056 cm/kΩ. Hence a fresh locus is needed in the MRPD.

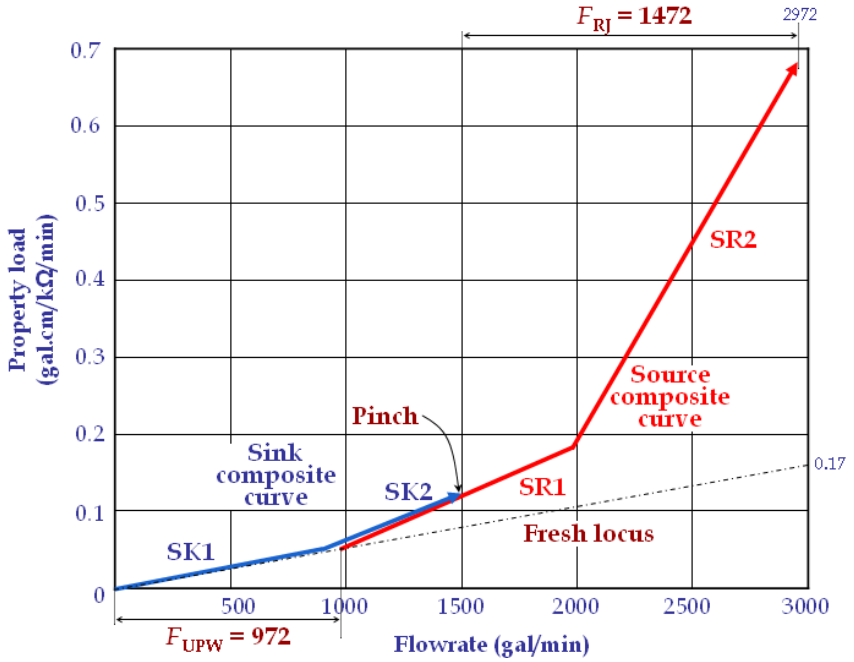


Figure S3.14 MRPD for Problem 3.11

Minimum flowrates for ultrapure water (F_{UPW}) = 972 gal/min; and reject streams (F_{RJ}) = 1472 gal/min.

Problem 3.12

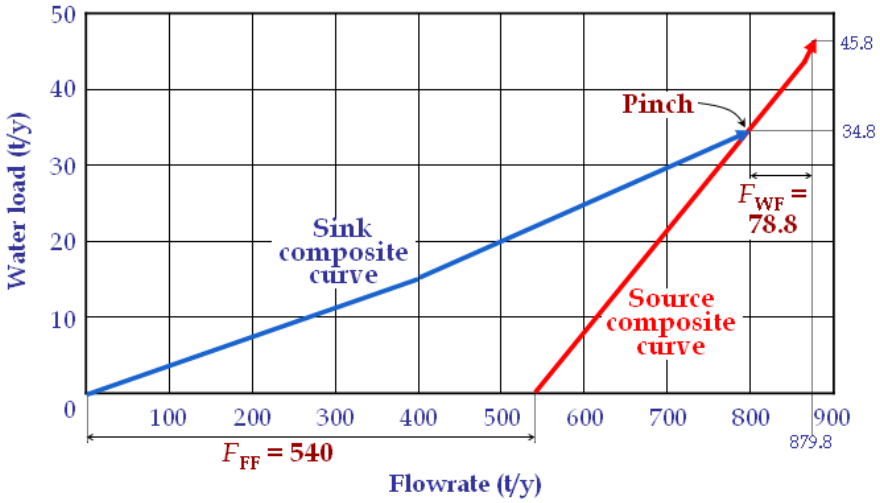


Figure S3.15 MRPD for Problem 3.12

Minimum flowrates for fresh fibre (F_{FF}) = 540 t/y; and waste fibre (F_{WF}) = 4 t/y.

References

Foo, D. C. Y. (2012). Resource Conservation through Pinch Analysis, in Foo, D. C. Y., El-Halwagi, M. M. and Tan, R. R. (Eds.) *Recent Advances in Sustainable Process Design and Optimisation*, World Scientific/Imperial College Press (in press).

Foo, D. C. Y. (2009). A State-of-the-art Review of Pinch Analysis Techniques for Water Network Synthesis. *Industrial & Engineering Chemistry Research*, 48 (11), 5125-5159.

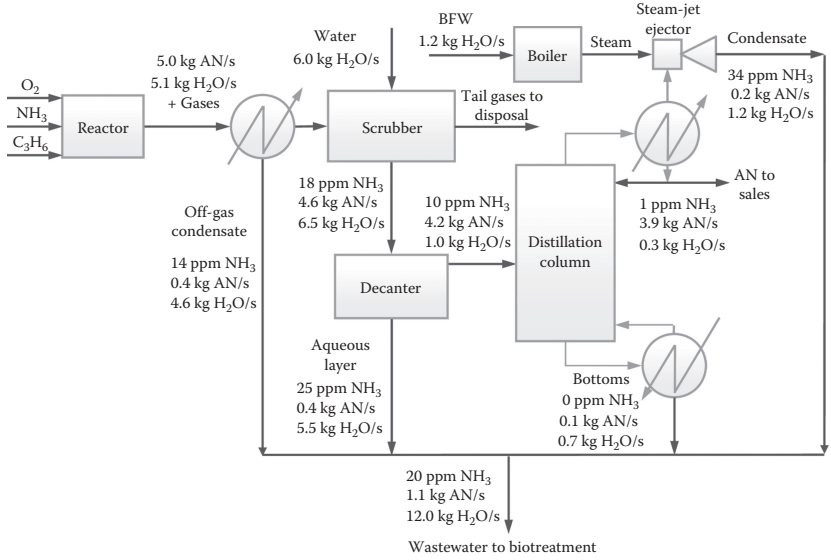


Figure 2.1
PFD for AN production. (From El-Halwagi, M.M., *Pollution Prevention through Process Integration: Systematic Design Tools*, Academic Press, San Diego, CA, 1997, p. 87. With permission.)

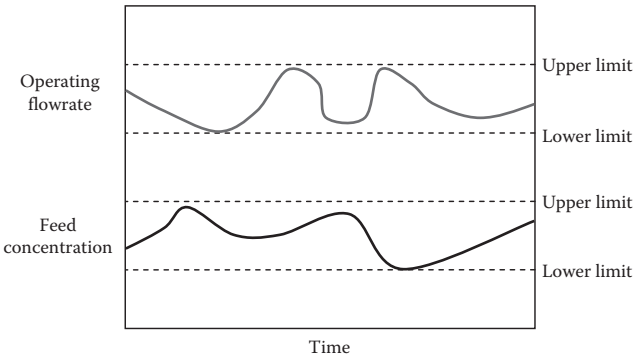


Figure 2.2
Historical data for plant operation. (From El-Halwagi, M.M., *Process Integration*, Academic Press, San Diego, CA, 2006, p. 42. With permission.)

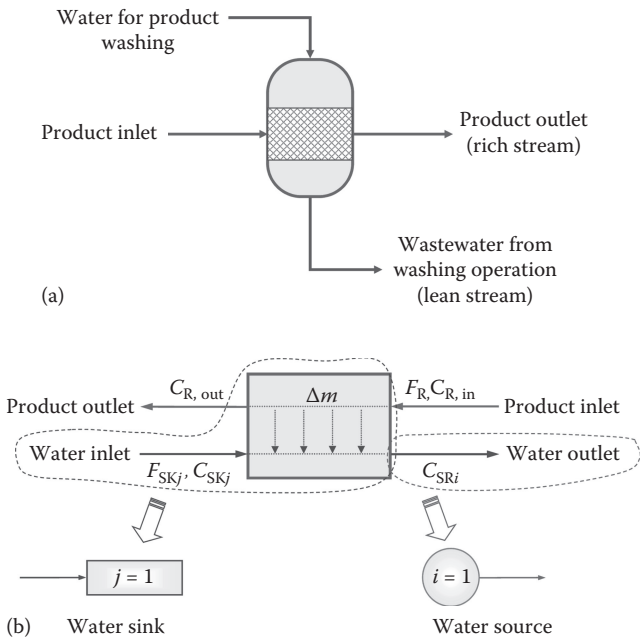


Figure 2.3
A product washing operation (a) for the abvoe and (b) for the below.

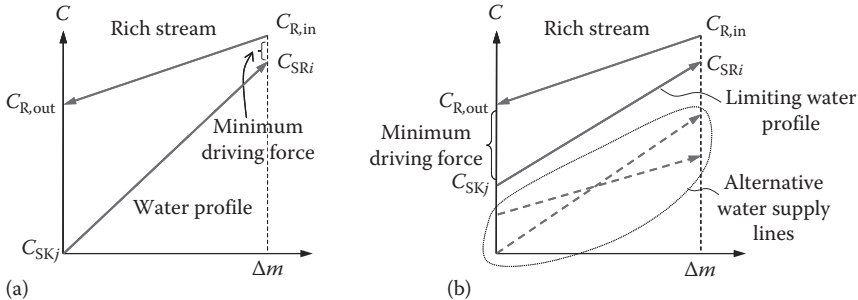


Figure 2.4
A product washing operation represented in concentration versus load diagram. (From *Chem. Eng. Sci.*, 49, Wang, Y.P. and Smith, R., Wastewater minimisation, 981–1006, 1994. Copyright 1994, with permission from Elsevier.)

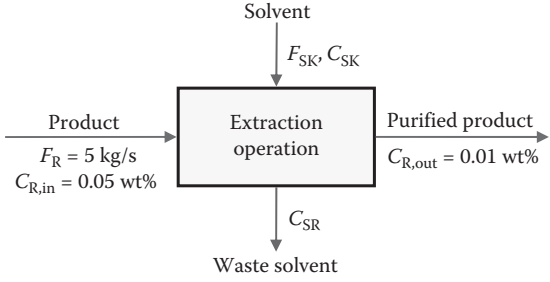


Figure 2.5
An extraction operation.

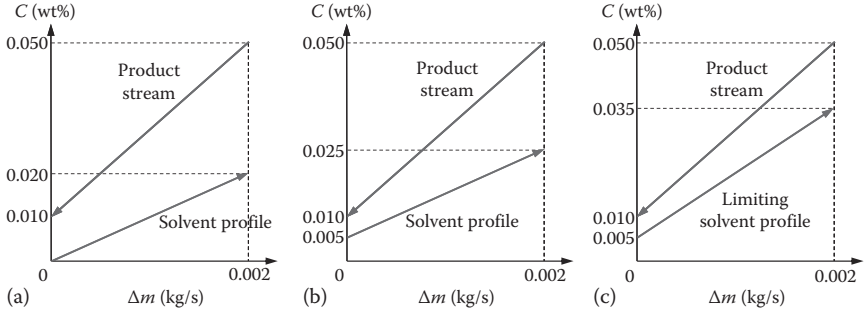


Figure 2.6
Concentration versus load diagrams for Example 2.3: (a) Scenario 1, (b) Scenario 2, and (c) Scenario 3—limiting solvent profile.

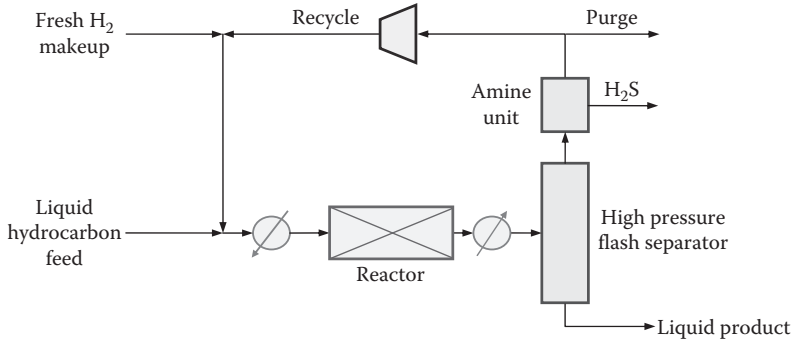


Figure 2.7
A simplified PFD for a hydrogen-consuming unit. (Reprinted with permission from Alves, J.J. and Towler, G.P., Analysis of refinery hydrogen distribution systems, *Ind. Eng. Chem. Res.*, 41, 5759–5769, 2002. Copyright 2002 American Chemical Society.)

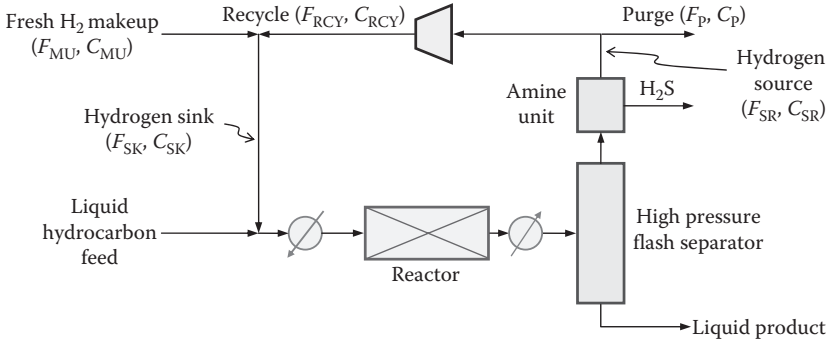


Figure 2.8
Identification of hydrogen sink and source. (From *Adv. Environ. Res.*, 6, Hallale, N. and Liu, F., Refinery hydrogen management for clean fuels production, 81–98, 2001. Copyright 2001, with permission from Elsevier.)

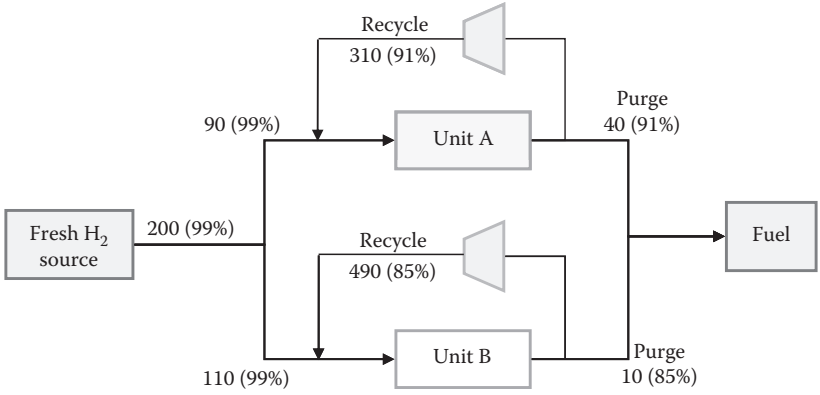


Figure 2.9
PFD of a refinery hydrogen network (stream flowrate given in million standard cubic feet/day—MMscfd; its hydrogen purity is given in parenthesis). (From *Adv. Environ. Res*., 6, Hallale, N. and Liu, F., Refinery hydrogen management for clean fuels production, 81–98, 2001. Copyright 2001, with permission from Elsevier.)

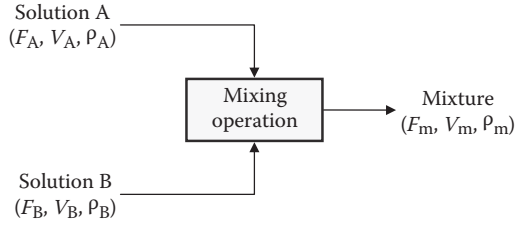


Figure 2.10
Mixing of solutions with different density.

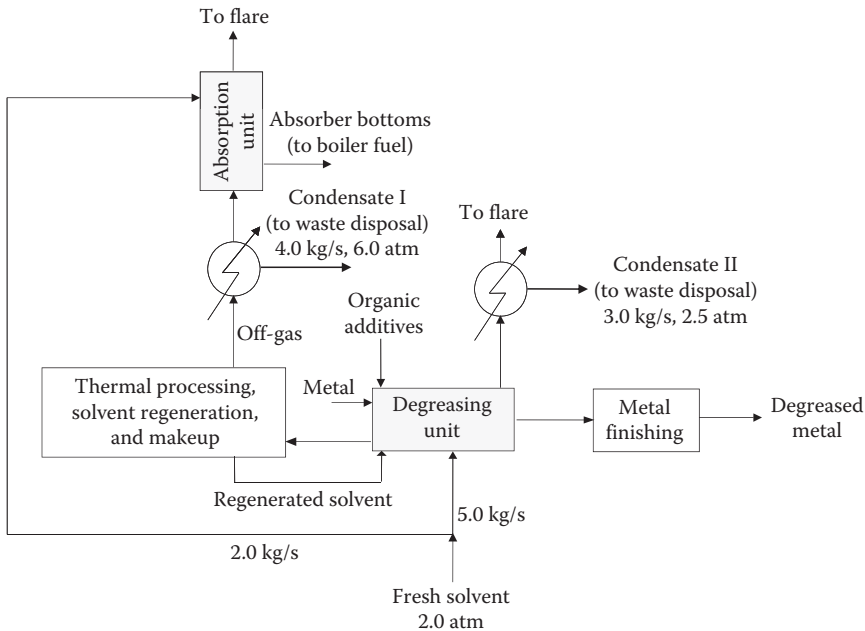


Figure 2.11
PFD of a metal degreasing process. (Reproduced from Kazantzi, V. and El-Halwagi, M.M., *Chem. Eng. Prog.*, 101(8), 28, 2005. With permission. Copyright 2005 American Institute of Chemical Engineers (AIChE).)

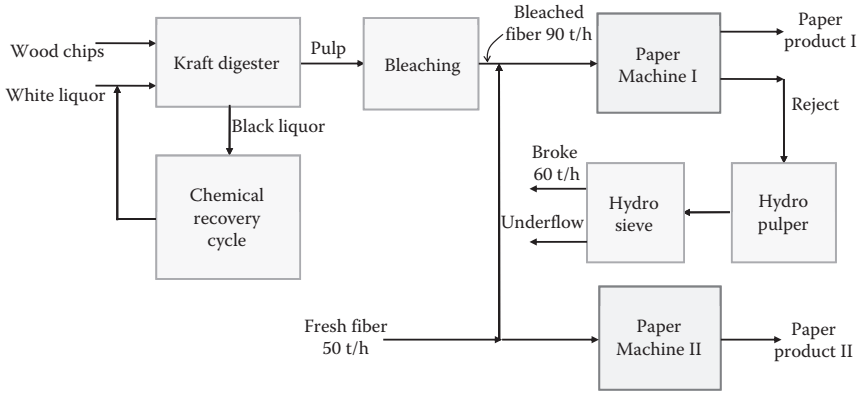


Figure 2.12
PFD of a papermaking process. (Reproduced from Kazantzi, V. and El-Halwagi, M.M., *Chem. Eng. Prog.*, 101(8), 28, 2005. With permission. Copyright 2005 American Institute of Chemical Engineers (AIChE).)

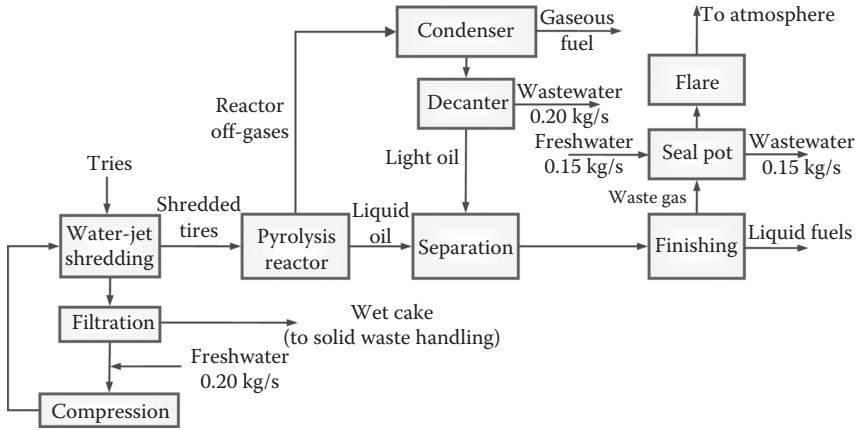


Figure 2.13
Tire-to-fuel process. (From El-Halwagi, M.M., *Pollution Prevention through Process Integration: Systematic Design Tools*, Academic Press, San Diego, CA, 1997, p. 97. With permission.)

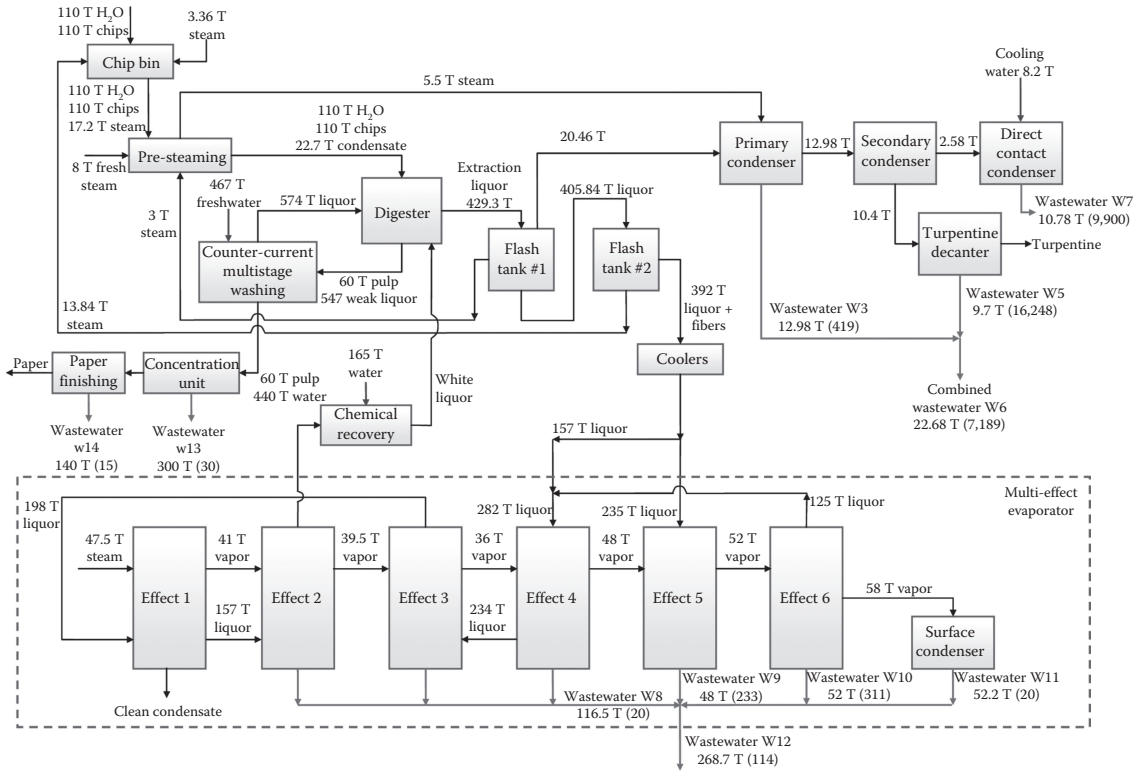


Figure 2.14
A Kraft pulping process (basis: 1 h; T refers to ton; values in parenthesis indicate methanol concentration in ppm). (From Hamad, A.A. et al., Systematic integration of source reduction and recycle reuse for cost-effective compliance with the cluster rules, in *AIChE Annual Meeting*, Miami, FL, 1995. With permission.)

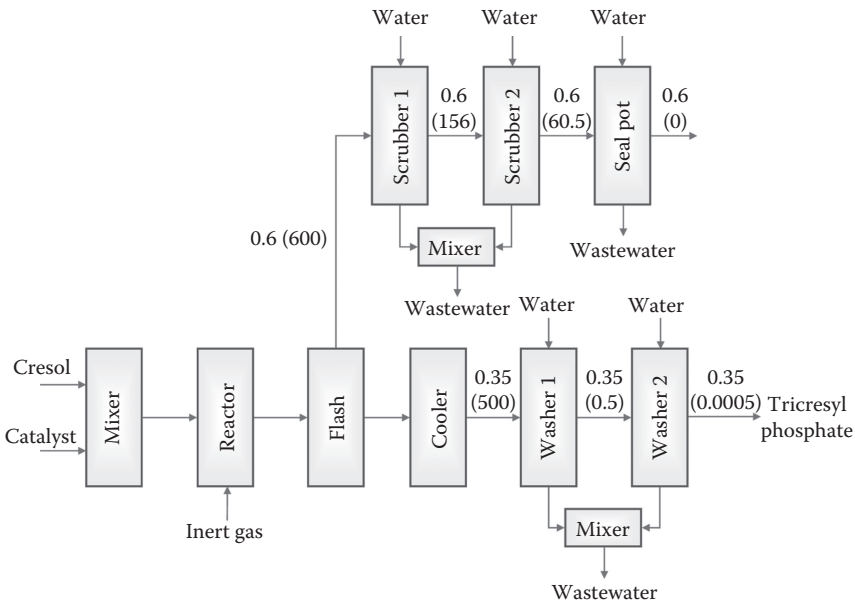


Figure 2.15
Tricresyl phosphate manufacturing process (stream flowrates given in kg/s; values in parenthesis indicate cresol concentration in ppm). (From Hamad, A.A. et al., Optimal design of hybrid separation systems for in-plant waste reduction, in *Proceedings of the Fifth World Congress of Chemical Engineering*, San Diego, CA, Vol. III, pp. 453–458, 1996. With permission.)

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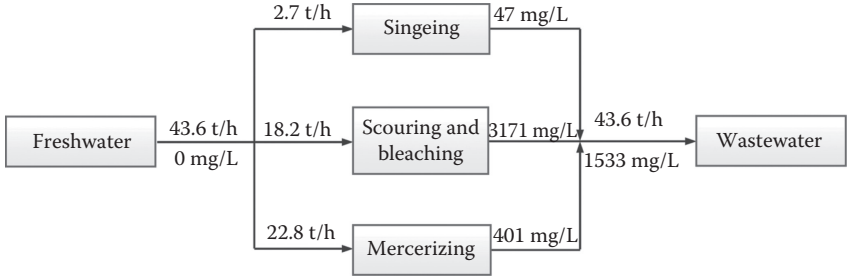


Figure 2.16
Water-using scheme for the bleaching section in a textile plant. (From Ujang, Z. et al., *Water Sci. Technol*., 46, 77, 2002. With permission.)

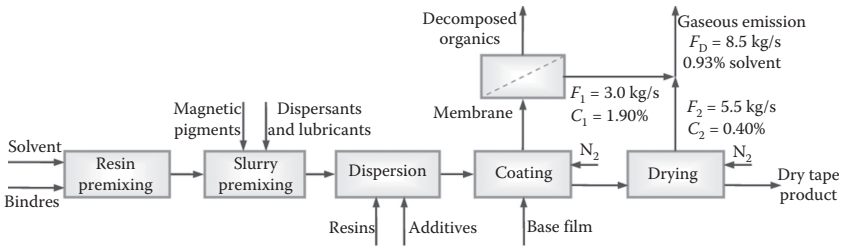


Figure 2.17
A magnetic tape process. (From Dunn, R.F. et al., Selection of organic solvent blends for environmental compliance in the coating industries, in Griffith, E.D., Kahn, H., and Cousins, M.C. eds., *Proceedings of the First International Plant Operations and Design Conference*, Vol. III, pp. 83–107, AIChE, New York, 1995. With permission.)

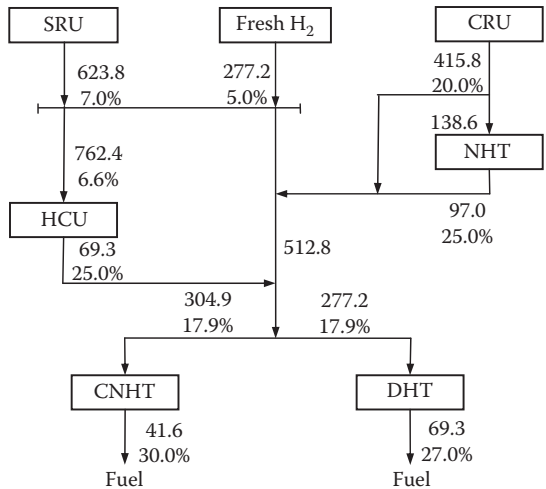


Figure 2.18
A refinery hydrogen network (numbers represent the total gas flowrate in mol/s and impurity concentration in mol%). (Reprinted with permission from Alves, J.J. and Towler, G.P., Analysis of refinery hydrogen distribution systems, *Ind. Eng. Chem. Res*., 41, 5759 , 2002. Copyright 2002 American Chemical Society.)

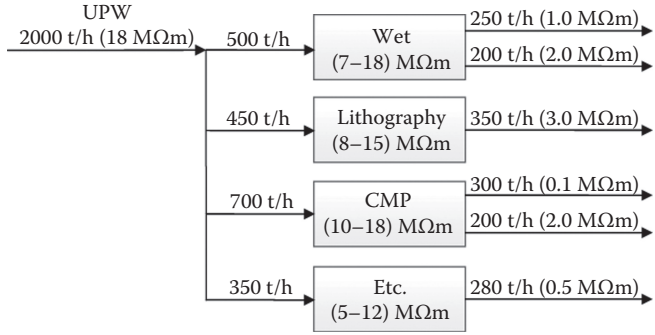


Figure 2.19
Usage of UPW in a wafer fabrication process.

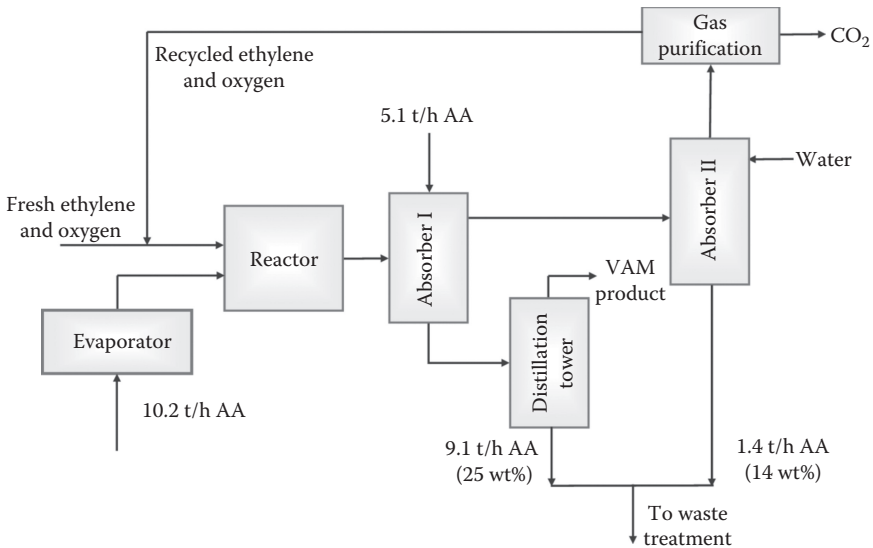


Figure 2.20
Vinyl acetate manufacturing process (numbers represent AA stream flowrate; values in parenthesis represent water concentrations in AA streams). (From El-Halwagi, M.M., *Process Integration*, Academic Press, San Diego, CA, 2006, p. 56. With permission.)

Chapter 2 – Data Extraction for Resource Conservation

Introduction

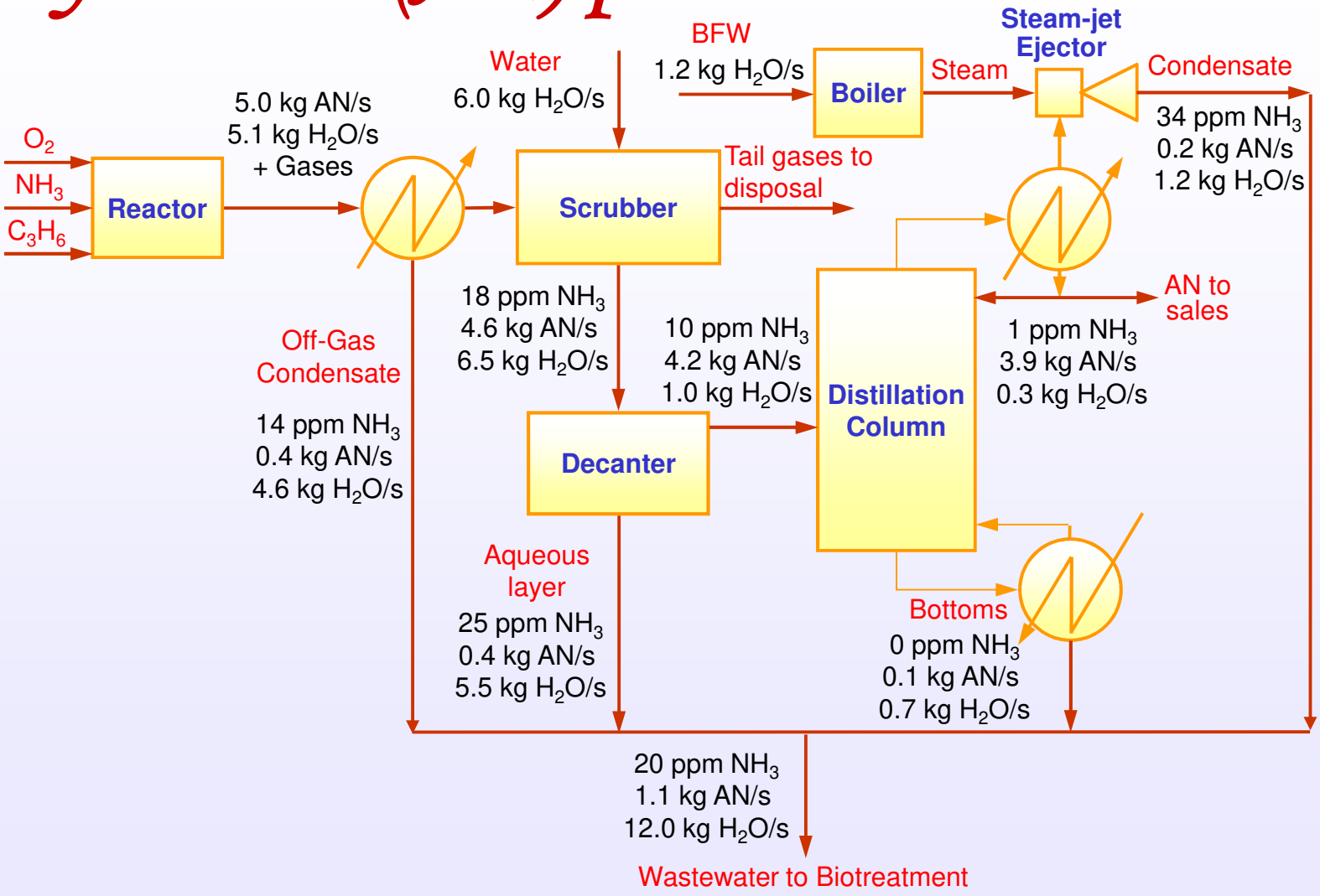
- Data extraction – **most crucial step** for any resource conservation activity
- Once the data is wrongly extracted, we might end up synthesising a sub-optimum resource conservation network (RCN).
- **Limiting data** needed for process sinks and sources:
  - ✓ Quantity aspect – flowrate
  - ✓ Quality aspects:
    - ❖ Mass integration-based RCN – impurity concentration
    - ❖ Property integration – linearised operator for property mixing rule

Segregation for material sources

Heuristic 1

Keep material sources segregated to maximise their recovery potential.

Ex 2.1 – Water minimisation in Acrylonitrile (AN) production



Ex 2.1 – Process description

- AN is produced in a fluidised-bed reactor (2 atm & 450°C) via vapour-phase ammoxidation of propylene.
- The reaction is single-pass, with almost complete conversion of propylene, with following stoichiometry

$$C_3H_6 + NH_3 + 1.5O_2 \xrightarrow{\text{catalyst}} C_3H_3N + 3H_2O$$

- Effluent from the reactor is cooled and partially condensed. The off-gas from the condenser is sent to a scrubber for purification; while its condensate to the biotreatment facility.

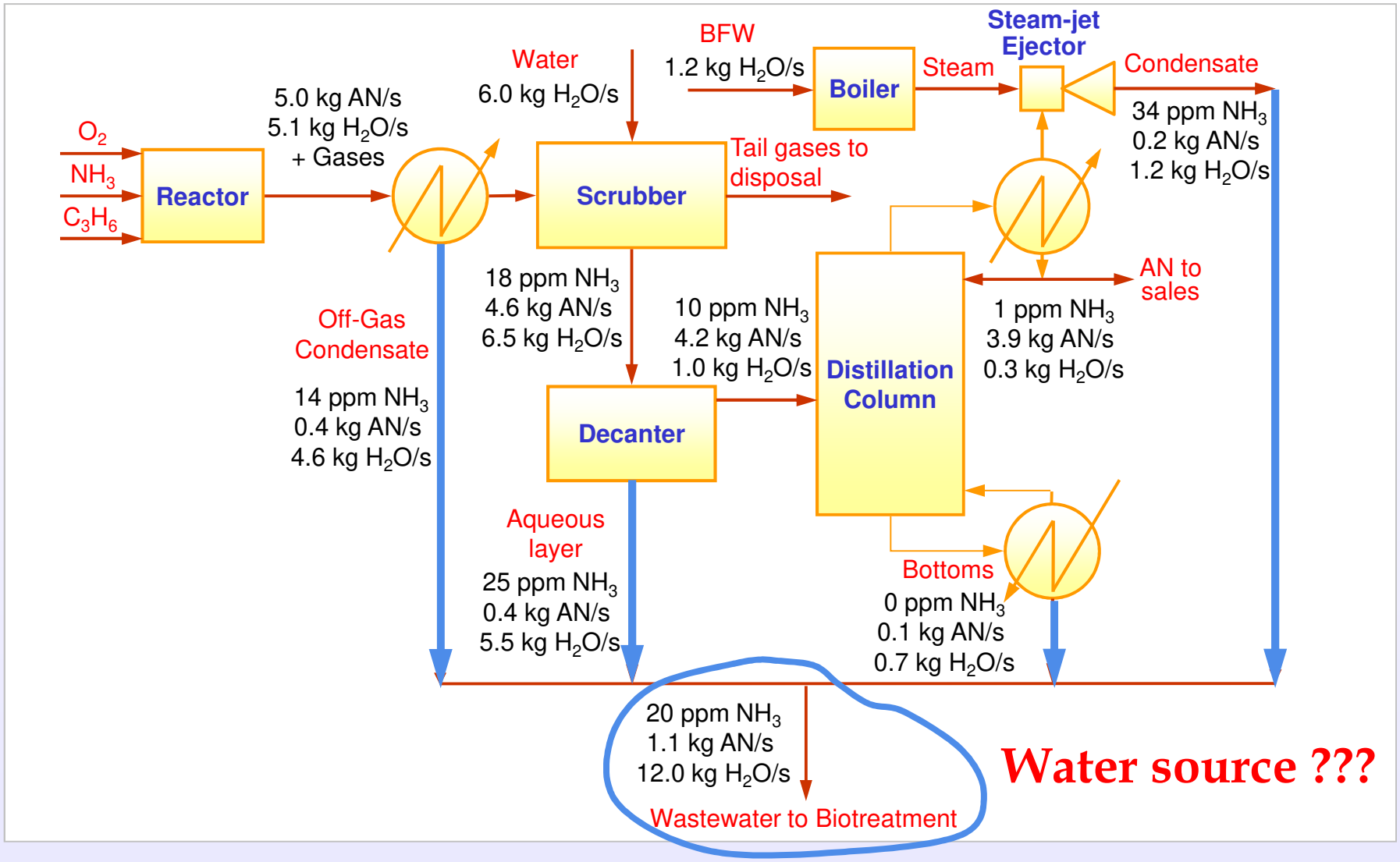
Ex 2.1 – Process description

- Fresh water is used as the scrubbing agent in the scrubber, before the tail gas may be sent for disposal.
- The bottom product from the scrubber is sent to a decanter when it is separated into aqueous (sent to the biotreatment facility) & organic layers, which is fractionated in a mild vacuumed distillation column. The column is induced by a steam-jet ejector where steam condensate is produced (sent to biotreatment).
- Distillation column bottom also produces wastewater that is sent to the biotreatment facility.
- Due to increased customer demand, the plant authority is exploring opportunity to increase the plant overall AN throughput.

Ex 2.1 – Process description

- The stoichiometry equation reveals that water is a by-product for AN production ➔ **increased AN production leads to increased wastewater flowrate** to the biotretment facility, which is operated at full hydraulic capacity.
- Any increase of production capacity is only possible upon the debottlenecking of the biotreatment facility, either by:
  - ✓ reducing the total wastewater flowrate, or
  - ✓ installing another biotreatment unit (an expensive strategy).
- It is decided to approach the problem by reducing the total wastewater flowrate, by carrying out water recovery between its process sinks and sources.
- **Task: identify water sinks & sources** in order to carry out a water recovery scheme for the process.
- Note: **ammonia (NH_3) concentration** is the main concern for water recovery (i.e. the quality index for this case).

Ex 2.1 – Identification of sources



Ex 2.1 – Identification of sources

- Following **Heuristic 1**, the individual streams that contribute to the terminal wastewater stream are segregated as water sources for recovery:
  - ✓ distillation bottom (0.1 kg/s; 0 ppm)
  - ✓ off gas condensate (5.0 kg/s; 14 ppm)
  - ✓ aqueous layer from the decanter (5.9 kg/s; 25 ppm)
  - ✓ steam condensate from steam-jet ejector (1.4 kg/s; 34 ppm)

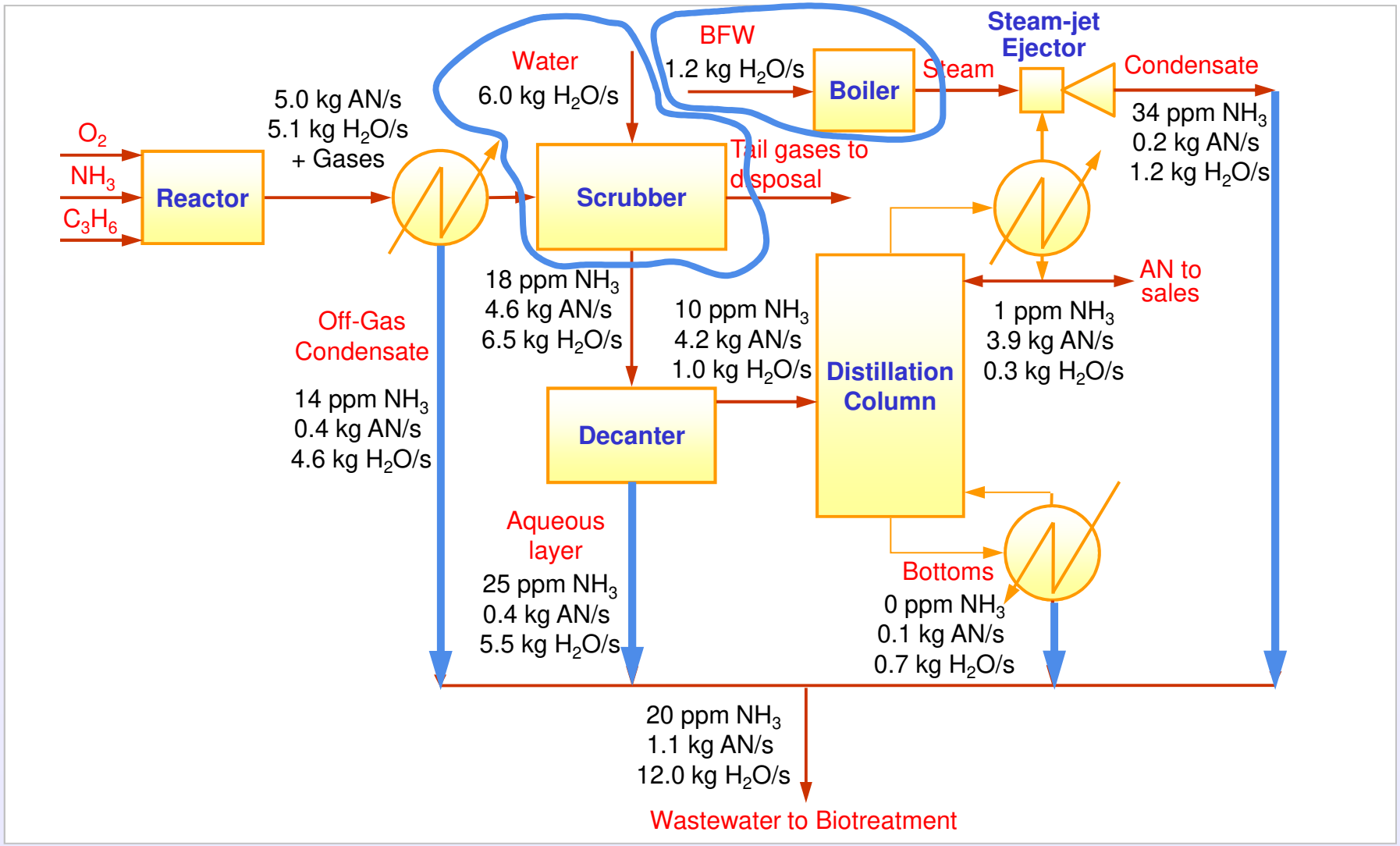
Extraction of limiting data for material sink for concentration-based RCN

Heuristics 2 & 3

Minimise flowrate for a sink to reduce the overall fresh resource intake.

Maximise the inlet concentration for a sink to maximise material recovery.

Ex 2.2 – AN production



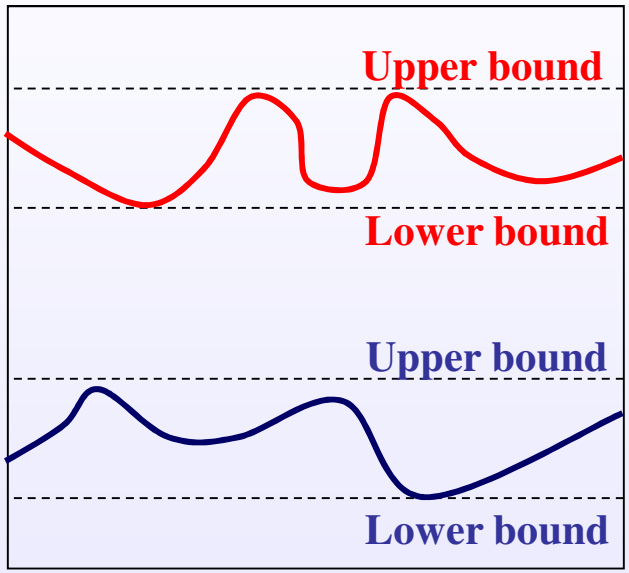
Ex 2.2 – technical constraints

i. Scrubber
   - ✓ **5.8 ≤ flowrate of wash feed (kg/s) ≤ 6.2**
   - ✓ **0.0 ≤ NH_3 content of wash feed (ppm) ≤ 10.0**

ii. Boiler feed water
   - ✓ **NH_3 content = 0.0 ppm**
   - ✓ AN content = 0.0 ppm

iii. Decanter
   - ✓ 10.6 ≤ feed flowrate (kg/s) ≤ 11.1

iv. Distillation column
   - ✓ 5.2 ≤ feed flowrate (kg/s) ≤ 5.7
   - ✓ 0.0 ≤ NH3 content of feed (ppm) ≤ 30.0
   - ✓ 80.0 ≤ AN content of feed (wt%) ≤ 100.0



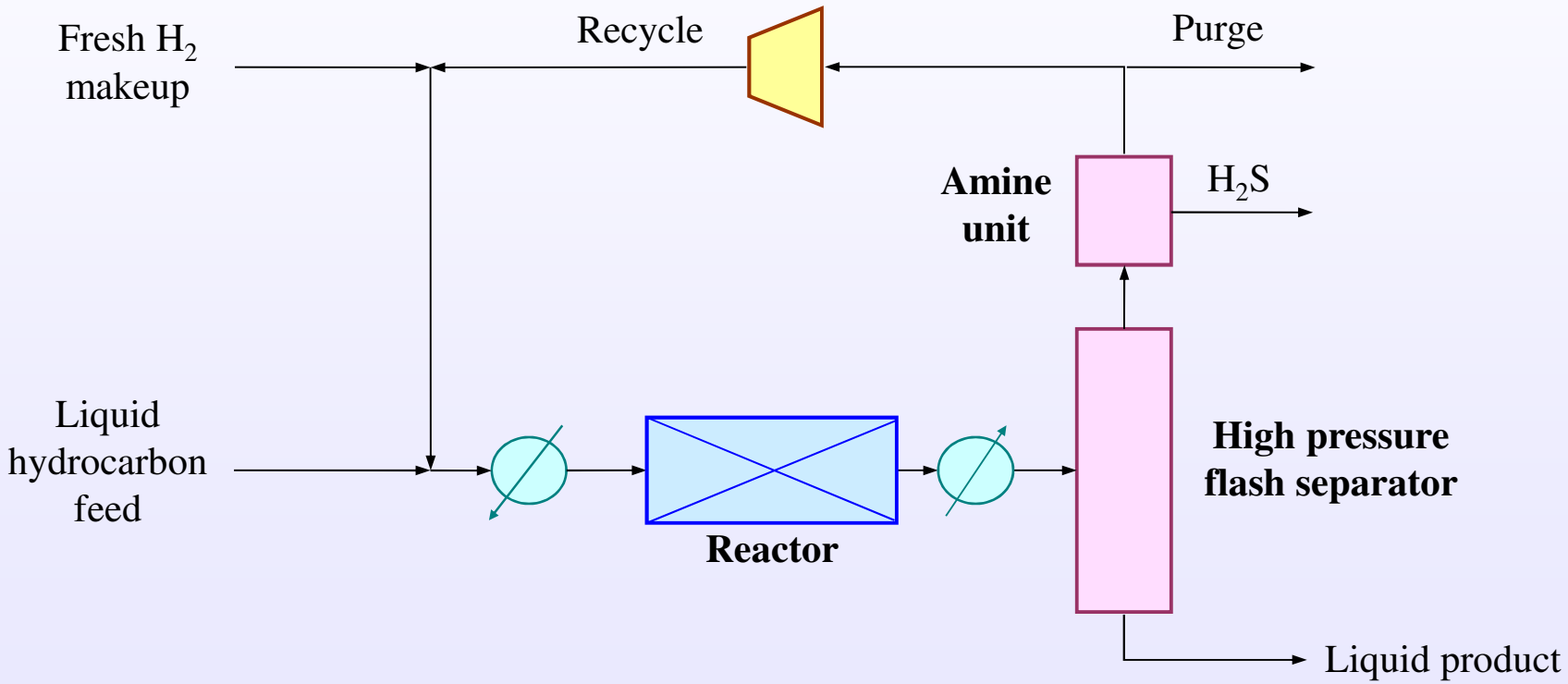
Ex 2.2 – Limiting water data

Water sinks, SK_j		**Flowrate**	**Concentration**
j	Stream	F_{SKj} (kg/s)	C_{SKj} (ppm)
1	Boiler feed water (BFW)	1.2	0
2	Scrubber	5.8	10
Water sources, SR_i		Flowrate	Concentration
i	Stream	F_{SRi} (kg/s)	C_{SRi} (ppm)
1	Distillation bottoms	0.8	0
2	Off-gas condensate	5.0	14
3	Aqueous layer	5.9	25
4	Ejector condensate	1.4	34

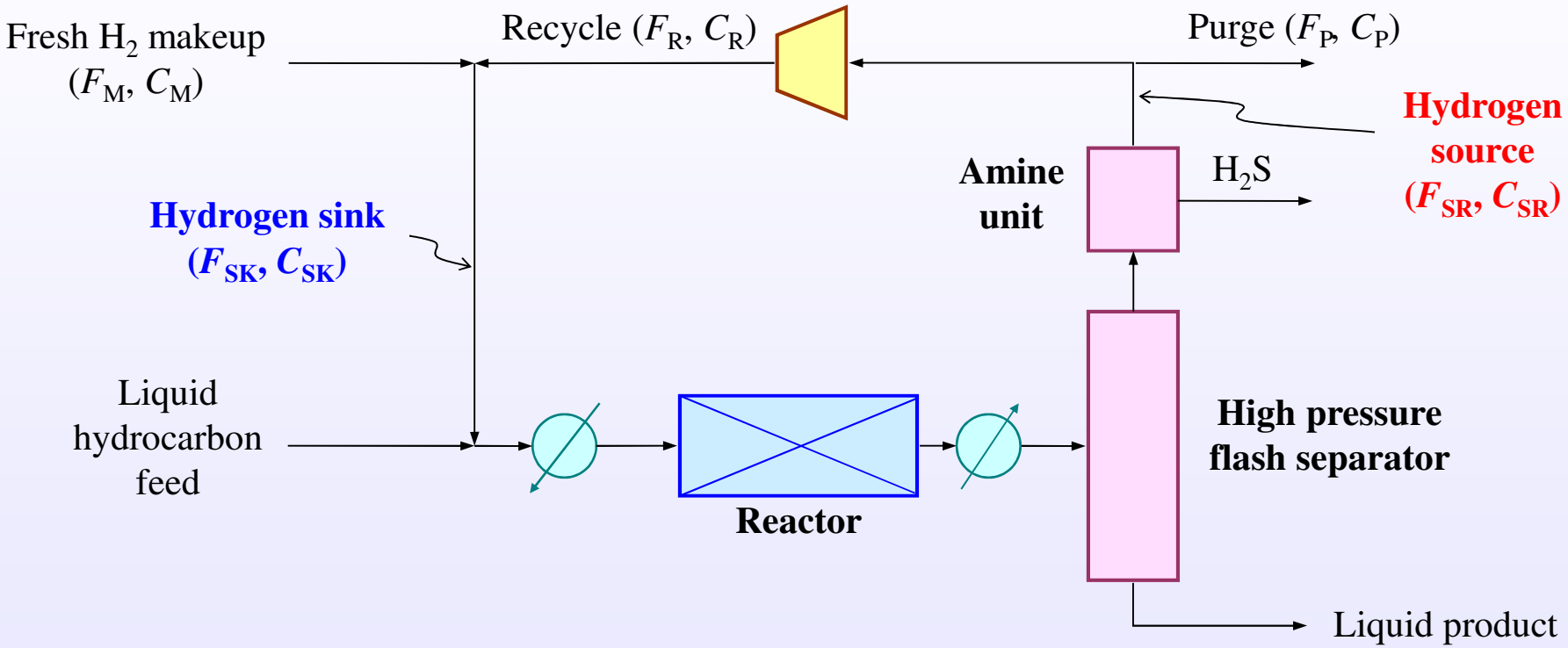
Data extraction for hydrogen-consuming units in refinery

Refinery hydrogen recovery

- Typical hydrogen-consuming units are hydrotreating and hydrocracking processes.



Identification of H_2 sinks & sources



Identification of H_2 sinks & sources

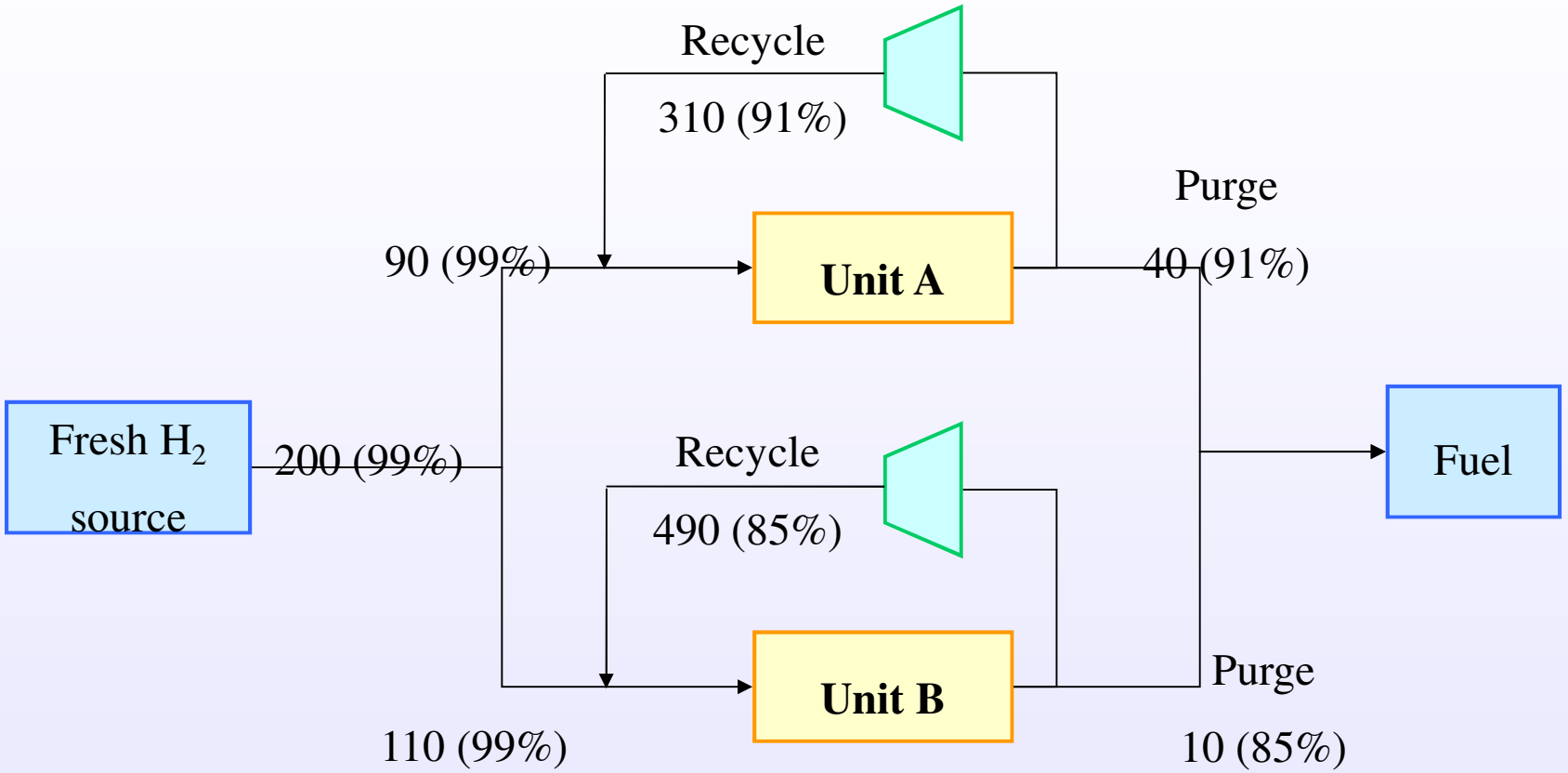
- Hydrogen sink:
  - ✓ Flowrate: $F_{SK} = F_M + F_R$
  - ✓ impurity concentration:

$$C_{SK} = \frac{F_M C_M + F_R C_R}{F_M + F_R}$$

where F_{SK}, F_M and F_R are the respective flowrates of the hydrogen sink, make-up and recycle streams; with their respective impurity concentrations of C_{SK}, C_M and C_R.

- Hydrogen source:
  - ✓ Flowrate: $F_{SK} = F_R + F_P$
  - ✓ Concentration: $C_{SK} = F_R = F_P$

Ex 2.4 – Refinery H_2 network

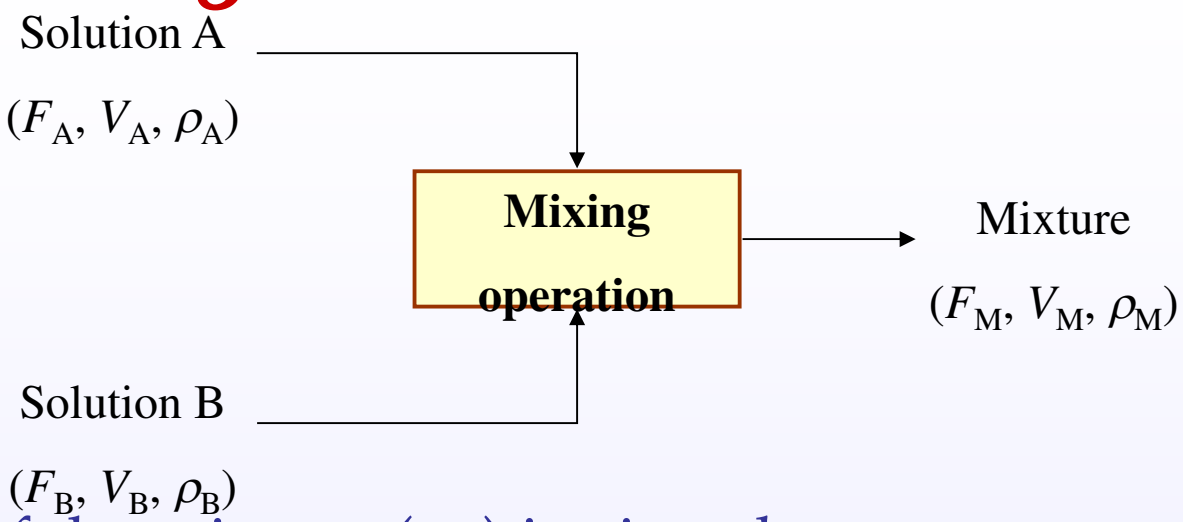


Ex 2.4 – Refinery H_2 network

	Make-up stream	Recycle stream	Purge stream	Hydrogen sink	Hydrogen source
Unit A					
Flowrate (MMscfd)	90	310	40	400	350
Concentration (%)	1	9	9	7.20	9
Unit B					
Flowrate (MMscfd)	110	490	10	600	500
Concentration (%)	1	15	15	12.43	15

Data extraction for property integration

Property integration



- Density of the mixture (ρ_M) is given by:

$$\frac{1}{\rho_M} = x_A \frac{1}{\rho_A} + x_B \frac{1}{\rho_B}$$

or the generic form

$$\frac{1}{\rho_M} = \sum_i \frac{x_i}{\rho_i}$$

- A generic form of the **linearised mixing rule** is given as:

$$\psi_M(P_M) = \Sigma i \; x_i \psi_i(P_i)$$

Property integration

- Example: Mixing of liquid of different density
  - ✓ 1 kg liquid A of 1000 kg/m^3 (ρ_A)
  - ✓ 1 kg liquid B of 1500 kg/m^3 (ρ_B)
- Mixture density (ρ_M) = 1/1000 + 1/1500 = 2/ρ_M

  ➔ **ρ_M = 1200 kg/m^3**
- If we work on the operator of density:
  - ✓ Liquid A: ψ_A = 1/1000 = 0.001
  - ✓ Liquid B: ψ_B = 1/1500 = 0.0067
  - ✓ Density operator of mixture, $\psi_M(P_M) = \Sigma_i\, x_i \psi_i(P_i)$

    ψ_M = 0.5(0.001) + 0.5(0.0067) = 0.000833

  ➔ **ρ_M = 1200 kg/m^3**

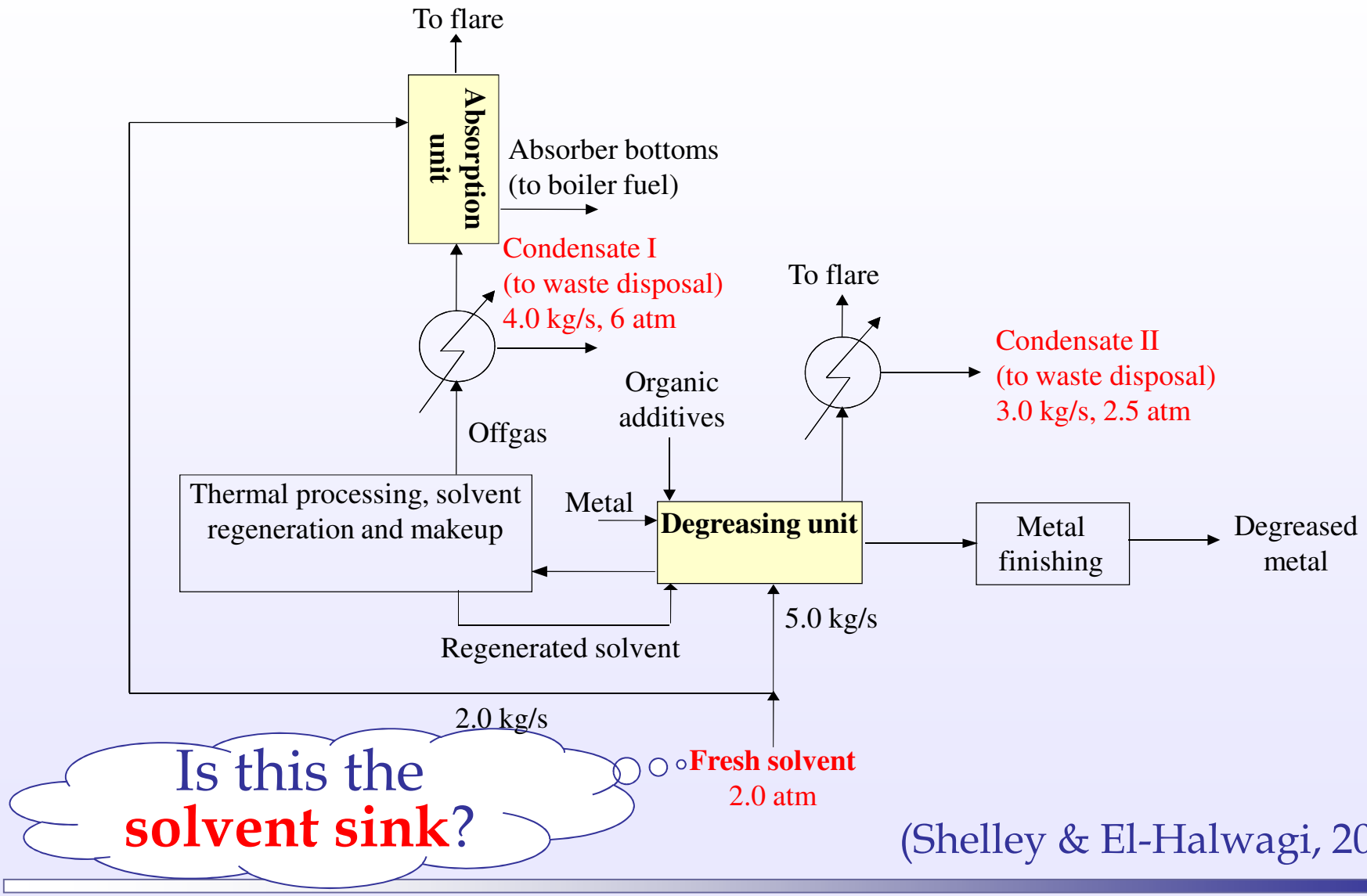
Reported linearised mixing rule

Property of mixture	Mixing rule	Operator	Reference
Density, $\overline{\rho}$	$\frac{1}{\overline{\rho}} = \sum_i \frac{x_i}{\rho_i}$	$\psi(\rho_i) = \frac{1}{\rho_i}$	Shelley and El-Halwagi (2000)
Reid Vapor Pressure, $\overline{RVP}$	$\overline{RVP} = \sum_i x_i RVP_i^{1.44}$	$\psi(RVP_i) = RVP_i^{1.44}$	Shelley and El-Halwagi (2000)
Material content, $\overline{M}$	$\overline{M} = \sum_i x_i M_i$	$\psi(M_i) = M_i$	Shelley and El-Halwagi (2000); El-Halwagi *et al.* (2002)
Electric resistivity, $\overline{R}$	$\frac{1}{\overline{R}} = \sum_i \frac{x_i}{R_i}$	$\psi(R_i) = \frac{1}{R_i}$	Kazantzi and El-Halwagi (2004)
Viscosity, μ	$\log(\overline{\mu}) = \sum_{i=1}^{N_s} x_i \log(\mu_i)$	$\psi(\mu_i) = \log(\mu_i)$	Qin *et al.* (2004)
Paper reflectivity, $\overline{R}_\infty$	$\overline{R}_\infty = \sum_i x_i R_{\infty,i}^{5.92}$	$\psi(R_{\infty,i}) = \sum_i x_i R_{\infty,i}^{5.92}$	El-Halwagi *et al.* (2002)

Heuristic 4

Choose the property operator of the sink that is **furthest from that of the fresh resource**.

Ex 2.5 – Metal degreasing



(Shelley & El-Halwagi, 2002)

Ex 2.5 – Metal degreasing

- The **fresh solvent** has an RVP value of 2.0 atm.
- The following process constraints on flowrate and RVP values are to be complied for the process sinks, i.e.:
  - ✓ Degreasing unit:

    Flowrate of solvent = 5.0 kg/s

    $2.0 \leq$ RVP of solvent (atm) ≤ 3.0
  - ✓ Absorption unit:

    Flowrate of solvent = 2.0 kg/s

    $2.0 \leq$ RVP of solvent (atm) ≤ 4.0

Ex 2.5 – Metal degreasing

- Operator values for **sources**:
  - ✓ Fresh solvent - 2.71 $atm^{1.44}$
  - ✓ Condensate I - 13.20 $atm^{1.44}$
  - ✓ Condensate II - 3.74 $atm^{1.44}$
- Operator values for **sinks**:

$$2.71 \leq \psi \text{ for degreasing unit } (atm^{1.44}) \leq 4.86$$

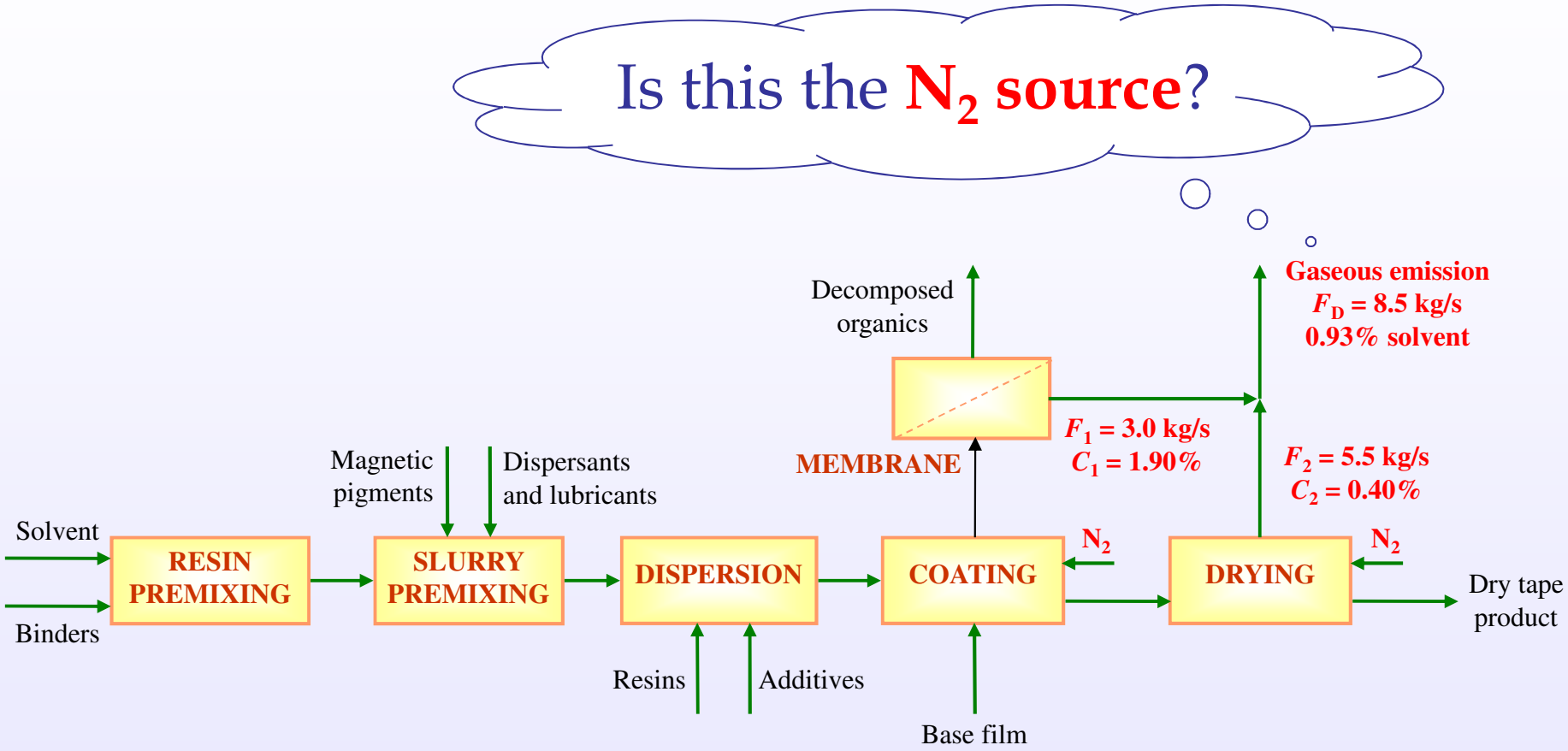
$$2.71 \leq \psi \text{ for absorption unit } (atm^{1.44}) \leq 7.36$$

Ex 2.5 – Metal degreasing

Sink	F_{SKj} (kg/s)	ψ_{SKj} (atm$^{1.44}$)
Degreasing unit	5	4.86
Absorption unit	2	7.36
Source	F_{SRi} (kg/s)	ψ_{SRi} (atm$^{1.44}$)
Condensate I	4	13.20
Condensate II	3	3.74
Fresh solvent	To be determined	2.71

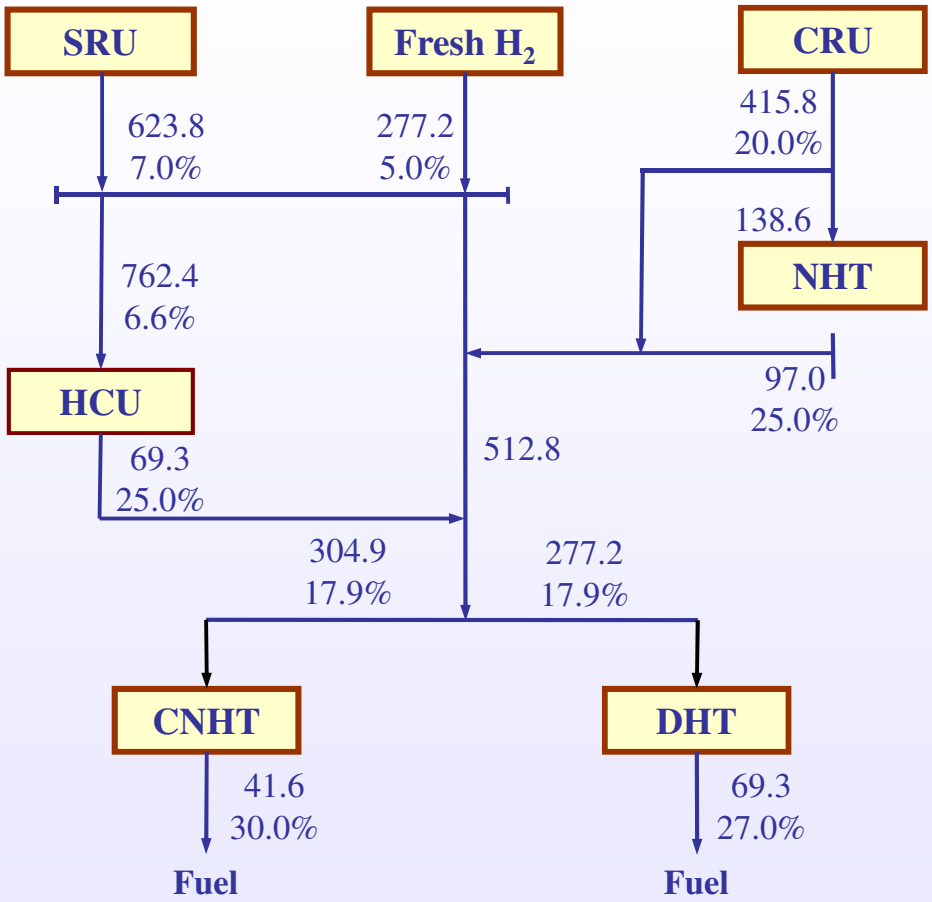
In-class exercise(s)

P2.5 – N_2 recovery



(El-Halwagi, 1997)

P2.6 – refinery H_2 network



Flowrate and concentration of recycle streams in all units:

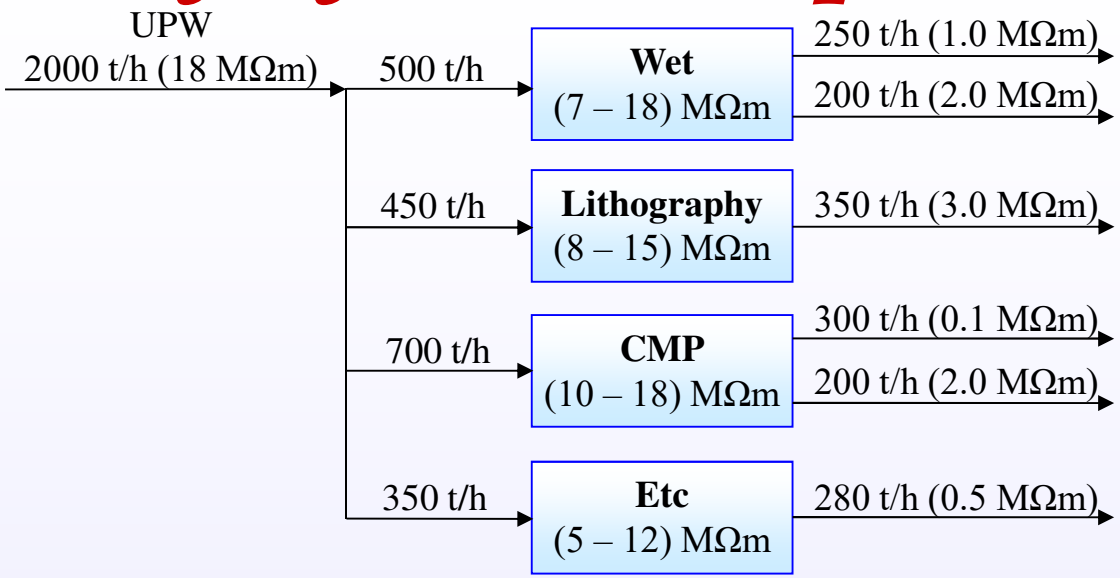
Units	F_R (mol/s)	C_R (mol%)
HCU	1732.6	25.0
NHT	41.6	25.0
CNHT	415.8	30.0
DHT	277.2	27.0

Tasks: Identify the limiting data in order to carry out a hydrogen recovery analysis

P2.6 – solution

j	Sinks, SK_j	F_{SKj} (mol/s)	C_{SKi} (mol%)	i	Sources, SR_i	F_{SRj} (mol/s)	C_{SRi} (mol%)
1	HCU	2495.0	19. 39	1	HCU	1801.9	25.0
2	NHT	180.2	21.15	2	NHT	138.6	25.0
3	CNHT	720.7	24.86	3	CNHT	457.4	30.0
4	DHT	554.4	22.43	4	DHT	346.5	27.0
				5	SRU	623.8	7.0
				6	CRU	415.8	20.0

P2.7 – wafer fabrication process



- Large amount of ultrapure water (UPW) is consumed in a wafer fabrication plant that consist of wet processing section (Wet), lithography, combined chemical and mechanical processing (CMP), & miscellaneous operations (Etc.).
- Water quality in considering water recovery is *resistivity* (R) that reflects the total ionic content in the aqueous streams, with property mixing rule:

$$\frac{1}{R_{\mathrm{M}}} = \sum_i \frac{x_i}{R_i}$$

P2.7 – technical info

- Operator values for **UPW** = 0.0556 $M\Omega^{-1}.m^{-1}$
- Operator values for **sources**:
  - ✓ Wet I - 1 $M\Omega^{-1}.m^{-1}$
  - ✓ Wet II - 0.5 $M\Omega^{-1}.m^{-1}$
  - ✓ Lithography - 0.3333 $M\Omega^{-1}.m^{-1}$
  - ✓ CMP I - 10 $M\Omega^{-1}.m^{-1}$
  - ✓ CMP II – 0.5 $M\Omega^{-1}.m^{-1}$
  - ✓ Etc - 2 $M\Omega^{-1}.m^{-1}$
- Operator values for **sinks**:

Wet

R_{min} = 7 MΩ.m ➔ ψ = 0.1429 $M\Omega^{-1}.m^{-1}$

R_{max} = 18 MΩ.m ➔ ψ = 0.0556 $M\Omega^{-1}.m^{-1}$

$$\frac{1}{R_M} = \sum_i \frac{x_i}{R_i}$$

$0.0556 \le \psi$ for Wet ($M\Omega^{-1}.m^{-1}$) ≤ 0.1429

$0.0667 \le \psi$ for Lithography ($M\Omega^{-1}.m^{-1}$) ≤ 0.1250

$0.0556 \le \psi$ for CMP ($M\Omega^{-1}.m^{-1}$) ≤ 0.1000

$0.0833 \le \psi$ for Etc ($M\Omega^{-1}.m^{-1}$) ≤ 0.2000

P2.7 – solution

Sink	F_{SKj} (kg/s)	ψ_{SKj} ($M\Omega^{-1}.m^{-1}$)
Wet (SK1)	500	0.1429
Litography (SK2)	450	0.1250
CMP (SK3)	700	0.1000
Etc (SK4)	350	0.2000
Source	F_{SRi} (kg/s)	ψ_{SRi} ($M\Omega^{-1}.m^{-1}$)
Wet I (SR3)	250	1
Wet II (SR4)	200	0.5
Litography (SR5)	350	0.3333
CMP I (SR6)	300	10
CMP II (SR7)	200	0.5
Etc (SR8)	280	2