Lecture 3.
Basic Separation Concepts (2)
[Ch. 1]

- Component Recoveries and Product Purities
  - Split fraction
  - Split ratio
- Separation Power (Separation Factor)
- Selection of Feasible Separation Processes
  - Keller's correlation
  - Technological and use maturities
  - Ease of scale-up

Component Recoveries and Product Purities

- Separation process
  - Conservation of mass
  - For no reaction and continuous, steady-state operation

$$n_i^{(F)} = \sum_{p=1}^{N} n_i^{(p)} = n_i^{(1)} + n_i^{(2)} + n_i^{(3)} + \ldots + n_i^{(N-1)} + n_i^{(N)}$$

i : 1 ~ C → Components

p : 1~ N → Product phases

F : feed

The molar (or mass) flow rate in the feed is equal to the sum of the product molar (or mass) flow rates

Split Fraction and Split Ratio

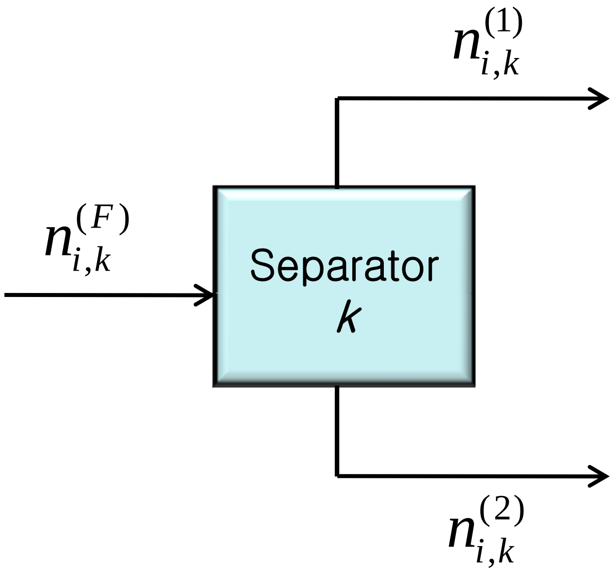
- Split fraction

$$SF_{i,k} = \frac{n_{i,k}^{(1)}}{n_{i,k}^{(F)}}$$

Fraction of component i found in the first product

- Split ratio

$$SR_{i,k} = \frac{n_{i,k}^{(1)}}{n_{i,k}^{(2)}} = \frac{SF_{i,k}}{(1-SF_{i,k})}$$



i : component
k : separator
(F) : feed
(1) : first product (ex: top product)
(2) : second product (ex : bottom product)

[Example] Hydrocarbon Recovery Process

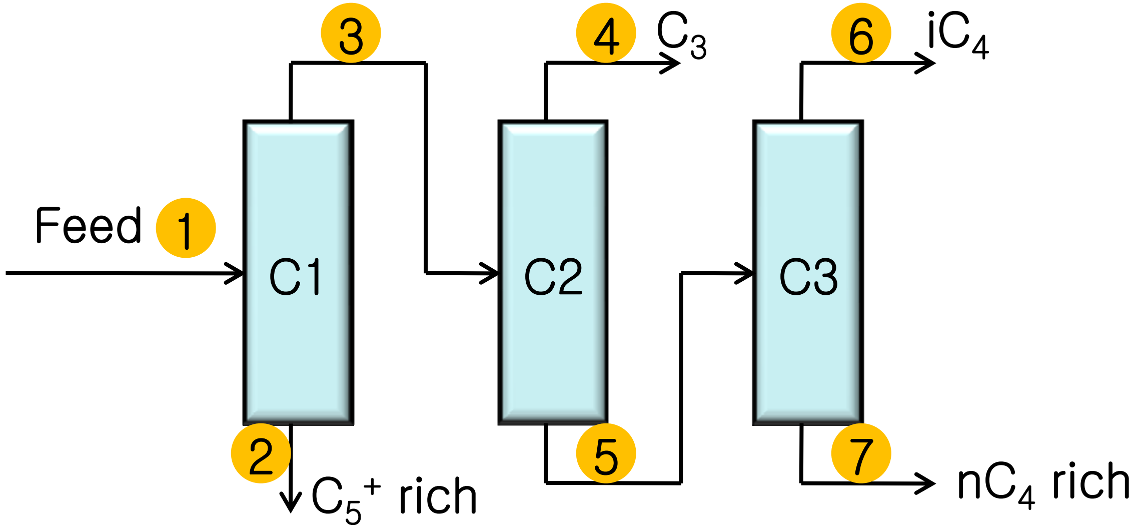
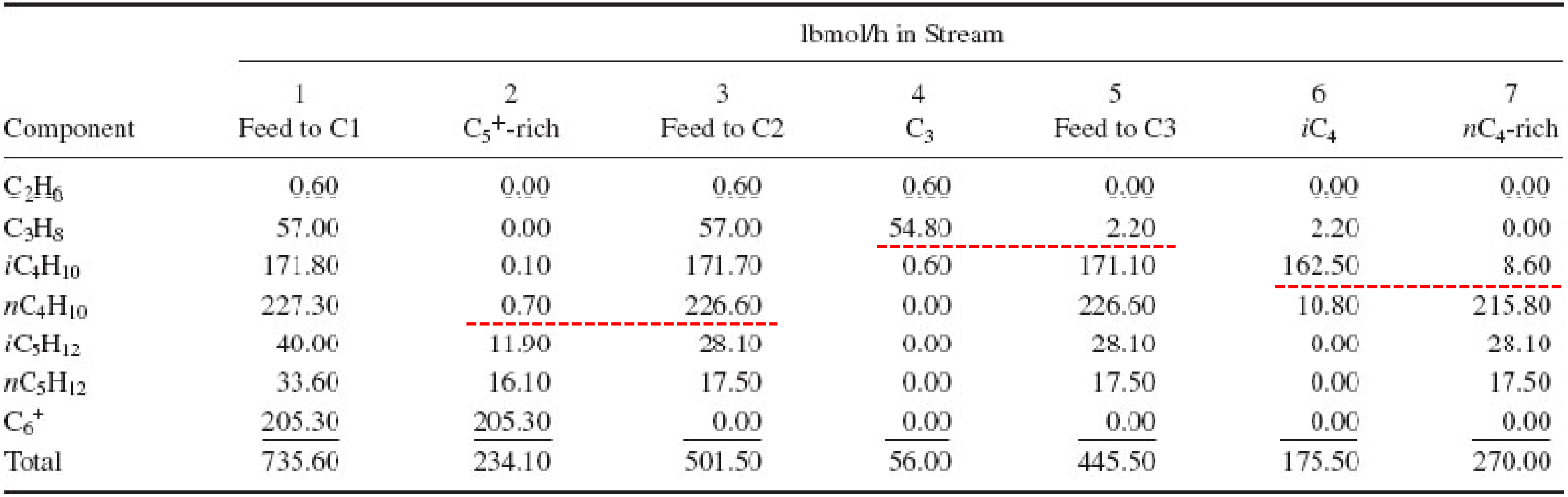


Table 1.5 Operating Material Balance for Hydrocarbon Recovery Process



	lbmol/h in Stream						
Component	1 Feed to C1	2 C_5^+-rich	3 Feed to C2	4 C_3	5 Feed to C3	6 iC_4	7 nC_4-rich
C_2H_6	0.60	0.00	0.60	0.60	0.00	0.00	0.00
C_3H_8	57.00	0.00	57.00	54.80	2.20	2.20	0.00
iC_4H_{10}	171.80	0.10	171.70	0.60	171.10	162.50	8.60
nC_4H_{10}	227.30	0.70	226.60	0.00	226.60	10.80	215.80
iC_5H_{12}	40.00	11.90	28.10	0.00	28.10	0.00	28.10
nC_5H_{12}	33.60	16.10	17.50	0.00	17.50	0.00	17.50
C_6^+	205.30	205.30	0.00	0.00	0.00	0.00	0.00
Total	735.60	234.10	501.50	56.00	445.50	175.50	270.00

Product Purity and Specification

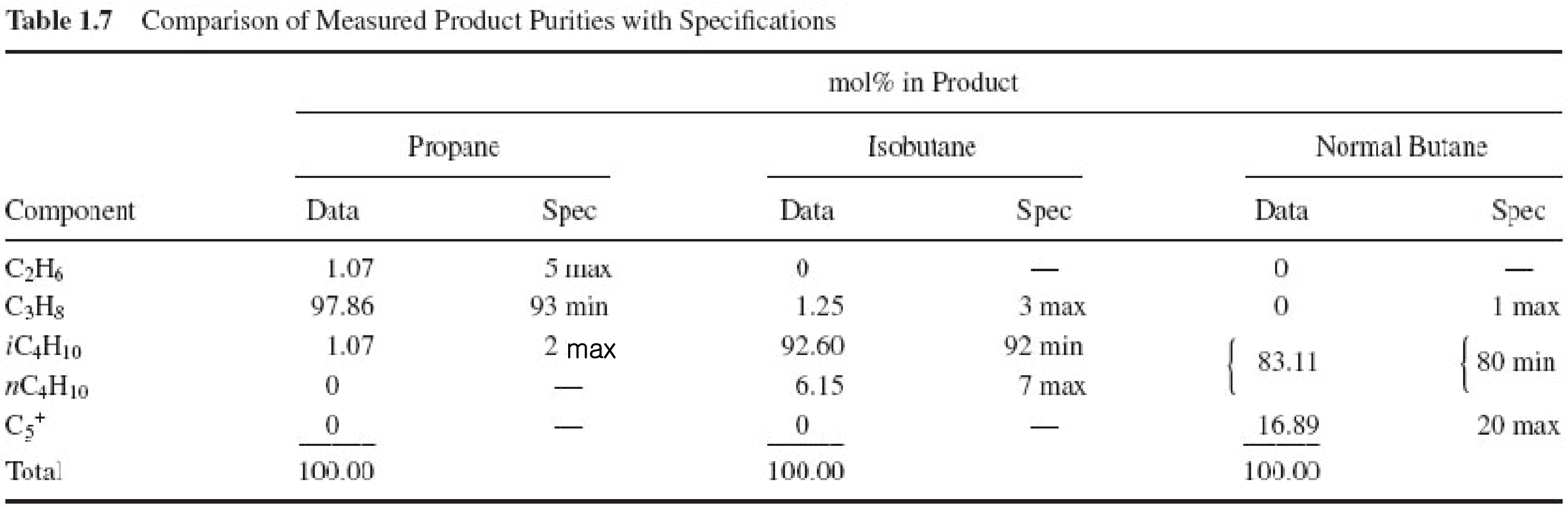


Table 1.7 Comparison of Measured Product Purities with Specifications

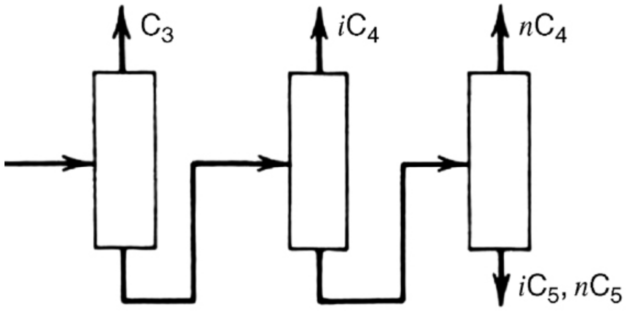
	mol% in Product					
	Propane		Isobutane		Normal Butane	
Component	Data	Spec	Data	Spec	Data	Spec
C_2H_6	1.07	5 max	0	—	0	—
C_3H_8	97.86	93 min	1.25	3 max	0	1 max
iC_4H_{10}	1.07	2 max	92.60	92 min	83.11	80 min
nC_4H_{10}	0	—	6.15	7 max		
C_5^+	0	—	0	—	16.89	20 max
Total	100.00		100.00		100.00	

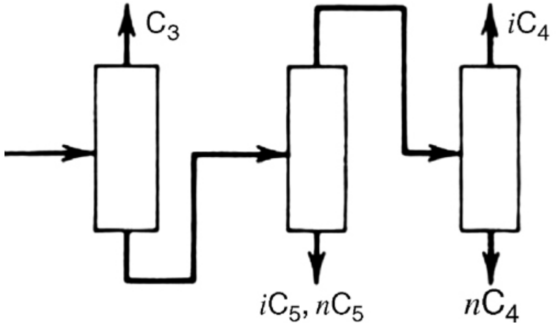
- Product specifications
  - mol%, vol%, wt%
  - ppm (parts per million), ppb (parts per billion)

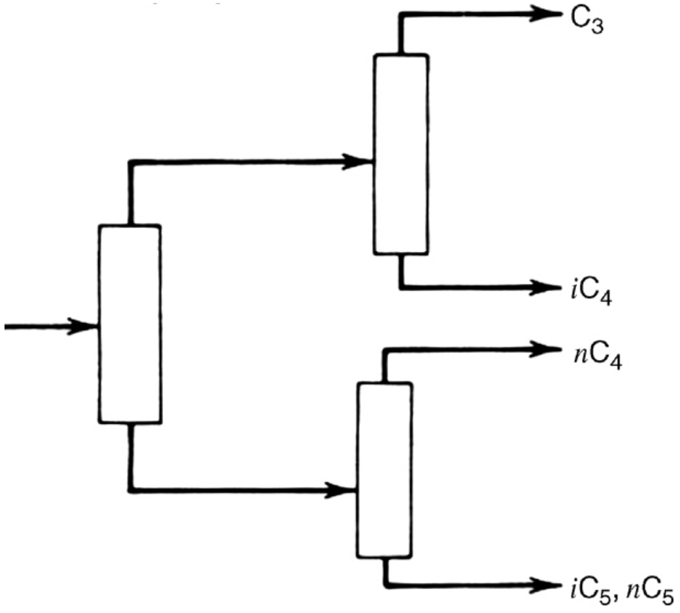
Separation Sequences

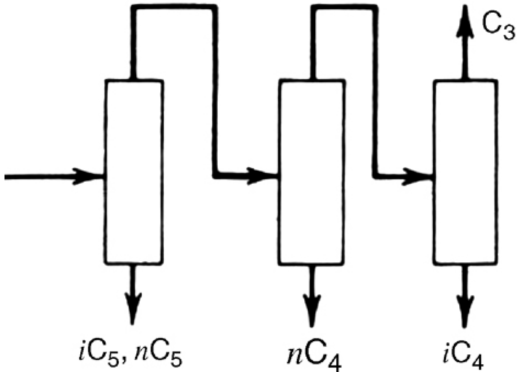
- Hydrocarbon feed : propane (C_3), isobutane (iC_4), n-butane (nC_4), isopentane (iC_5), n-pentane (nC_5)

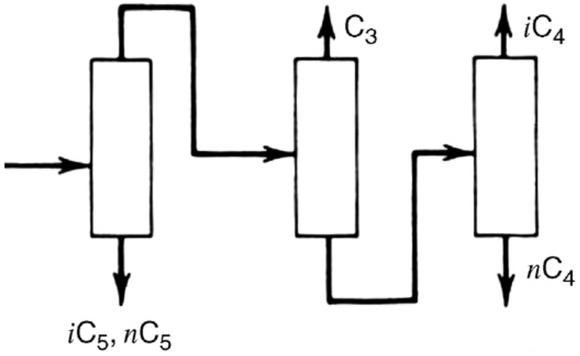
⇒ Products : C_3, iC_4, nC_4, iC_5 + nC_5











Separation Power

- Separation power (relative split ratio; separation factor)
  : relative degree of separation between two components, i and j, measured by the compositions of the two products

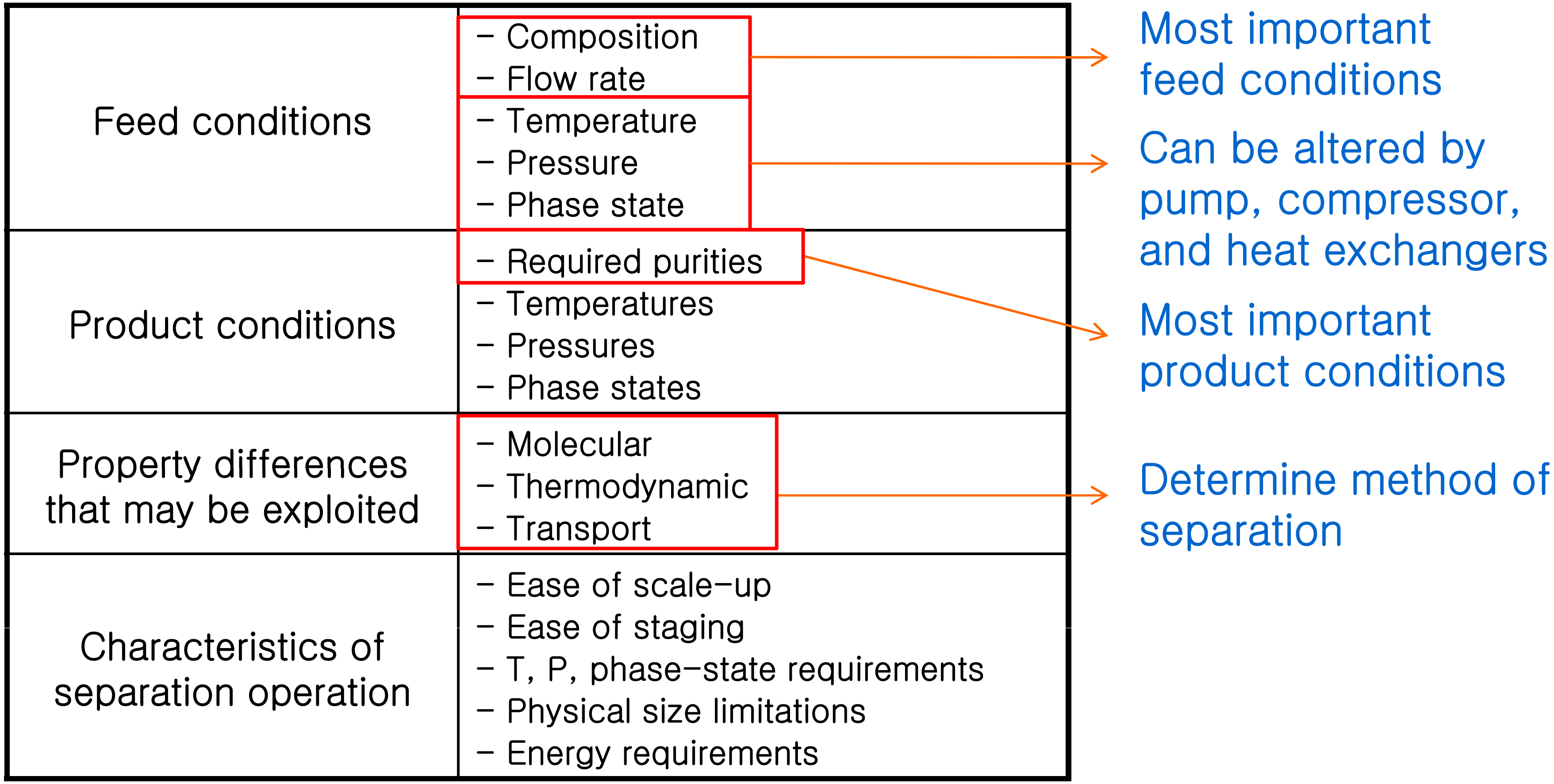
$$SP_{i,j} = \frac{C_i^{(1)} / C_i^{(2)}}{C_j^{(1)} / C_j^{(2)}} = \frac{SR_i}{SR_j} = \frac{SF_i / SF_j}{(1 - SF_i)/(1 - SF_j)}$$

Key-component split	Column	Separation power
nC_4H_{10} / iC_5H_{12}	C1	137.1
C_3H_8 / iC_4H_{10}	C2	7103
iC_4H_{10} / nC_4H_{10}	C3	377.6

Achievable SP depends on the number of stages, and the relative thermodynamic and mass transport properties of components

Selection of Feasible Separation

- Selection of a best separation process
  - Selection among a number of feasible candidates
  - A combination of two or more operations may be best
- Factors that influence the selection of feasible separation



Feed conditions	– Composition – Flow rate – Temperature – Pressure – Phase state
Product conditions	– Required purities – Temperatures – Pressures – Phase states
Property differences that may be exploited	– Molecular – Thermodynamic – Transport
Characteristics of separation operation	– Ease of scale-up – Ease of staging – T, P, phase-state requirements – Physical size limitations – Energy requirements

Most important feed conditions

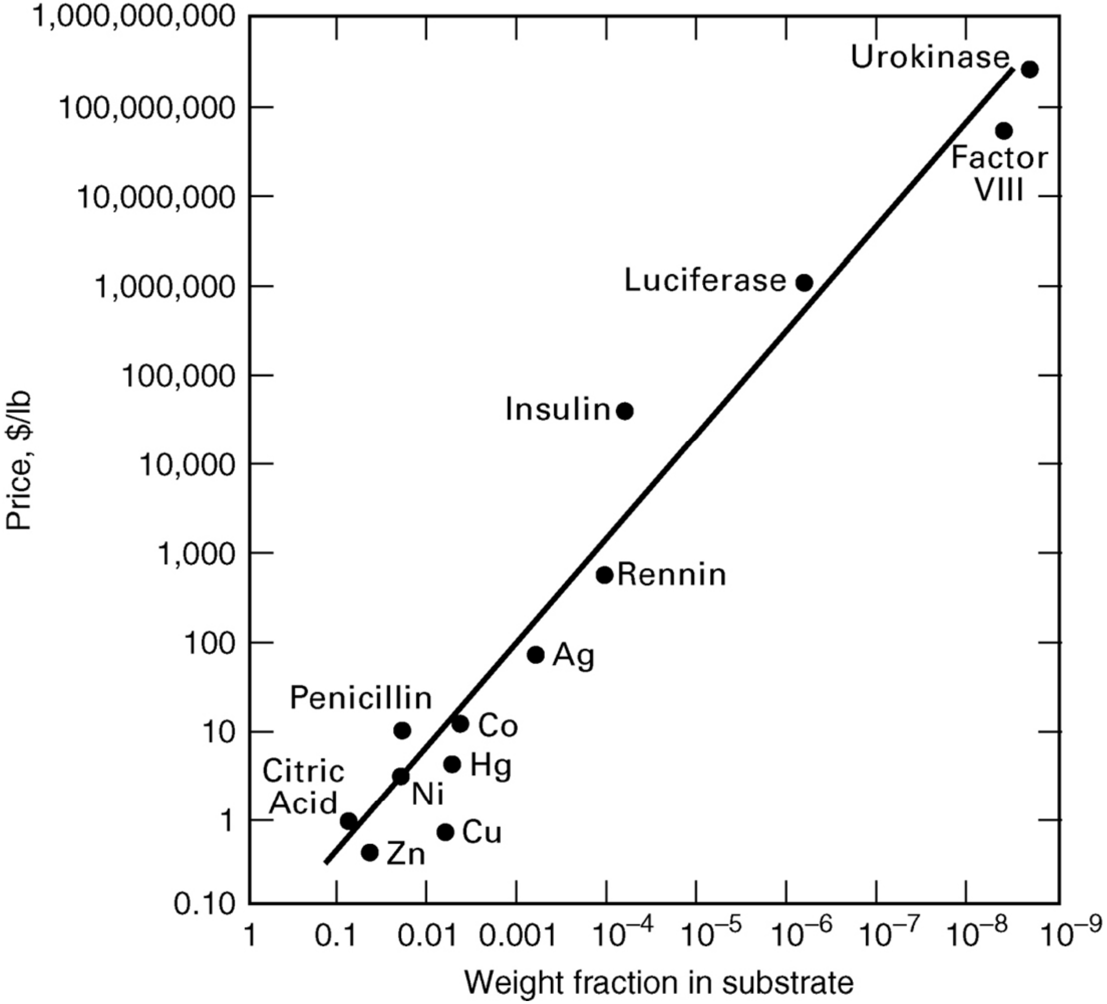
Can be altered by pump, compressor, and heat exchangers

Most important product conditions

Determine method of separation

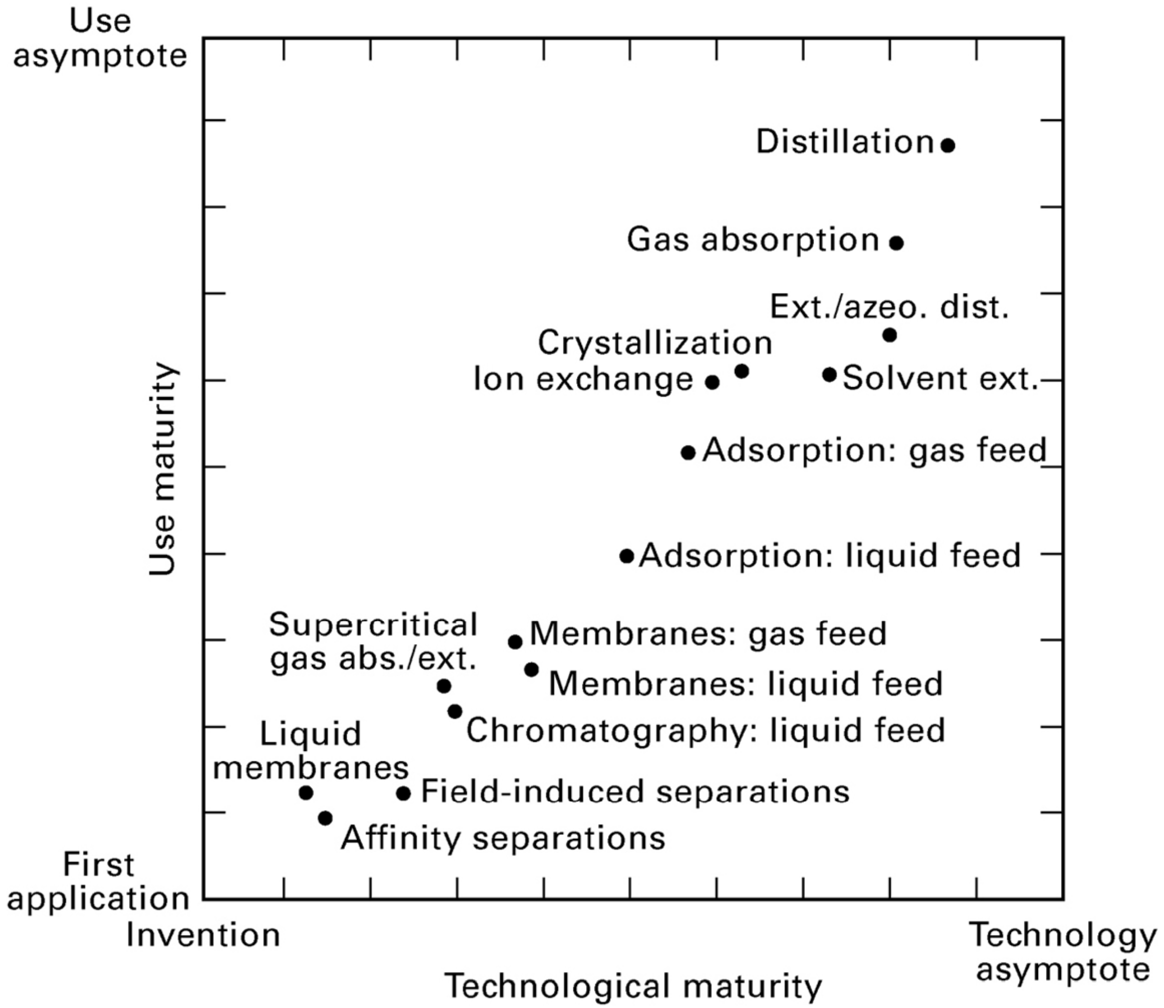
Keller's correlation

- The cost of recovering and purifying a chemical in a mixture can depend strongly on the concentration.
- The more dilute the feed, the higher the product price.

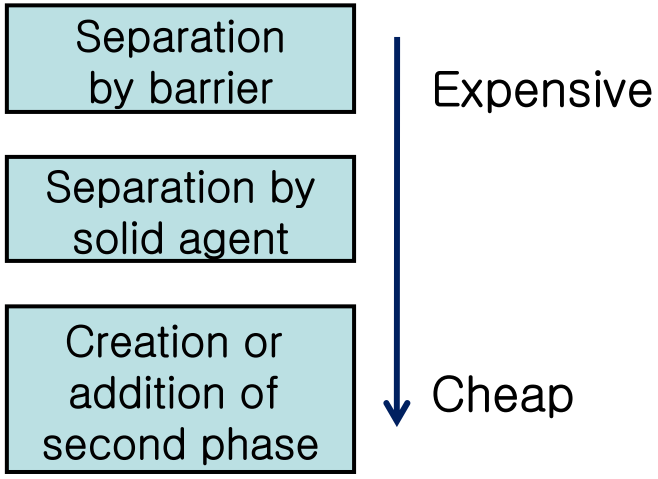


Effect of concentration of product in feed material on price

Technological and Use Maturities of Separation Processes



Technological and use maturities of separation processes


Separation by barrier

Separation by solid agent

Creation or addition of second phase

Expensive

Cheap

Ease of Scale-up

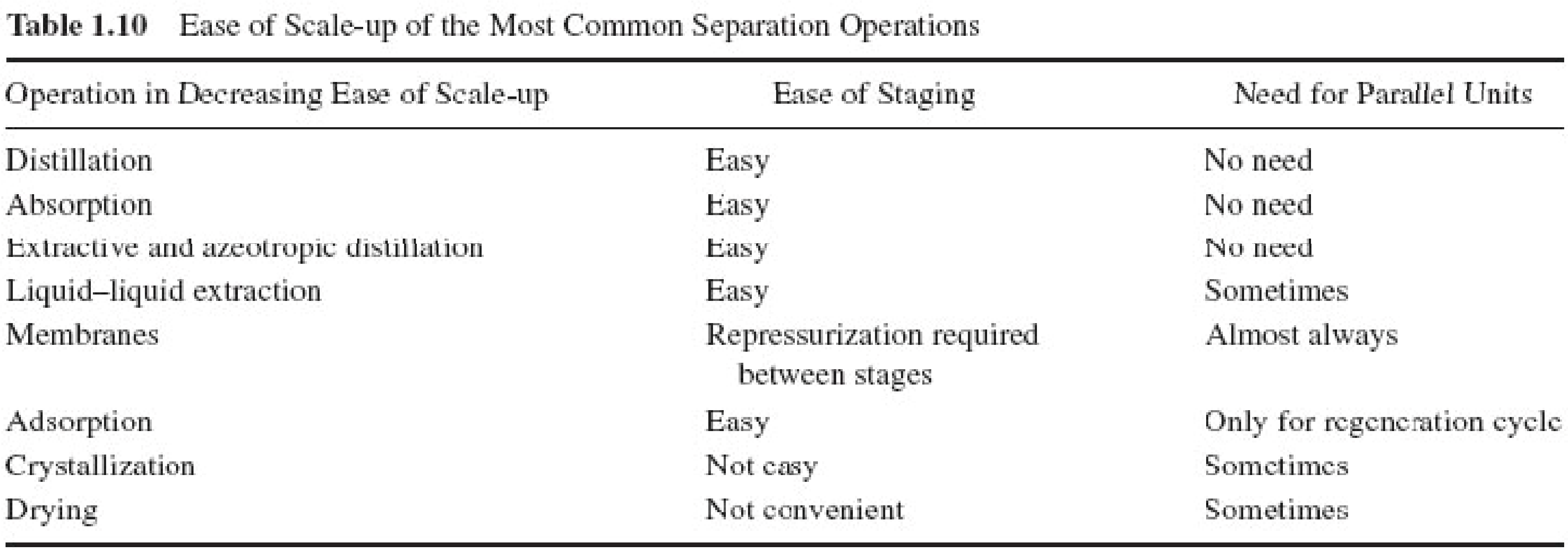
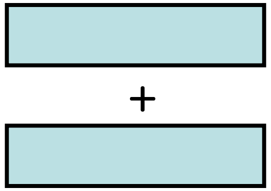


Table 1.10 Ease of Scale-up of the Most Common Separation Operations

Operation in Decreasing Ease of Scale-up	Ease of Staging	Need for Parallel Units
Distillation	Easy	No need
Absorption	Easy	No need
Extractive and azeotropic distillation	Easy	No need
Liquid–liquid extraction	Easy	Sometimes
Membranes	Repressurization required between stages	Almost always
Adsorption	Easy	Only for regeneration cycle
Crystallization	Not easy	Sometimes
Drying	Not convenient	Sometimes

- If two parallel units are installed, the additional investment is 100%

- The capacity of a single unit can be doubled for an additional investment cost of about 60%



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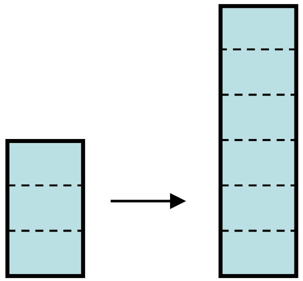

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