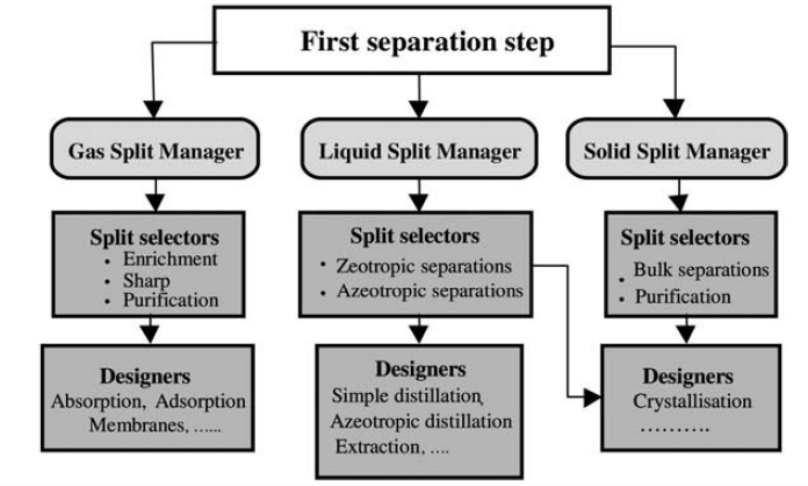
PERANCANGAN SISTEM/ JARINGAN PEMISAH & RECYCLE

PERANCANGAN PROSES KIMIA (*CHEMICAL PROCESS DESIGN*)

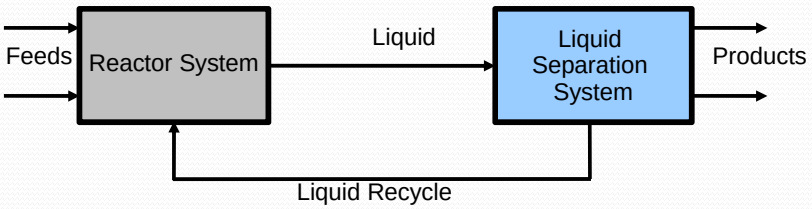
Section 2 oleh: Dr. Istadi, ST, MT

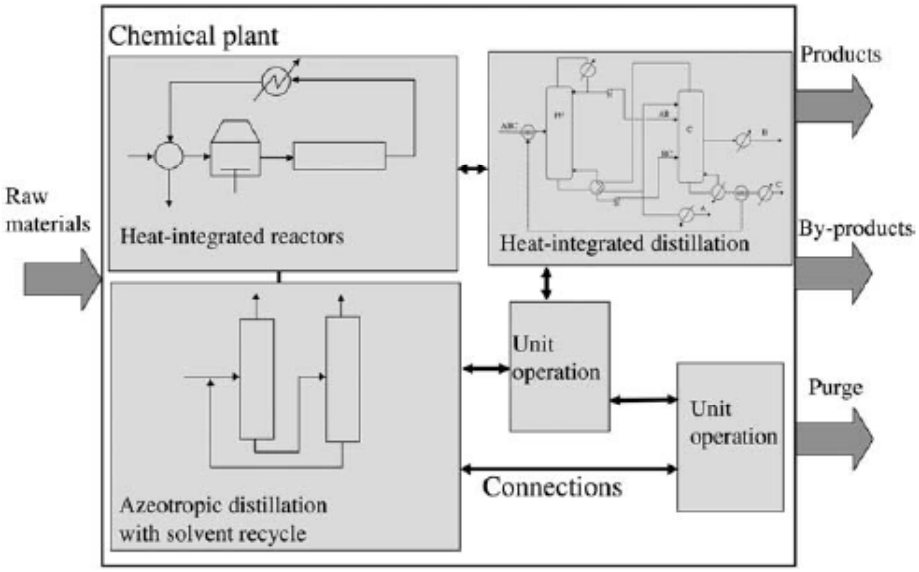
Kode Mata Kuliah : TKK 345
Beban : 3 SKS

Separation synthesis hierarchy

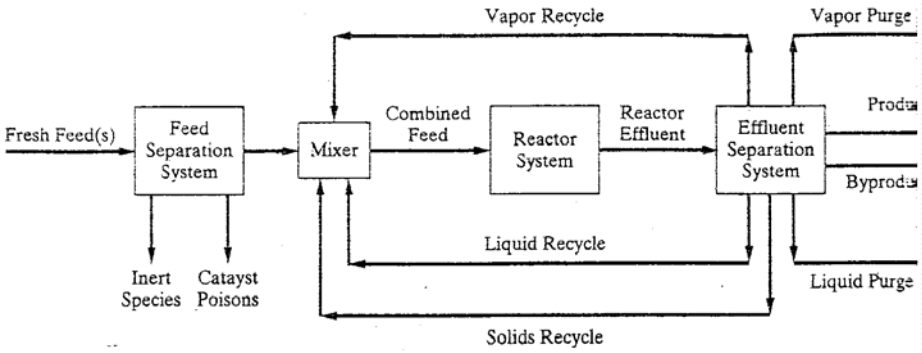


Basic Configuration of Chemical Process

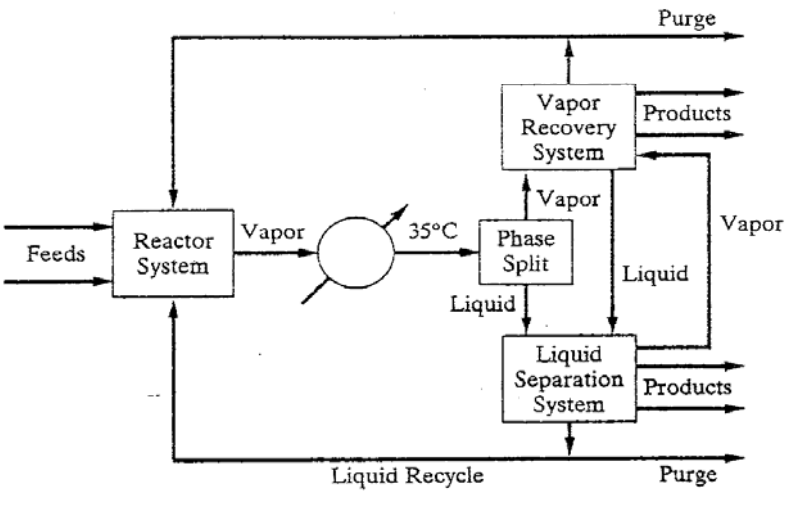




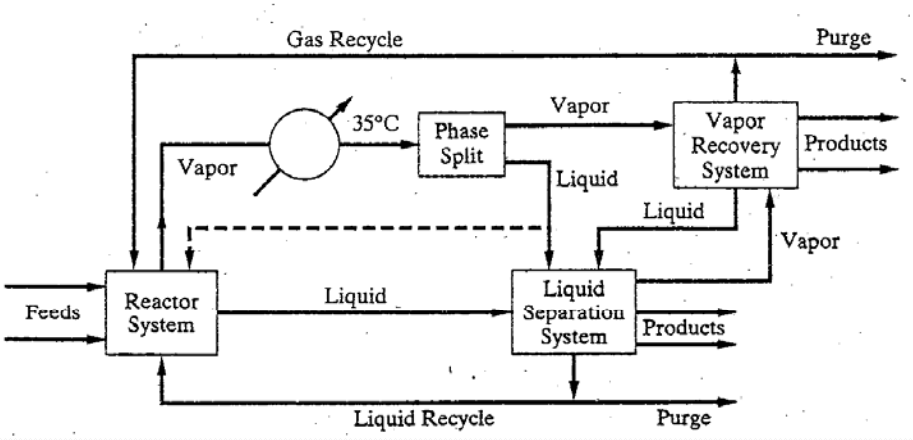
General Flowsheet for a Separation Process



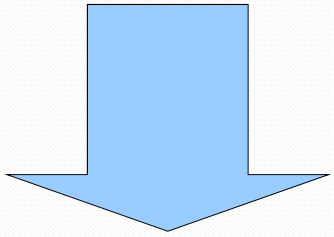
Separation of Vapor Reactor Effluents



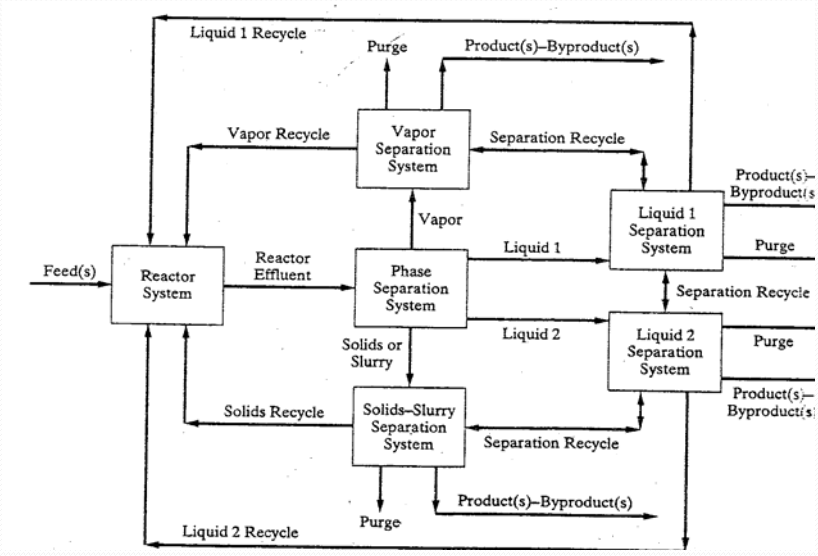
Separation of Vapor/Liquid Reactor Effluents



- Each exiting phase is either:
  - recycled to the reactor
  - purged from the system
  - sent to separate vapor, liquid, or slurry separation systems



Separate Separation Systems with Reactor-system and Separation-System Recycles



Phase Separation of Reacton Effluent

- **Reactor effluent**: homogeneous phase or heterogeneous phase
- **Homogeneous phase** ==> change Temperature and/or Pressure ==> to obtain partial separation of heterogeneous mixture
- **Three-phase model** considers the possibility that a vapor may also be present, together with two liquid phases
- **If solids are present** with one or two liquid phases, it is not possible to separate completely the solids from the liquid phase(s).
- Instead, a centrifuge of filter is used to deliver a wet cake of solids

LIQUID SEPARATION SYSTEM

- The liquid separation system involves one or more of the following separators:
  - distillation and/or enhanced distillation,
  - stripping,
  - liquid-liquid extraction,
  - and so on, with the unreacted chemicals recovered in a liquid phase and recycled to the reaction operation

Separation methods for liquid mixtures

Separation method	Characteristic property	Observation
Simple distillation	Relative volatility α	Use heuristics for sequencing. Not feasible if $\alpha < 1.1$
Simple and azeotropic distillations	Vapor-pressure variation	Check thermal stability of components
Stripping, L–L extraction	Boiling point	Use stripping and L–L extraction for thermal sensitive components
Melt crystallization	Freezing point	Differences larger than 20°C
Adsorption chromatography	Polarity	Pay attention to adsorbent regeneration
Membrane permeation	Shape and size	Emerging technology
Azeotropic distillation, Extractive distillation, L–L extraction	Chemical family	MSA selection is the main issue. Recycling of MSA increases the costs
L–L extraction, stripping, adsorption, crystallization	Temperature sensitivity	Recycle of MSA increases the costs

Heuristic for Liquid Separation System

Table 3.11 General heuristics for separation sequencing of liquid mixtures.

1. Remove first corrosive, hazardous, fouling, reactive and any troublesome components. Consider also in the first place the removal of light-ends.
2. Deliver high-purity products as top distillate. The same is valid for reactants sent to reactors sensitive to impurities.
3. When separation by distillation is feasible, prefer it in a first attempt.
4. Isolate zeotropic and azeotropic mixtures.
5. Perform difficult zeotropic separations later, but before azeotropic separations. Examine other options, such as extractive distillation, L–L extraction, crystallization, adsorption, or molecular sieves.
6. Examine the separation of azeotropic mixtures last.
7. Remove the components in order of decreasing percentage of the feed. This operation will reduce the cost of the next separation.
8. Favor 50/50 splits.

Factors for Separation Selection

- Phase condition of the feed
- **Separation Factor** (SF)

$$SF = y_1 / x_1 / y_2 / x_2 = K_1 / K_2 = \alpha_{1,2}$$

- Reason for Separation
  - purification
  - removal of undesirable components
  - recovery

Heuristic of Separations

- **Heuristic 9**: Separate liquid mixtures using distillation, stripping, enhanced (exctractive, azeotropic, reactive) distillation, liquid-liquid extraction, crystallization, and/or absorption
- **Heuristic 10**: Attempt to condense or partially condense vapor mixtures with cooling water or a refrigerant. Then use Heuristic 9
- **Heuristic 11**: Separate vapor mixtures using partial condensation, cryogenic distillation, absorption, adsorption, membrane separation and/or desublimation

Vapor Recovery and Gas - Separation System

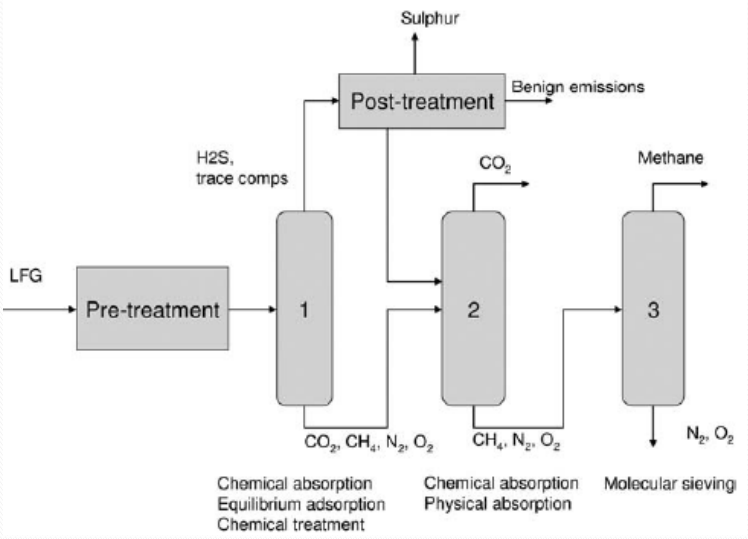
- **on the purge**, if significant amount of product is being lost,
- **on the gas - recycle stream**, if impurities could affect the reactor operation,
- **on the vapor stream after flash**, if both items 1 and 2 are valid,
- does not use vapor recovery if neither item 1 nor 2 are important.

Method used in Vapor Recovery and Gas Separation

Table 3.2 Methods used in vapor recovery and gas separations.

Method	Characteristic property	Condition	Observation
Condensation	Boiling points Relative volatility	Difference in boiling points >40 °C or $\alpha_{ij} > 7$	Optimize pressure and temperature
Cryogenic distillation	Boiling points Relative volatility	$\alpha_{ij} > 2$	Large-scale processes Remove first freezable components
Physical absorption	Solubility	$K_i > 4$	Optimize P and T Recycle the solvent
Chemical absorption	Reactive function as acid or base groups	Reversible process	Optimize the solvent ratio
Molecular sieving	Size/shape	Significant differences	Remove first fouling components
Equilibrium adsorption	Adsorption coefficient	Favorable adsorption	Remove first fouling components
Membrane permeation	Perselectivity	Perselectivity greater than 15	Remove first fouling components
Catalytic oxidation	Chemical family	Impurities below 10% of the flammability point	Danger of dioxine, not for halogenated organics
Catalytic hydrogenation	Chemical family	Components containing double bound	Develop selective catalyst
Chemical treatment	Chemical family	Selective reaction	Dry treatment preferred Recovery of chemical agent

Separation sequence and methods for landfill gas treatment.



Split Sequencing : Enrichment

- Gas - separation manager makes use of three selectors: enrichment, sharp separation, and purification
- Enrichment consists of a significant increase in the concentration of one or several species in the desired stream, although by this operation neither high recovery nor purity is achieved.
- Condensation, physical absorption, membrane permeation, cryogenic distillation, and adsorption are convenient separation techniques.

Split Sequencing : sharp separation

- Sharp separation consists of obtaining splitting of the mixture into products with a high recovery of target components.
- The sharpness is defined as the ratio of key component concentrations in products. This should be better than 10.
- Potential techniques are: physical absorption, cryogenic distillation, molecular sieving, as well as equilibrium adsorption when the molar fraction of the adsorbate is less than 0.1.
- Chemical absorption may also be applicable when the component concentration is low.

Split Sequencing : purification

- Purification deals with the removal of impurities with the goal of achieving very high concentration of the dominant component.
- The initial concentration of impurity in the mixture should be lower than 2000 ppm, while the final concentration of impurity in the product should be less than 100 ppm.
- Suitable separation methods are equilibrium adsorption, molecular - sieve adsorption, chemical absorption and catalytic conversion

General heuristics for separation sequencing of liquid mixtures.

1. Remove first corrosive, hazardous, fouling, reactive and any troublesome components. Consider also in the first place the removal of light-ends.
2. Deliver high-purity products as top distillate. The same is valid for reactants sent to reactors sensitive to impurities.
3. When separation by distillation is feasible, prefer it in a first attempt.
4. Isolate zeotropic and azeotropic mixtures.
5. Perform difficult zeotropic separations later, but before azeotropic separations. Examine other options, such as extractive distillation, L–L extraction, crystallization, adsorption, or molecular sieves.
6. Examine the separation of azeotropic mixtures last.
7. Remove the components in order of decreasing percentage of the feed. This operation will reduce the cost of the next separation.
8. Favor 50/50 splits.

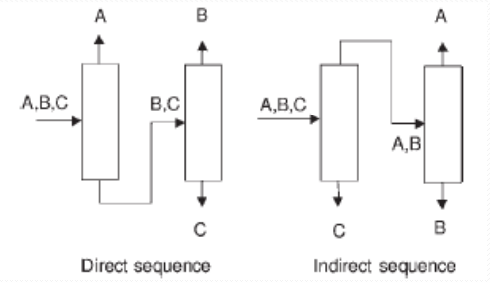
Sequencing of Ordinary Distillation Columns

- The relative volatility between the two selected key components for the separation in each column is >1.05
- The reboiler duty is not excessive. (low relative volatility ==> high duty reboiler)
- The tower pressure does not cause the mixture to approach its critical temperature
- The overhead vapor can be at least partially condensed at the column pressure to provide reflux without excessive refrigeration requirements
- The bottoms temperature for the tower pressure is not so high that chemical decomposition occurs
- Azeotropes do not prevent the desired operation
- Column pressure drop is tolerable, particularly if operation is under vacuum

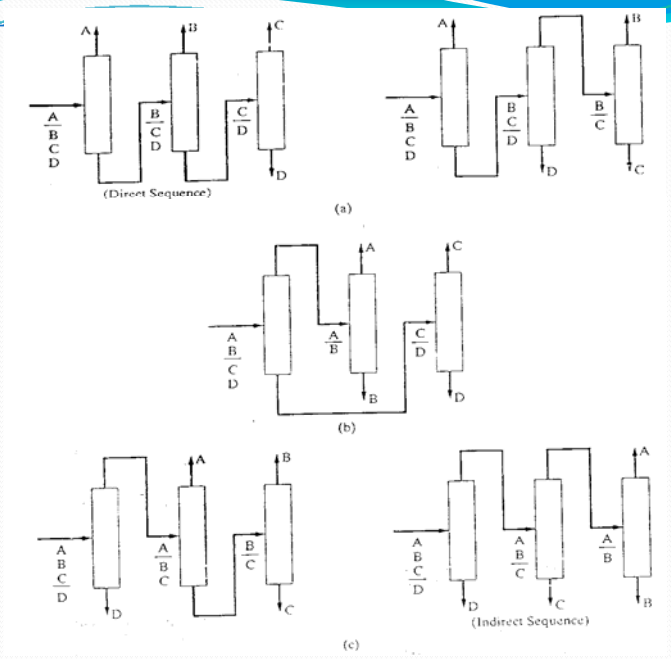
Heuristics for separation sequencing of zeotropic mixture

1. Perform difficult separations the last, but before separations of azeotropes.
2. Remove firstly the lightest component one by one as overhead products.
3. Remove components in order of decreasing percentage of the feed. This operation will reduce the cost of the next separation.
4. Favor near 50/50 splits.

DIRECT AND INDIRECT SEQUENCES



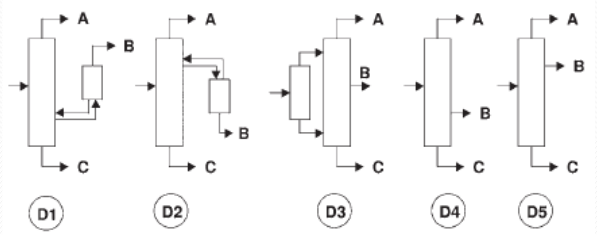
No.	Type	First split	Second split	Third split
1	Direct	**A**/BCD	**B**/CD	C/D
2	Equal split	AB/CD	A/B	C/D
3	Indirect	ABC/**D**	AB/**C**	A/B
4	Direct/indirect	**A**/BCD	BC/**D**	B/C
5	Indirect/direct	ABC/**D**	**A**/BC	B/C



Heuristics for Determining Favorable Sequence ==> Economic

- Remove thermally unstable, corrosive, or chemically reactive components early in the sequence
- Remove final products one by one as distillates
- Sequence separation points to remove, early in the sequence, those components of greatest molar percentage in the feed
- Sequence separation points in the order of decreasing relative volatility so that the most difficult splits are made in the absence of other components
- Sequence separation points to leave last those separations that give the highest purity products
- Sequence separation points that favor near equimolar amounts of distillate and bottoms in each column

Types of Complex Columns



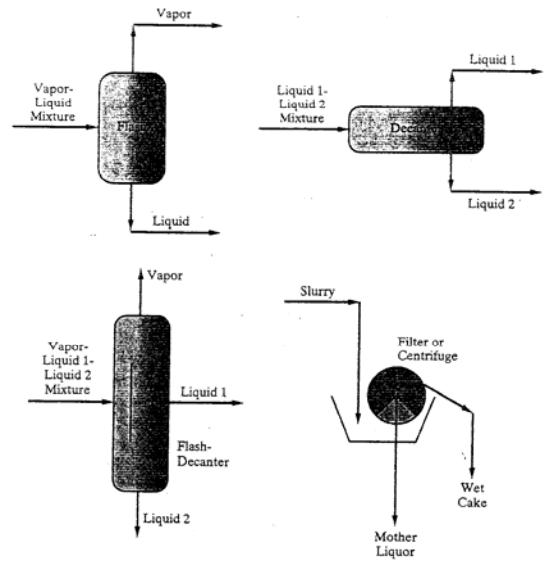
- 1. **Side - stream rectifier**: A and C from main column, B as top product of side rectifier.
- 2. **Side - stream stripper**: A and C as before, but B as bottoms of side stripper.
- 3. **Prefractionator**: separate AB and BC mixtures in fi rst column by sloppy separation, then take pure components A, B, and C in a side - stream second column.
- 4. **Side - stream low position**: take B as side stream below the feed.
- 5. **Side - stream high position**: take B as side stream above the feed.

Phase Conditions of The Feed as Criterion

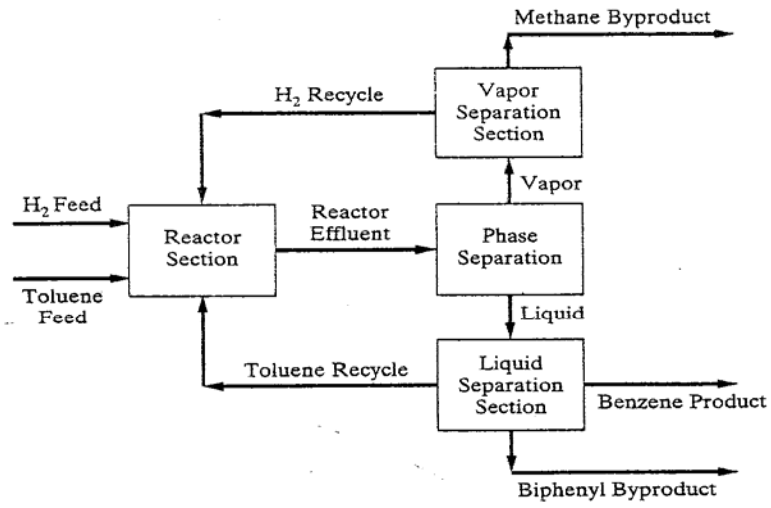
- **Vapor feed**:
  - Partial condensation
  - Distillation under cryogenic conditions
  - Gas absorption
  - Gas adsorption
  - Gas permeation with a membrane
  - desublimation

- **Liquid Feed**:
  - Flash
  - Distillation
  - Stripping
  - Exctractive distillation
  - Azeotropic distillation
  - Liquid-liquid extraction
  - Crystallization
  - Liquid adsorption
  - Dialysis, reverse osmosis, ultrafiltration, etc
  - Supercritical extraction

Various Phase-Separation Devices



Example: hydrodealkylation of toluene to benzene



Slurries, wet cake, dry solids

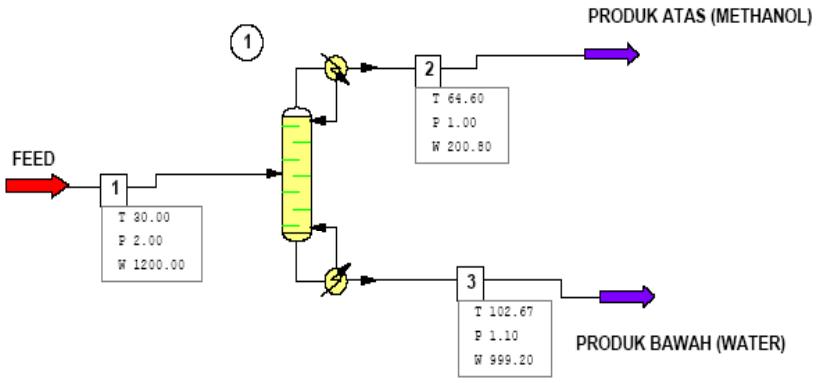
- Filtration
- Centrifugation ➔ obtain a wet cake
- The separated into a vapor and a dry solid by drying

Enhanced/ Azeotropic Distillation

- Extractive Distillation
- Chemically Enhanced Distillation
- Pressure - Swing Distillation

Shortcut Column untuk Prediksi Jumlah Stage dan Feed Stage

SHORTCUT COLUMN
(setelah jumlah tray ketemu baru ke distilasi jenis lainnya untuk simulasi)



Shortcut Column Specification

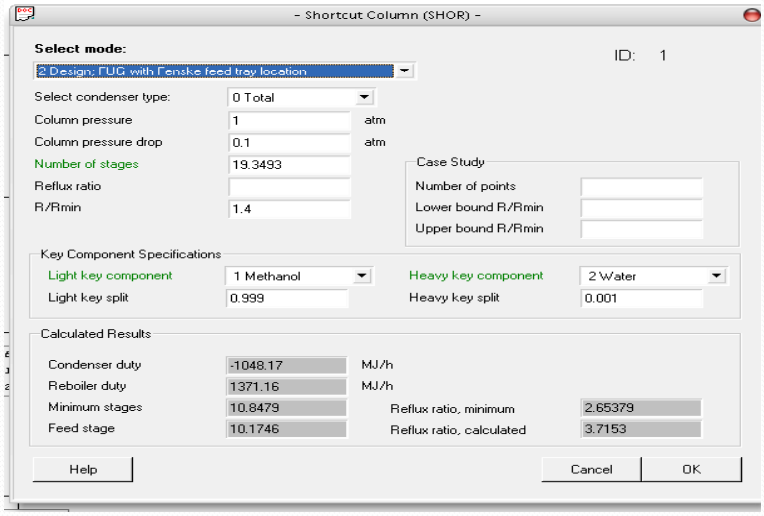


Plate Column from Shortcut Column

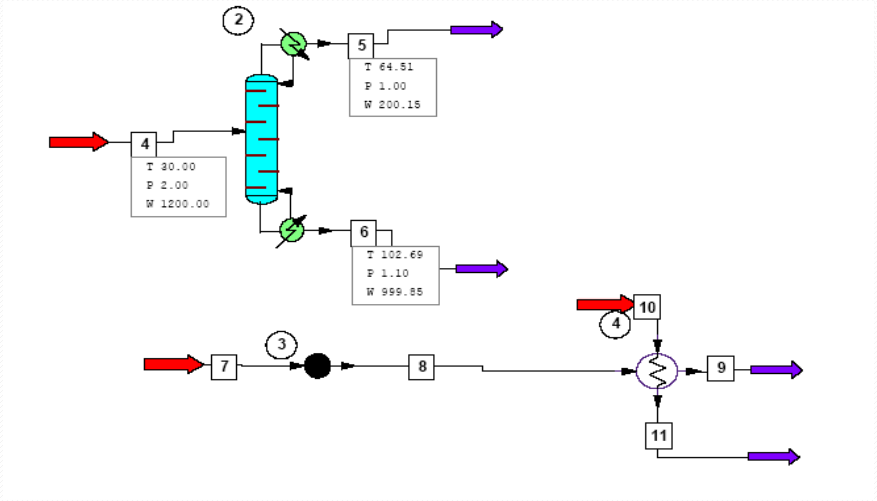
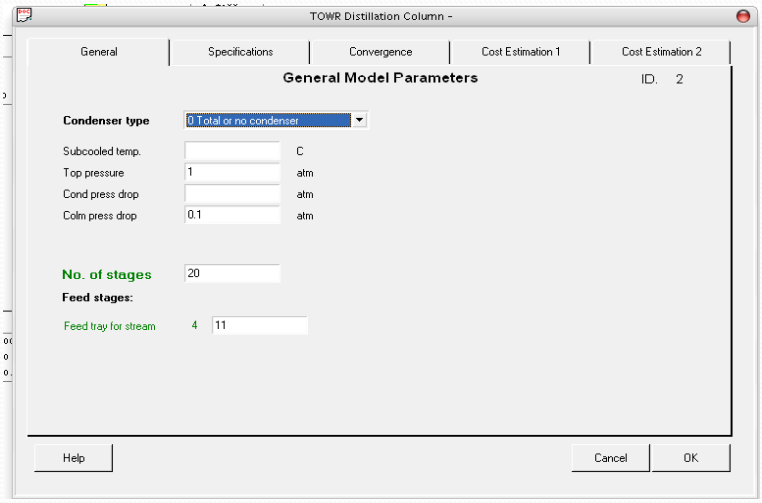
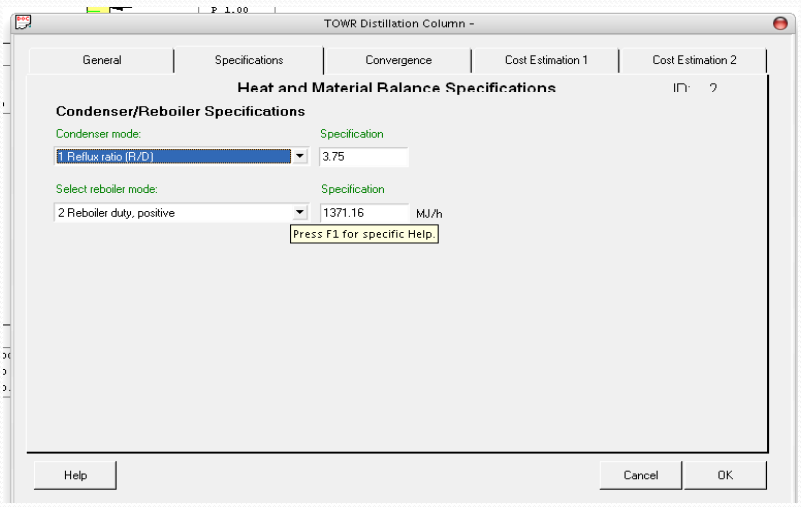
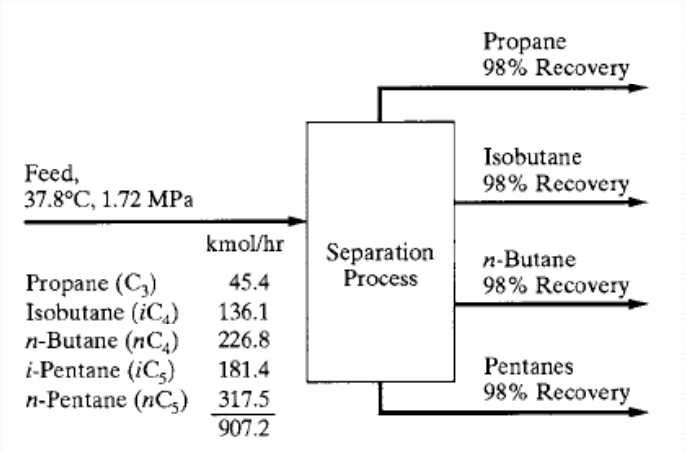


Plate Column Specification





Example for Separation Heuristics

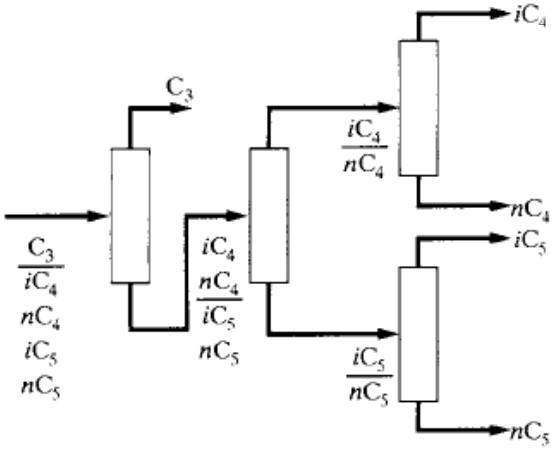


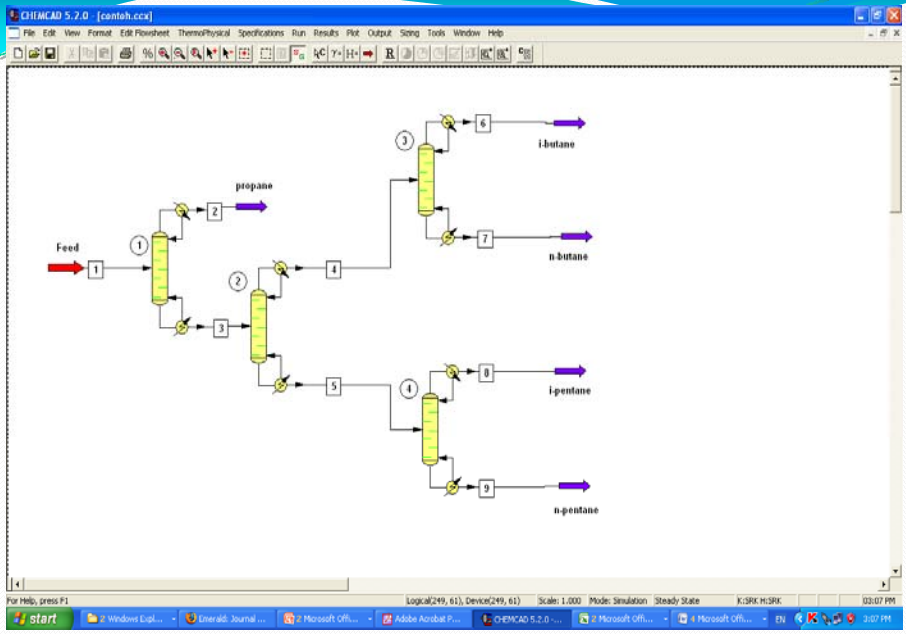
	kmol/hr
Propane (C_3)	45.4
Isobutane (iC_4)	136.1
n-Butane (nC_4)	226.8
i-Pentane (iC_5)	181.4
n-Pentane (nC_5)	317.5
	907.2

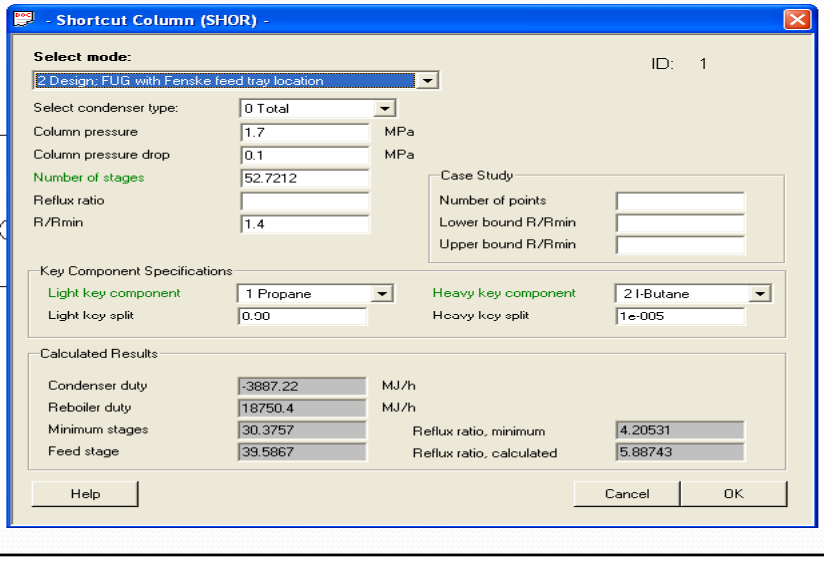
Relative Volatility Data

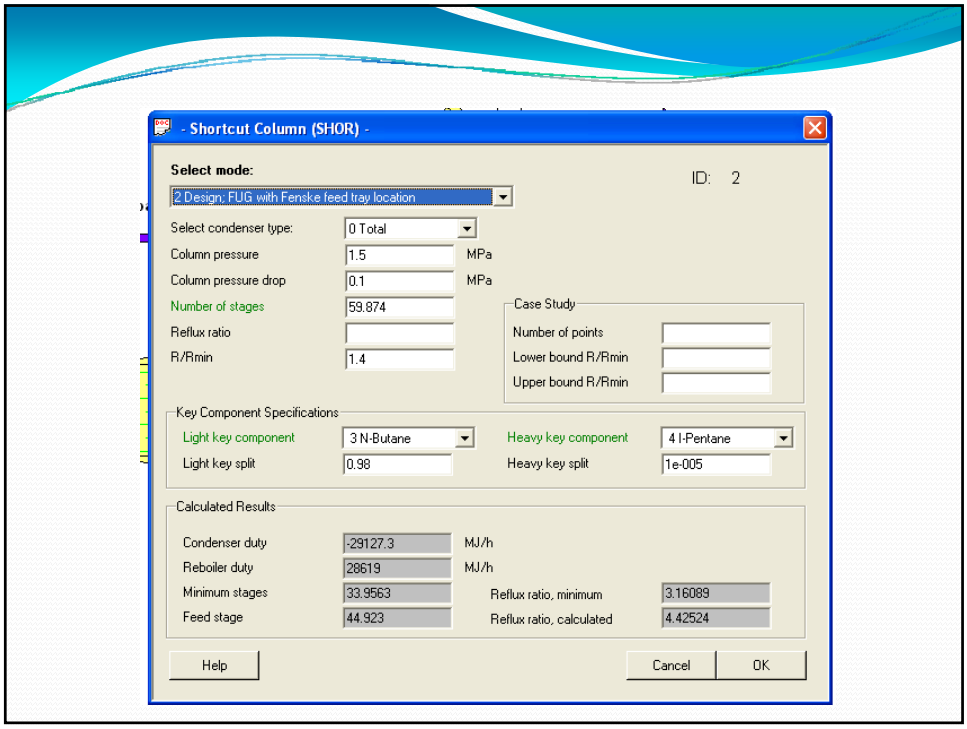
Component pair	Approximate α at 1 atm
C_3/iC_4	3.6
iC_4/nC_4	1.5
nC_4/iC_5	2.8
iC_5/nC_5	1.35

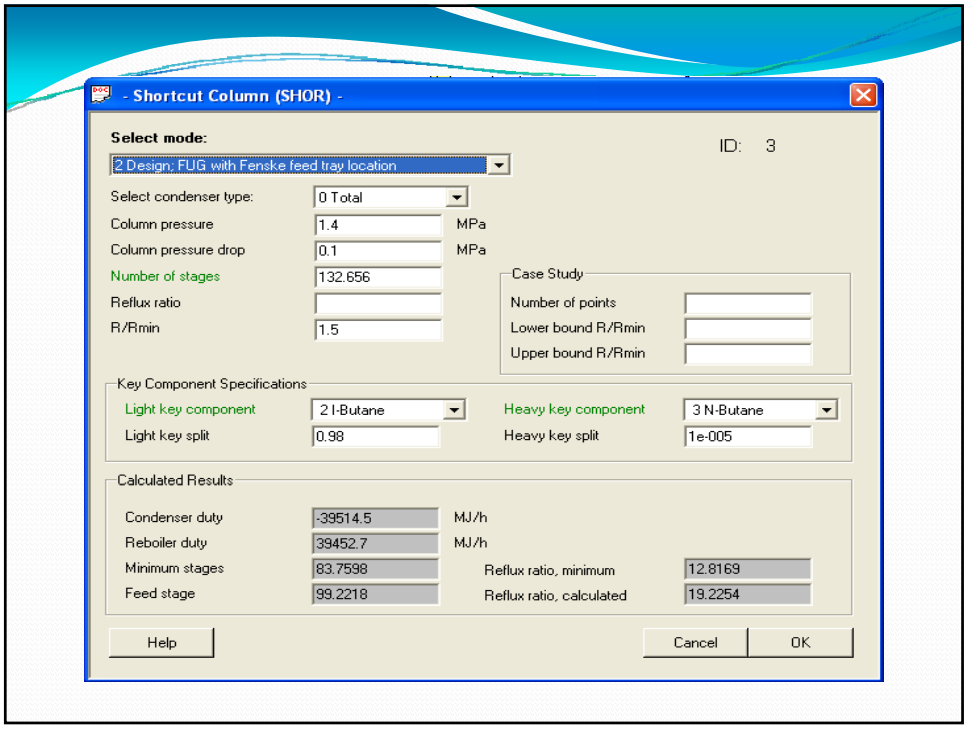
Solution based on heuristics

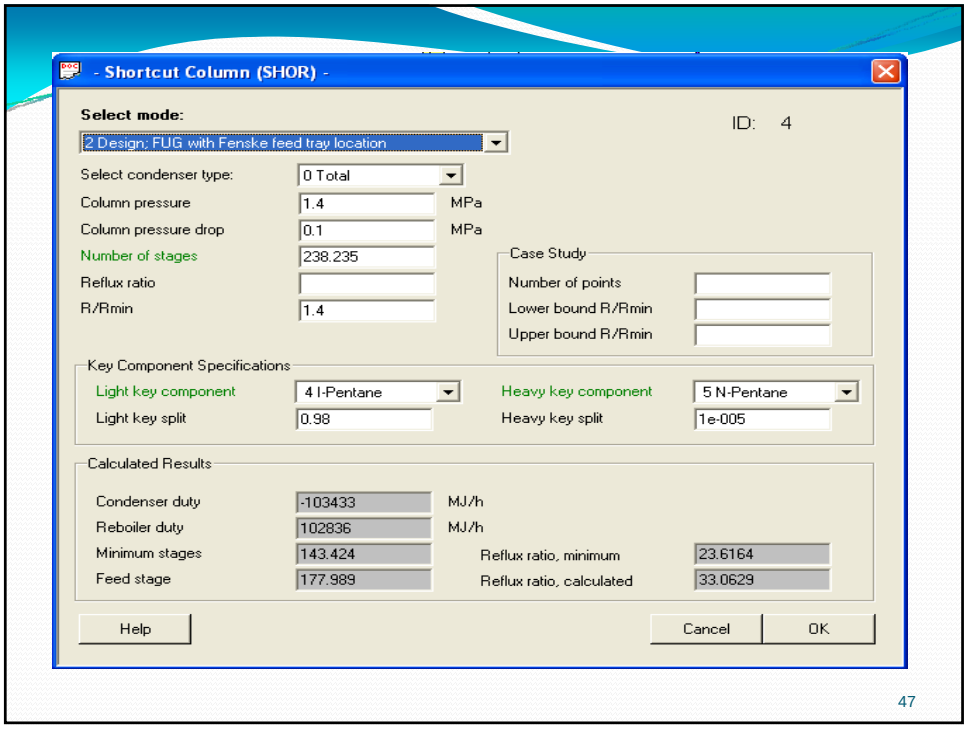



CHEMCAD 5.2.0 - [conteh.ccx]
Feed
propane
i-butane
n-butane
i-pentane
n-pentane


- Shortcut Column (SHOR) -
Select mode:
2 Design: FUG with Fenske feed tray location
ID: 1
Select condenser type:
0 Total
Column pressure
1.7
MPa
Column pressure drop
0.1
MPa
Number of stages
52.7212
Reflux ratio
R/Rmin
1.4
Case Study
Number of points
Lower bound R/Rmin
Upper bound R/Rmin
Key Component Specifications
Light key component
1 Propane
Heavy key component
2 I-Butane
Light key split
0.90
Heavy key split
1e-005
Calculated Results
Condenser duty
-3887.22
MJ/h
Reboiler duty
18750.4
MJ/h
Minimum stages
30.3757
Feed stage
39.5867
Reflux ratio, minimum
4.20531
Reflux ratio, calculated
5.88743
Help
Cancel
OK


- Shortcut Column (SHOR) -
Select mode:
ID: 2
2 Design; FUG with Fenske feed tray location
Select condenser type: 0 Total
Column pressure 1.5 MPa
Column pressure drop 0.1 MPa
Number of stages 59.874
Reflux ratio
R/Rmin 1.4
Case Study
Number of points
Lower bound R/Rmin
Upper bound R/Rmin
Key Component Specifications
Light key component 3 N-Butane
Heavy key component 4 I-Pentane
Light key split 0.98
Heavy key split 1e-005
Calculated Results
Condenser duty -29127.3 MJ/h
Reboiler duty 28619 MJ/h
Minimum stages 33.9563
Reflux ratio, minimum 3.16089
Feed stage 44.923
Reflux ratio, calculated 4.42524
Help
Cancel
OK


- Shortcut Column (SHOR) -
Select mode:
ID: 3
2 Design; FUG with Fenske feed tray location
Select condenser type: 0 Total
Column pressure 1.4 MPa
Column pressure drop 0.1 MPa
Number of stages 132.656
Reflux ratio
R/Rmin 1.5
Case Study
Number of points
Lower bound R/Rmin
Upper bound R/Rmin
Key Component Specifications
Light key component 2 I-Butane
Heavy key component 3 N-Butane
Light key split 0.98
Heavy key split 1e-005
Calculated Results
Condenser duty -39514.5 MJ/h
Reboiler duty 39452.7 MJ/h
Minimum stages 83.7598
Reflux ratio, minimum 12.8169
Feed stage 99.2218
Reflux ratio, calculated 19.2254
Help
Cancel
OK


- Shortcut Column (SHOR) -
Select mode:
ID: 4
2 Design; FUG with Fenske feed tray location
Select condenser type:
0 Total
Column pressure
1.4
MPa
Column pressure drop
0.1
MPa
Number of stages
238.235
Reflux ratio
R/Rmin
1.4
Case Study
Number of points
Lower bound R/Rmin
Upper bound R/Rmin
Key Component Specifications
Light key component
4 I-Pentane
Heavy key component
5 N-Pentane
Light key split
0.98
Heavy key split
1e-005
Calculated Results
Condenser duty
-103433
MJ/h
Reboiler duty
102836
MJ/h
Minimum stages
143.424
Reflux ratio, minimum
23.6164
Feed stage
177.989
Reflux ratio, calculated
33.0629
Help
Cancel
OK