

Tray Sizing & Rating

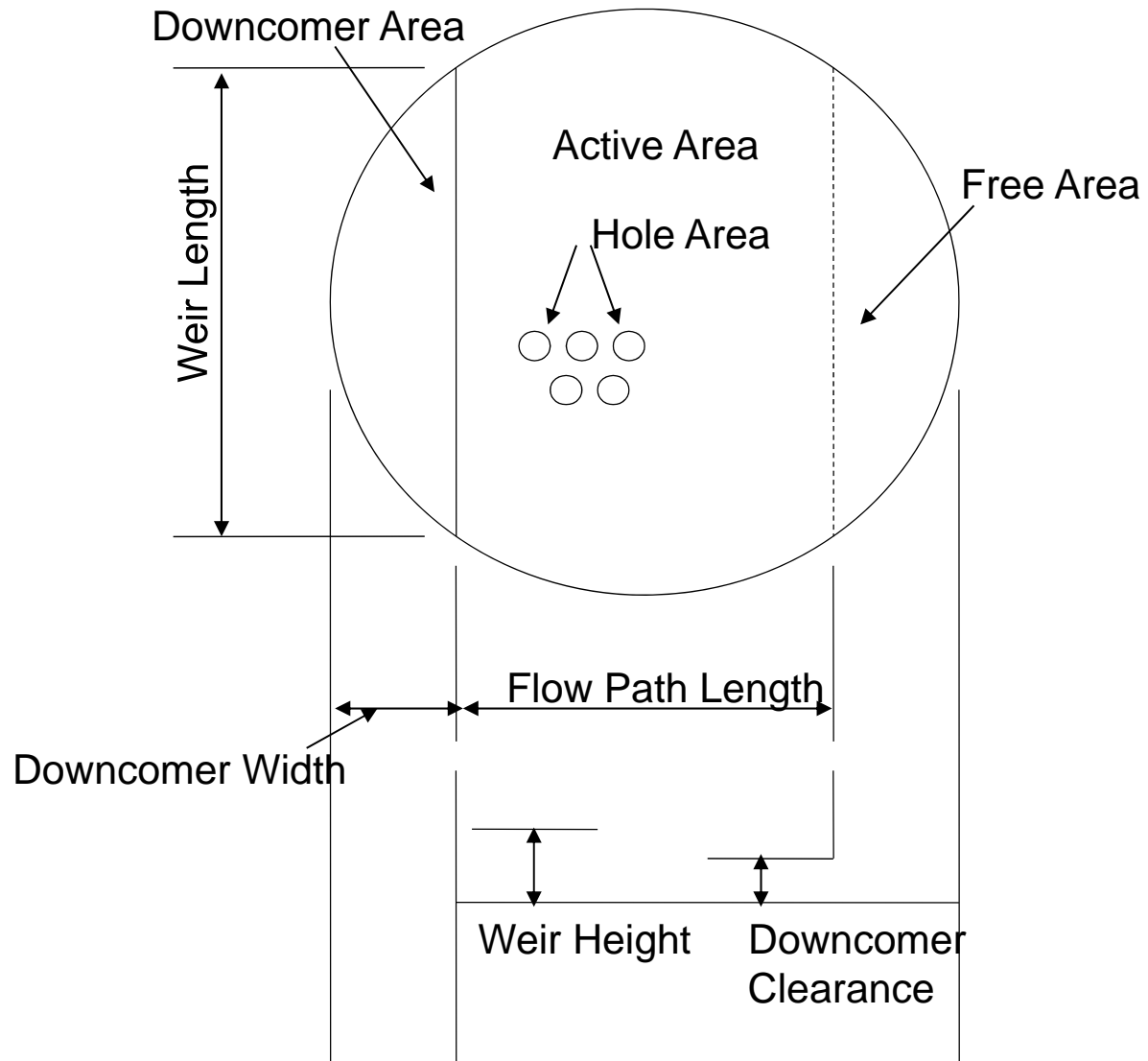


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Tray

- Mass Transfer Operation에 최초로 이용된 Fractionation Equipment
- 1813년에 프랑스의 Cellier-Blumenthal에 의해 최초로 제작
- Distillation, Absorption, Extraction에 이용
- 1950년대 이전: Sieve, Bubble-cap Tray 사용
- 현재: Valve Tray를 많이 사용
- 그 밖의 Special Tray Type

Tray Components

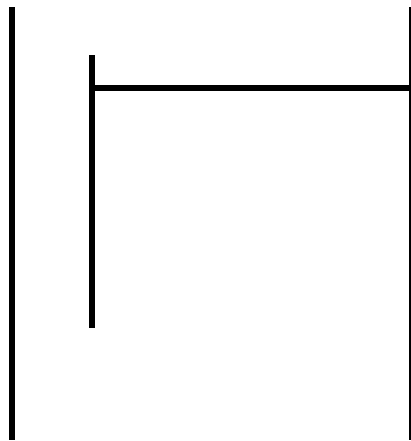


Tray Components – Tray Deck (Tray Floor)

- Tray Deck : Active Area + Downcomer Inlet Area
- Active Area:
 - Vapor와 Liquid가 Cross Flow로 서로 접촉하여 Mass Transfer가 일어나는 부분
- Downcomer Inlet Area:
 - 윗 단의 Liquid가 내려오는 통로

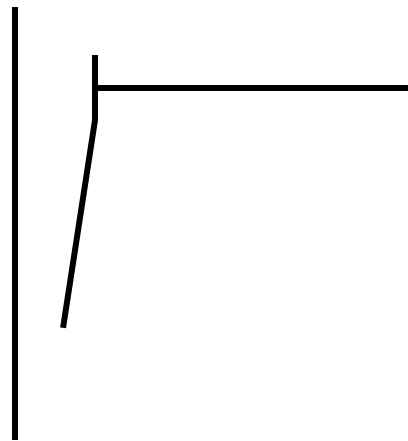
Tray Components – Downcomer

Downcomer는 Tray Deck를 통과한 Liquid를 아랫단의 Tray Deck로 보내기 위한 통로로서, 다음 그림과 같이 여러 형태로 분류된다.



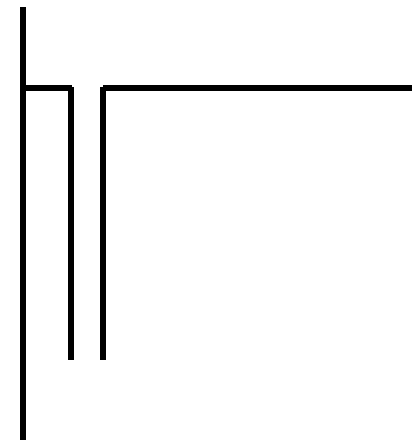
(a)

Straight downcomer



(b)

Sloped downcomer



(c)

Pipe downcomer

Pipe Downcomer의 예



Tray Components - Continued

- Outlet Weir

Outlet Weir는 Tray Deck에서 Downcomer로 떨어지는 Liquid를 정체 시켜서 접촉시간을 늘리기 위한 역할을 하는 것으로 Tray의 Pressure Drop에 가장 큰 영향을 미친다.

- Inlet Weir

Inlet Weir는 Downcomer로부터 Tray Deck의 Active Area로 유입되는 와류 상태의 Liquid를 Steady하게 바꾸고자 할 때와 Vapor의 양이 많고 Liquid의 양이 적을 때 Sealing을 위하여 사용한다.

- Recessed Sump

Tray Deck의 Inlet Area를 Tray Deck보다 낮게 하는 것으로 Column Dia.가 고정되어 있고 Downcomer Flood가 너무 클 경우 사용되며, Inlet Weir와 같은 용도로 사용되기도 한다.

Tray Components - Continued

- Tray Spacing

Tray Spacing은 Tray Deck와 Deck 사이의 간격으로 Maintenance를 고려하여 300 mm에서 900 mm로 정한다.

Column Diameter	Tray Spacing
– 1,200 mm	– 450 mm
1,200 – 7,200 mm	600 mm – 900 mm

Tray Layout

- **Active Area:**

Active Area는 Tray 한단의 전체 면적에서 Outlet, Inlet Downcomer Area를 뺀 면적으로 실질적인 기-액 접촉이 일어나는 Area이다.

- **Downcomer Area:**

Downcomer Area 는 Tray에서 Liquid가 내려가는 부분의 Area로, Multi-pass Tray 에서는 전체 Downcomer Area를 더한 Area이다.

- **Hole Area:**

Hole Area는 Active Area에 있는 Hole의 전체 면적으로 Tray의 종류에 관계 없이 전체 Hole Area를 말한다.

- **Flow Path Length:**

Flow Path Length는 Tray Deck에서 Liquid가 흐르는 거리이다. Multi-path일 때는 전체 Flow Path Length를 더한 값이다.

Tray Layout - Continued

- Downcomer Width:

Downcomer Width는 Tower Wall 에서 Downcomer 까지의 길이이다.

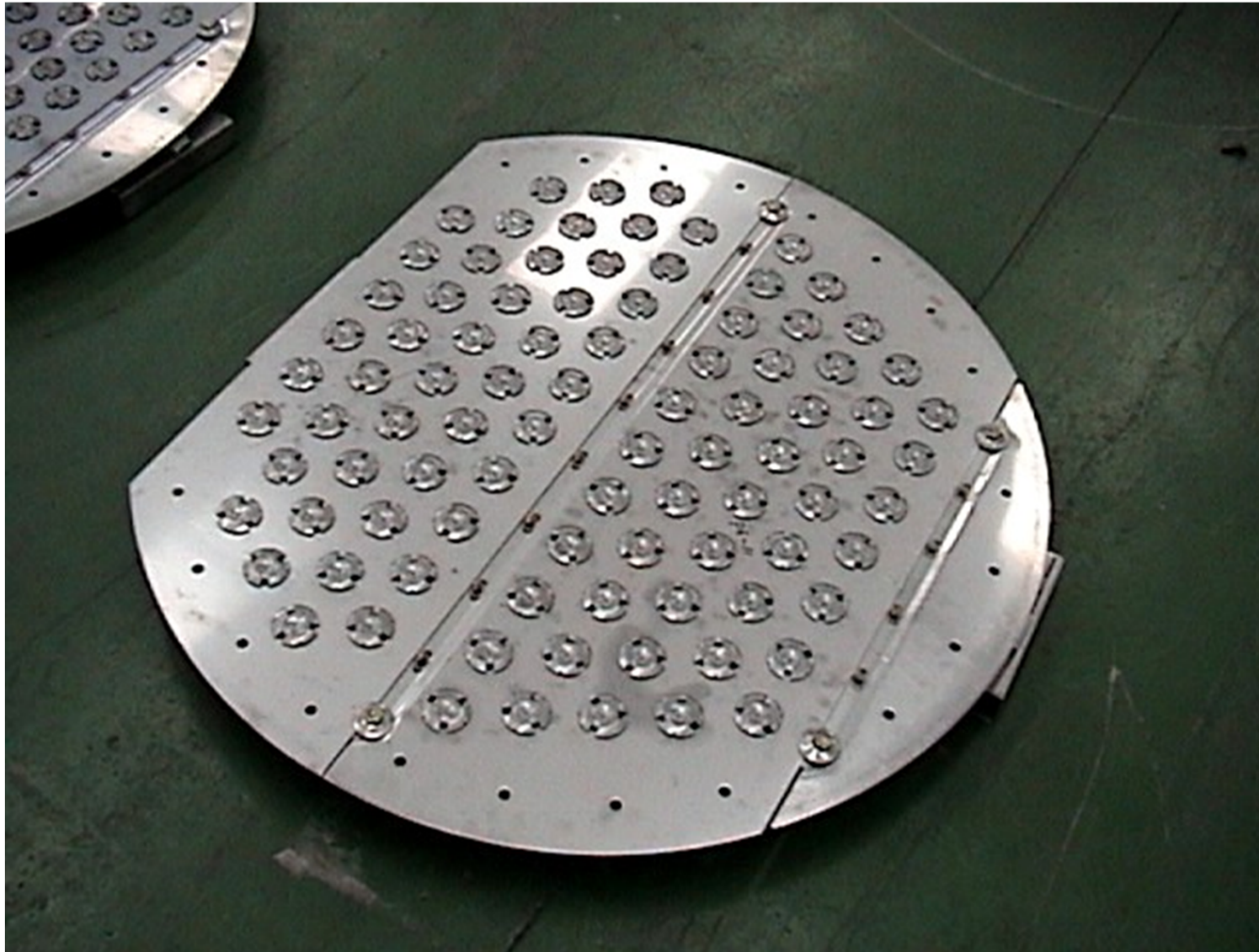
- Downcomer Clearance:

Downcomer 와 Tray Deck 사이의 간격으로 Weir Height보다 항상 작다. Downcomer Flood가 크고, Liquid Flow를 조정하기 위하여 Downcomer Clearance는 Zero로 하고 Recessed Sump를 설치하는 경우도 있다.

Tray 종류 (1) – Sieve Tray



Tray 종류 (2) – Valve Tray



Tray 종류 (3) – Bubble Cap Tray



Tray 종류 (4) – *Dual Flow Tray*



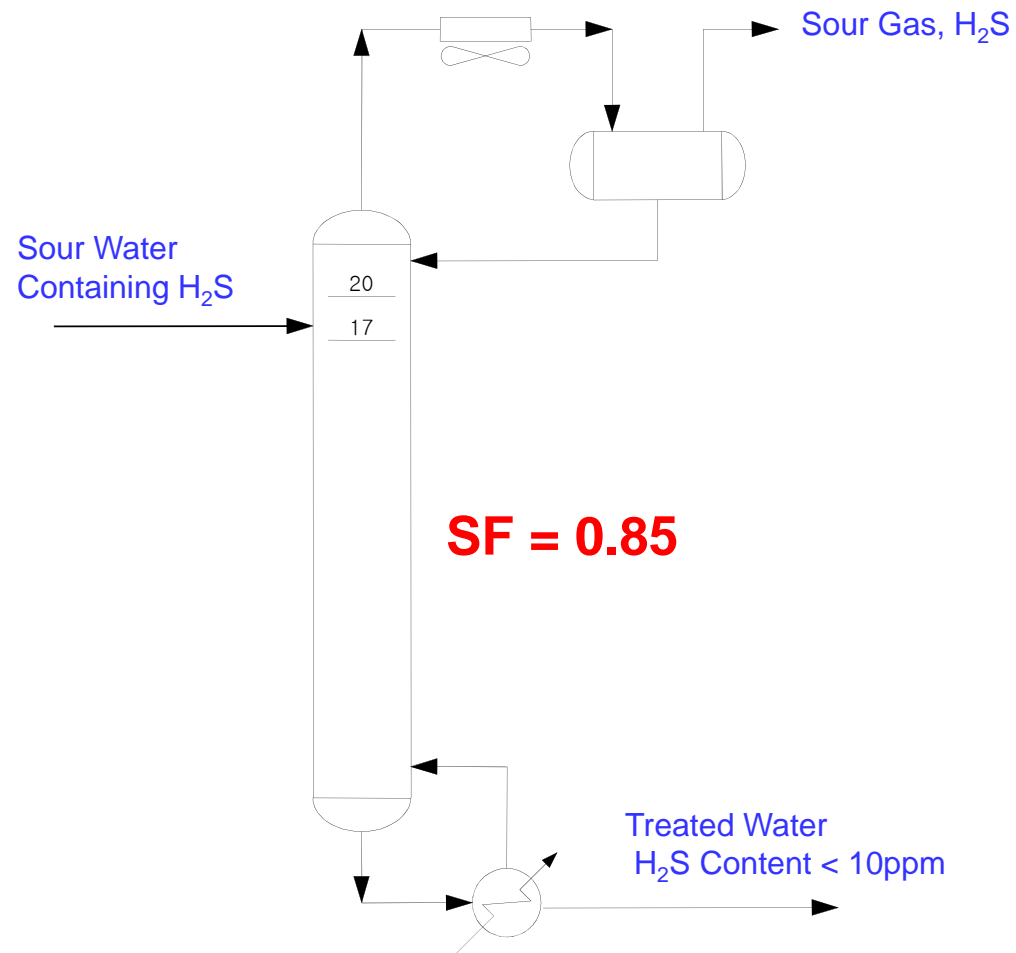
Process Requirements for Tray Design

항목	Description
Flow rate	Feed나 Product를 기준으로 해서 증류탑을 몇 개의 Group으로 나누어 그 Group에서는 유량이 일정하다고 가정하고 Tray를 계산한다.
Density	Vapor와 Liquid의 Density를 필요로 한다.
Viscosity/Surface Tension	이 물성치는 Liquid Phase 만의 물성치를 필요로 한다.
Foaming Factor	Foaming on trays is taken into account by using a so-called "system factor".

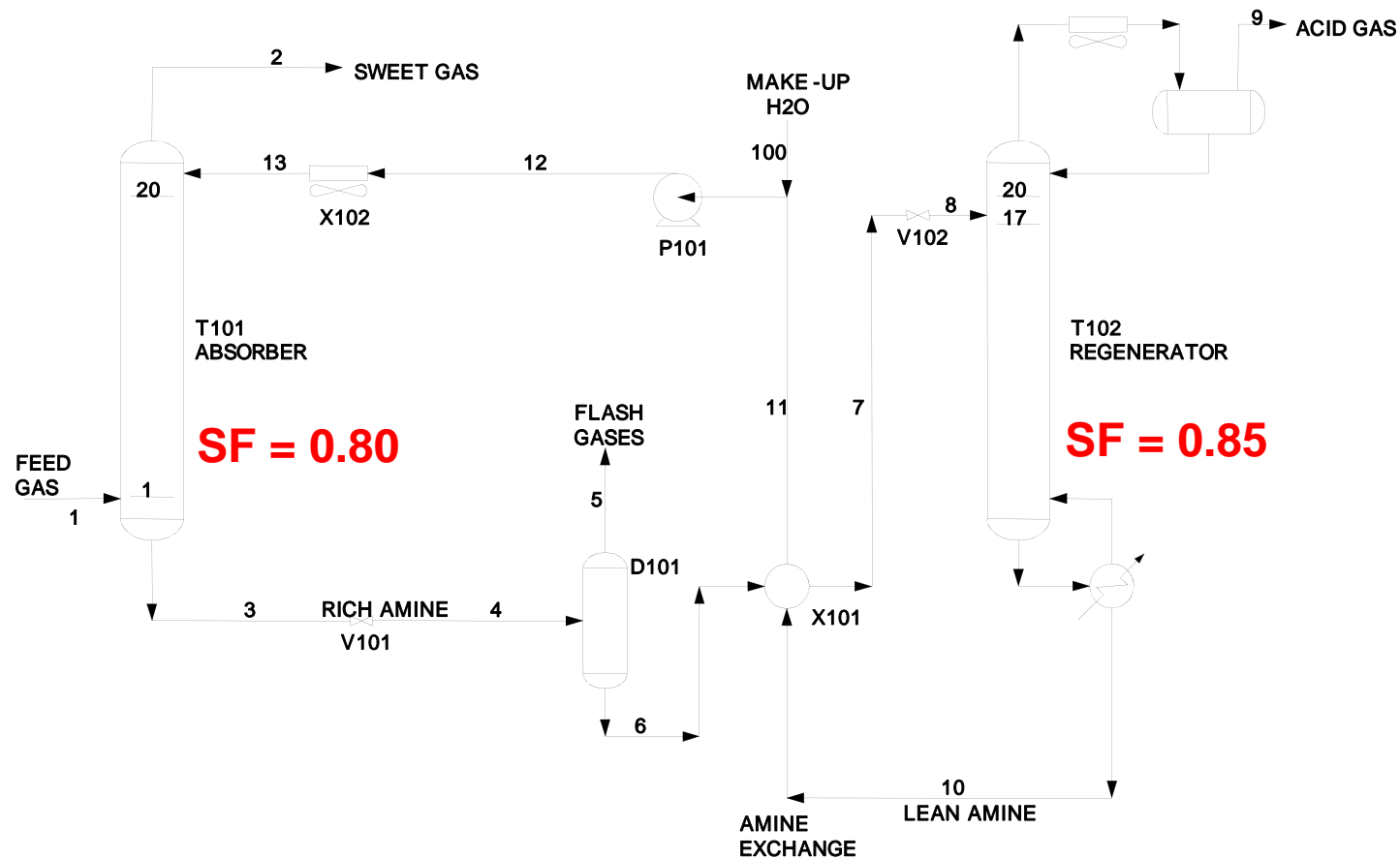
System Factors for Foaming Applications

System	Factor
Sour Water Stripper	0.85
Amine Contactor	0.80
CO ₂ Absorber	0.80
CO ₂ Regenerator	0.85
Vacuum Towers	0.85
Glycol Contactors	0.50

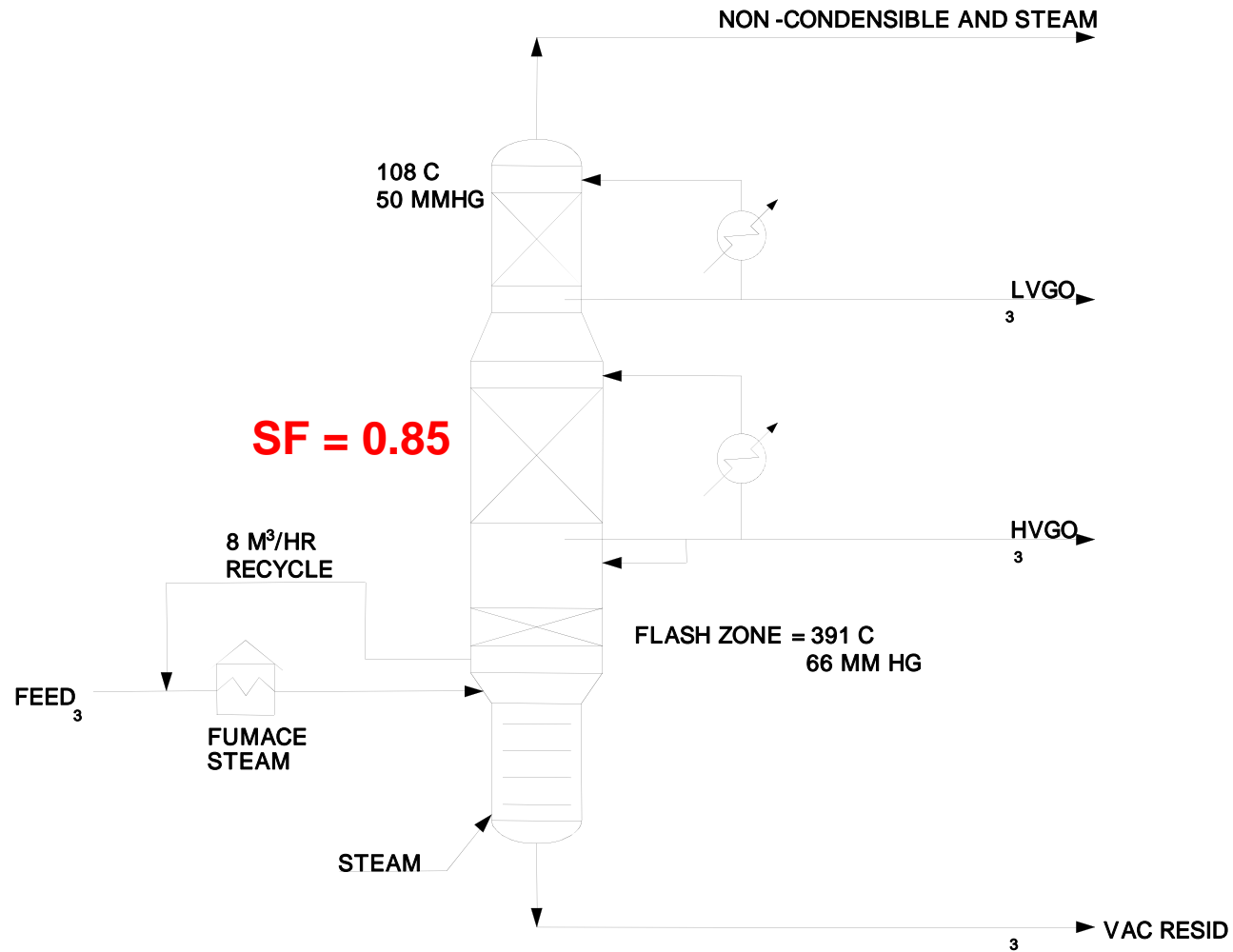
System Factor for Sour Water Stripper



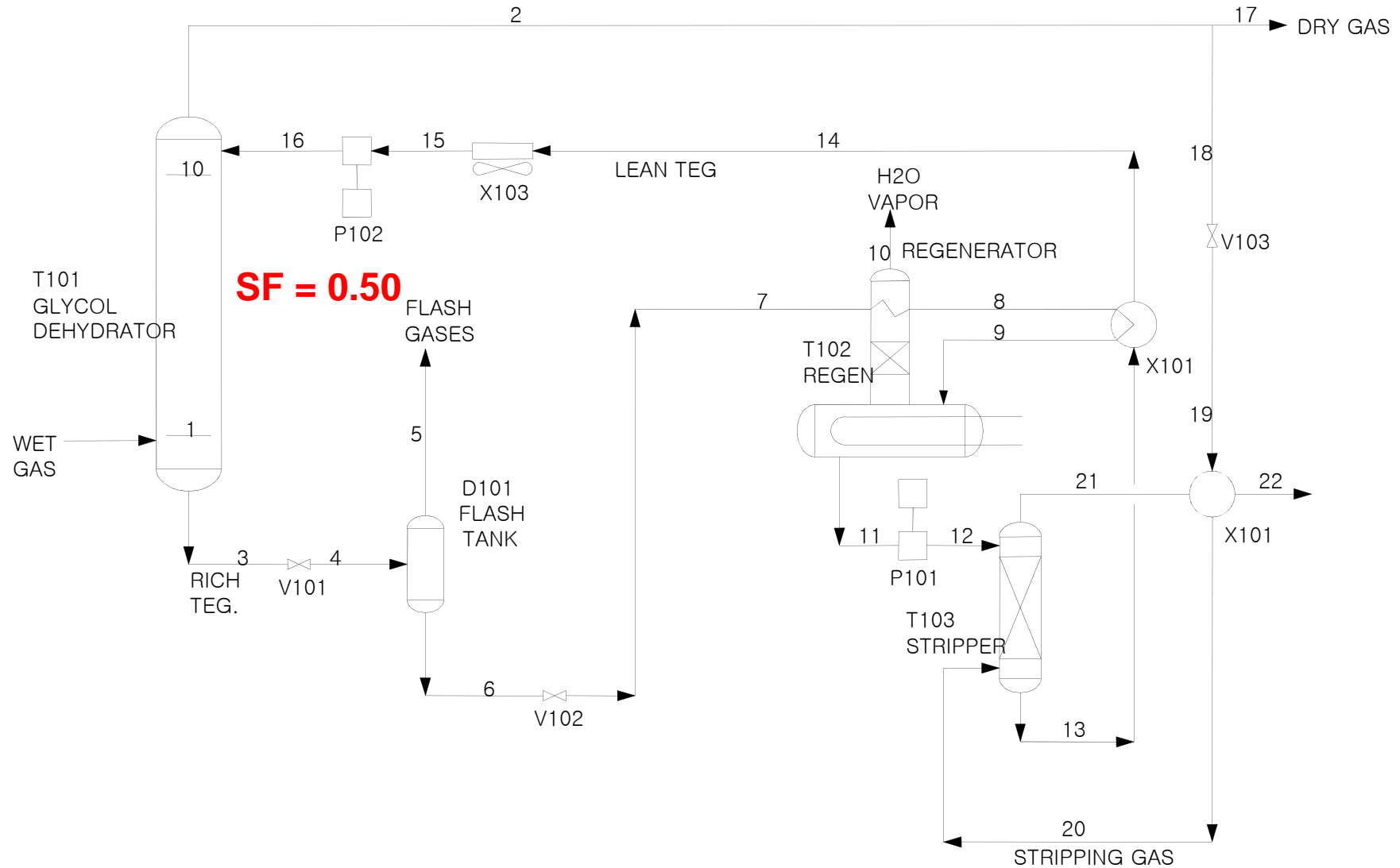
System Factors for CO₂ Absorber and Regenerator



System Factor for Vacuum Tower



System Factor for Glycol Dehydrator

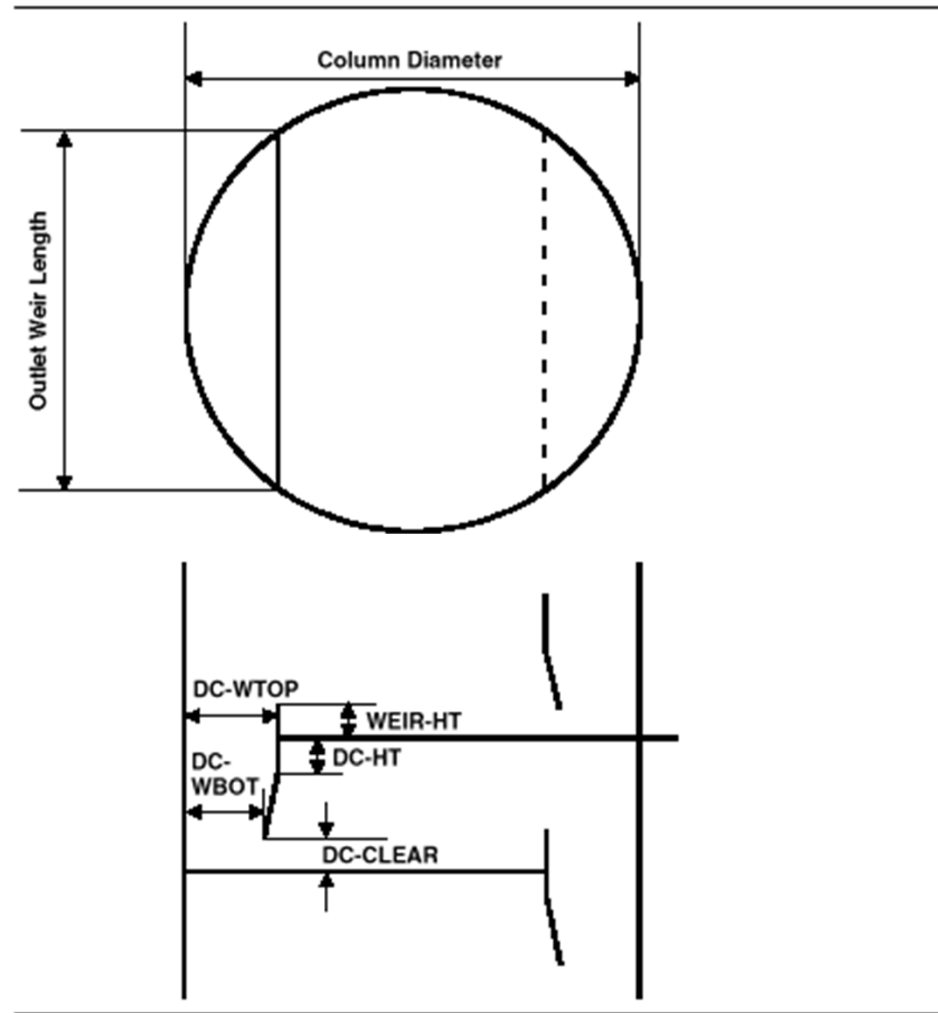


Tray Number of Passes

Column 의 Diameter 가 클 경우에 1 Pass로 설계하게 되면, Active Area에 Dead Zone이 생기며, Outlet Weir를 통과하는 Liquid의 양이 커서 Tray의 Performance가 낮아지므로 아래와 같이 Multi Pass Tray로 설계한다.

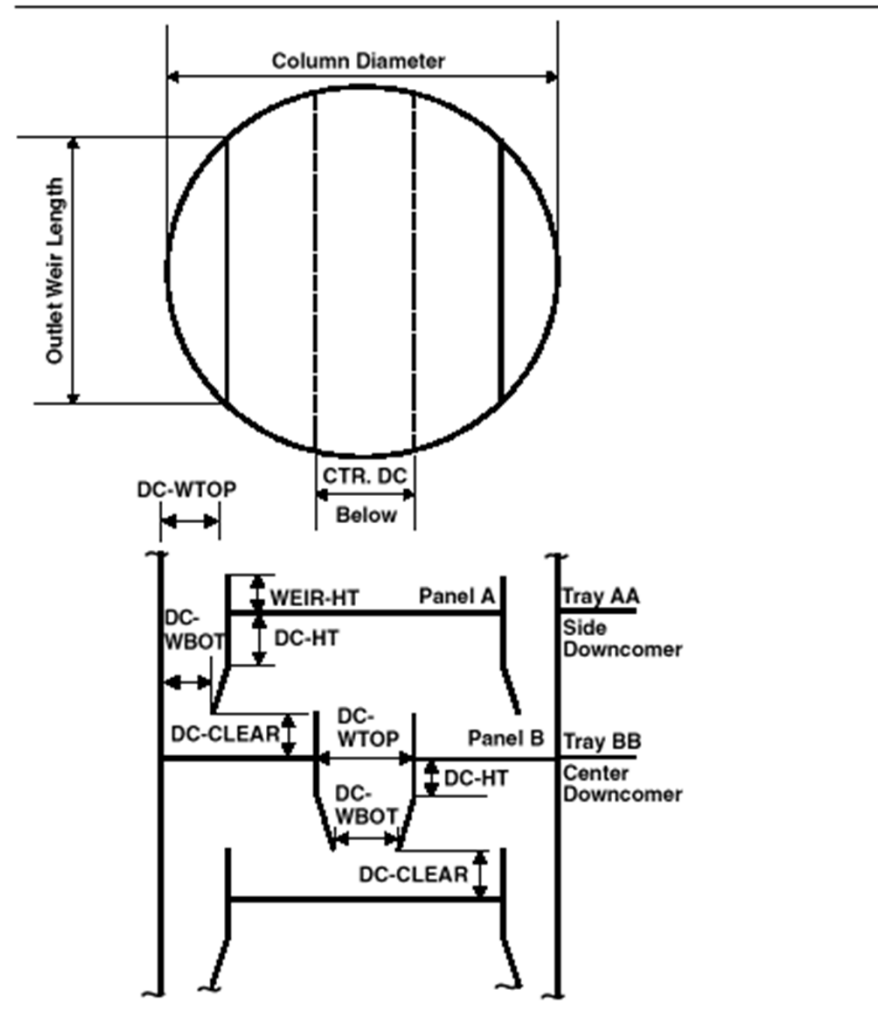
Column Diameter	Number of Passes
– 1,500 mm	1
1,500 mm – 2,400 mm	2
2,400 mm – 3,000 mm	3
3,000 mm – 4,000 mm	4
4,000 mm –	5

One Pass Tray



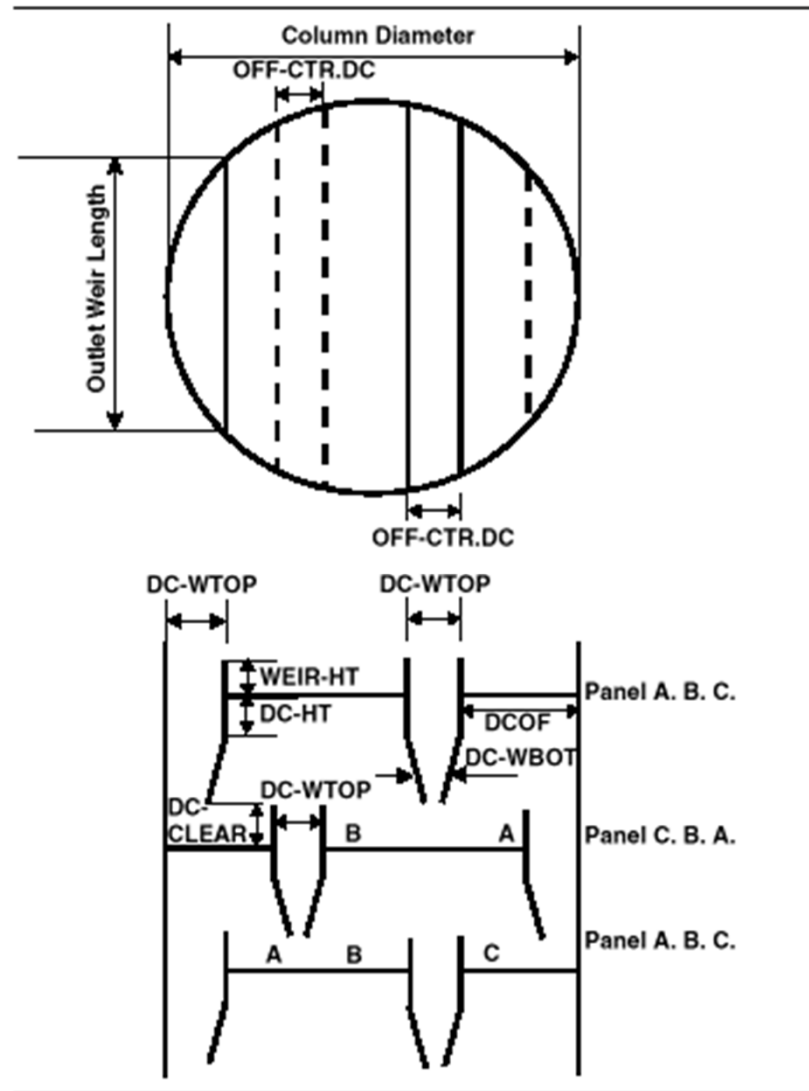
A One-Pass Tray

Two Pass Tray



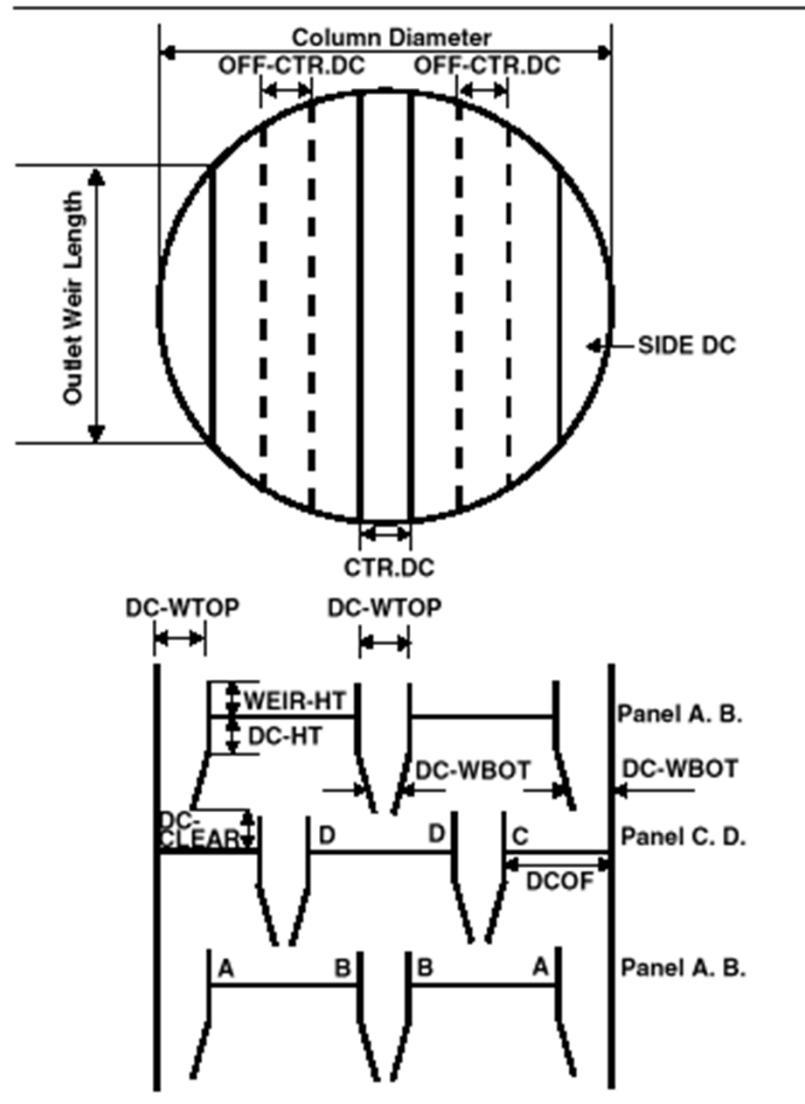
A Two-Pass Tray

Three Pass Tray



A Three-Pass Tray

Four Pass Tray



A Four-Pass Tray

Tower Diameter

Initial estimation

$$D_t(\text{feet}) = \left[\frac{6.8(V - \text{LOAD}) + 10(L - \text{LOAD})}{\sqrt{\text{Tray_Spacing}(\text{feet})}} \right]^{0.5}$$

where

$$V - \text{LOAD} = (\text{Vapor_Rate, CFS}) \sqrt{\frac{\rho_v}{\rho_l - \rho_v}}$$

$$L - \text{LOAD} = (\text{Liquid_Rate, CFS})$$

Tray Sizing and Rating

- Rating vs. Sizing:
 - Simulating a column with fixed operating conditions is called **“rating”**.
 - Manipulating operating conditions to achieve some overall result is called **“sizing”**.
- Sizing Mode:
 - Sizing Mode determines column diameter to satisfy the flooding approach specified for each stage. The largest diameter is selected.
- Rating Mode:
 - Rating Mode calculates performance and hydraulic information such as flooding approach, downcomer backup, and pressure drop.

Tray Sizing and Rating

- ASPEN PLUS or PRO/II calculates sizing and performance parameters such as:
 - Column diameter
 - Flooding approach or approach to maximum capacity
 - Downcomer backup
 - Pressure drop
- These results are based on:
 - Column loadings (vapor and liquid traffic)
 - Tray geometry
 - Transport properties

Tray Performance

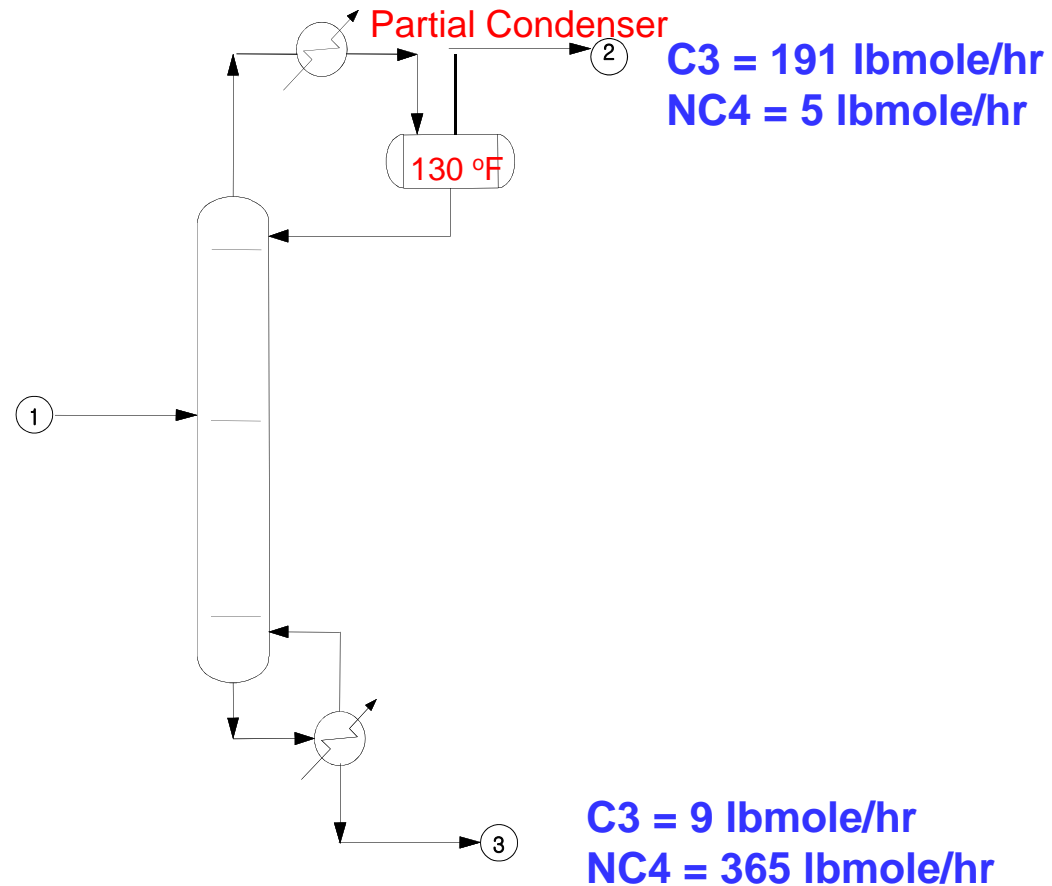
유형	현상
Flooding	<ul style="list-style-type: none"> • 정해진 Tower Size에서 Tray 용량의 한계를 의미 • Tray Type마다 차이는 있으나 % Flooding이 80보다 크고 20보다 작은 경우에는 Tray 효율이 급격히 저하된다.
Weeping	<ul style="list-style-type: none"> • Hole Area로 올라오는 Vapor의 양이 너무 적어 Liquid 중 일부분이 Hole Area를 통하여 떨어지는 현상
Blowing	<ul style="list-style-type: none"> • Liquid 양이 Vapor 양에 비해 너무 적어 Active Area 상의 Liquid의 일부분이 Vapor와 함께 위로 올라가는 현상
Entrainment	<ul style="list-style-type: none"> • Blowing과 유사한 현상으로 Active Area의 Liquid 중 많은 양이 Vapor 와 함께 올라오는 현상 • Tray에 Drying 현상을 유발시킬 수 있다.
Dumping	<ul style="list-style-type: none"> • Weeping 양이 많아져서 액유량과 같아지는 경우

Tray Sizing Example – Depropanizer

Feed, lbmole/hr	
C2	30
C3	200
NC4	370
NC5	350
NC6	50
Total	1000
Press.	320 psia
Temp.	225 °F

LK → **C3**

HK → **NC4**

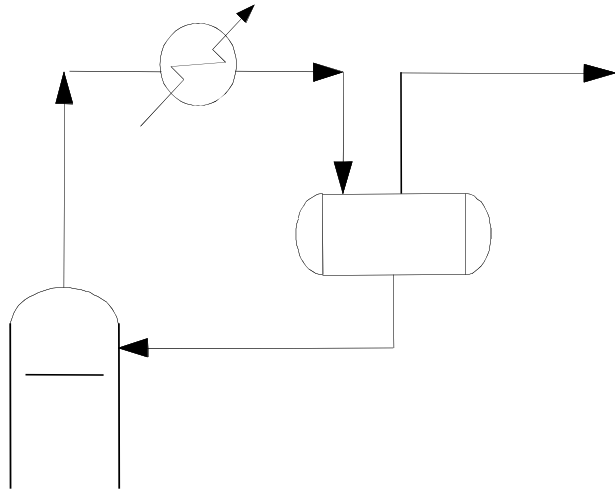


Tray Sizing for Depropanizer New Design

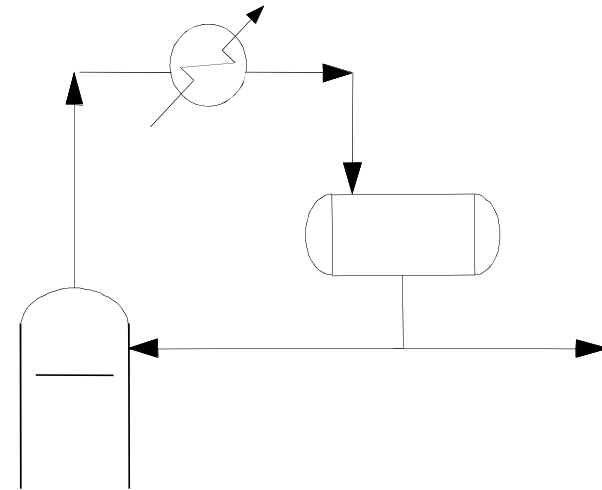
1. Determine the number of tray to obtain:
 - a) C3 recovery at overhead : 95.5 %
 - b) NC4 recovery at overhead : 1.35 %
2. Determine the column operating pressure, based on a dew point condenser temperature of 130°F.
3. Use RK-Soave (in A+) (SRK in PRO/II) method for VLE calculation.
4. Find an actual reflux ratio which minimizes the summation of total utility consumptions (*operating costs*) and theoretical number of stages (*capital costs*).
5. Use Sieve Tray Internal Type.

How we can determine the condenser type? or How we can determine the column pressure?

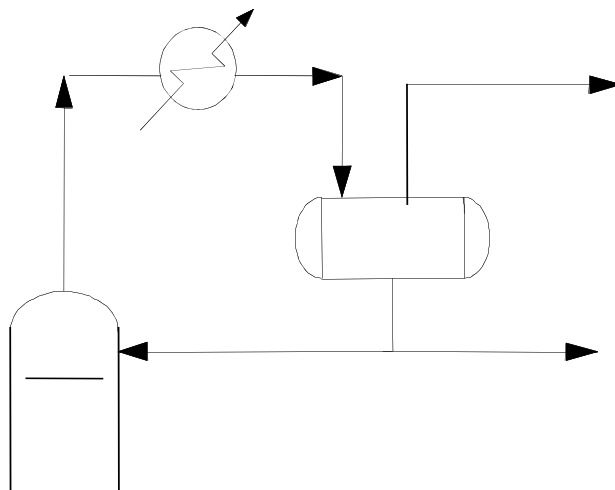
A. Partial



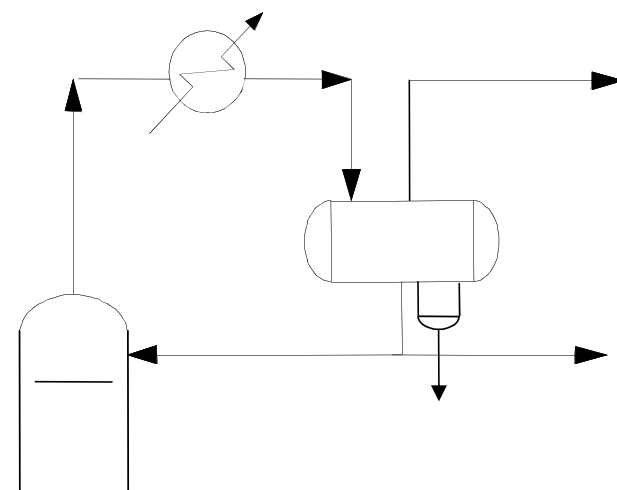
B. Bubble or sub-cooled



C. Mixed



D. Mixed with decanter



It depends on the refrigerant available and overhead compositions to be assumed.

- Overhead molar flow rate (assume)
 - $C2 = 30, C3 = 191, NC4 = 5, \text{Total} = 226$
- Normalize ! (Component mole %)
 - $C2 = 13.27, C3 = 84.51, NC4 = 2.22$
- First, we have to determine the dew point pressure !

Component	Mole %
C2	13.27
C3	84.51
NC4	2.22
Temperature (°F)	130.00
Dew P at 130 °F	?

Component Specification in ASPEN PLUS

The screenshot displays the Aspen Plus software interface for component specification. The window title is "Aspen Plus - Dewp - [Components Specifications - Data Browser]". The menu bar includes File, Edit, View, Data, Tools, Run, Plot, Library, Window, and Help. The toolbar contains various icons for file operations and simulation control. The left sidebar shows a tree view of the simulation setup, with "Specifications" selected. The main area is divided into tabs: "Selection", "Petroleum", "Nonconventional", and "Databanks". The "Selection" tab is active, showing a table for defining components. The table has four columns: Component, Type, Component, and Formula. The rows list C2 (ETHANE), C3 (PROPANE), NC4 (N-BUTANE), NC5 (N-PENTANE), and NC6 (N-HEXANE), all of type "Conventional". A row with an asterisk (*) is also present. Below the table are buttons for "Find", "Elec Wizard", "User Defined", and "Reorder". The status bar at the bottom shows "For Help, press F1", the current directory "C:\My Simulations", the number of components "NUM", and a red error message "Required Input Incomplete".

Component	Type	Component	Formula
C2	Conventional	ETHANE	C ₂ H ₆
C3	Conventional	PROPANE	C ₃ H ₈
NC4	Conventional	N-BUTANE	C ₄ H ₁₀ -1
NC5	Conventional	N-PENTANE	C ₅ H ₁₂ -1
NC6	Conventional	N-HEXANE	C ₆ H ₁₄ -1
*			

Feed Composition Specification in ASPEN PLUS

The screenshot shows the Aspen Plus Data Browser interface for stream 1. The 'Specifications' tab is active, showing the following configuration:

- Substream name: MIXED
- State variables: Temperature (130 F), Vapor fraction (1)
- Total flow: 100 kmol/hr
- Composition: Mole-Flow (kmol/hr)

Component	Value
C2	13.27
C3	84.51
NC4	2.22
NC5	
NC6	

Total: 100

At the bottom of the window, a status bar displays the message: **Required Input Incomplete**

Thermo Option in ASPEN PLUS

The screenshot displays the Aspen Plus software interface, specifically the 'Properties Specifications - Data Browser' window. The window title is 'Aspen Plus - Dewp - [Properties Specifications - Data Browser]'. The menu bar includes File, Edit, View, Data, Tools, Run, Plot, Library, Window, and Help. The toolbar contains various icons for file operations and navigation. The main area is divided into three tabs: 'Global', 'Flowsheet Sections', and 'Referenced', with 'Global' selected. The left sidebar shows a tree view of specifications, with 'Properties' and 'Specifications' expanded. Under 'Specifications', 'Property Methods' is checked, and under 'Property Methods', 'Binary Interaction' is checked, with 'PRKIJ-1' and 'RKSKIJ-1' selected. The main panel shows the following settings:

- Property methods & models:**
 - Process type: ALL
 - Base method: RK-SOAVE
 - Henry: [empty]
- Petroleum calculation options:**
 - Free-water: STEAM-T
 - Water solubility: 3
- Electrolyte calculation options:**
 - Chemistry ID: [empty]
 - Use true-compon
- Property:** RK-SOAV
- Modify property m:**
 - Modify property m
 - r: ESRKSTI
 - Data set: 1
 - Liquid gamma: [empty]
 - Data set: [empty]
 - Liquid: HLMX107
 - Liquid volume: VLMX20
 - Poynting correc
 - Heat of mixi

The status bar at the bottom shows 'For Help, press F1', 'C:\My Simulations', 'NUM', and a red error message: 'Required Input Incomplete'.

Dew Point Calculation in ASPEN PLUS

Aspen Plus - Dewp - [Block DEWP (Flash2) - Data Browser]

File Edit View Data Tools Run Plot Library Window Help

DEWP

ENGAS

Specifications Flash Options Entrainment

Flash specifications

Temperature 130 F

Vapor fraction 1

Valid phases

Vapor-Liquid

Lets you type the molar vapor fraction. 0.0 for bubble point, 1.0 for dew point. For subcooled liquid or superheated vapor use temperature and pressure specifications. See Help.

For Help, press F1

C:\My Simulations NUM Required Input Complete

Examine Result ASPEN PLUS

The screenshot displays the Aspen Plus Data Browser interface for a DEWP (Dew Point) block. The window title is "Aspen Plus - Dewp - [Block DEWP (Flash2) - Data Browser]". The menu bar includes File, Edit, View, Data, Tools, Run, Plot, Library, Window, and Help. The toolbar contains various icons for file operations and simulation control. The left pane shows a tree view with "Streams" (1, 2, 3) and "Blocks" (DEWP, Results, Stream Results). The right pane shows the "Summary" tab with the following data:

Block results summary		
Outlet temperature:	130	F
Outlet pressure:	298.73626	psi
Vapor fraction:	1	
Heat duty:	3.4973E-0	MMBtu/hr
Net duty:	3.4973E-0	MMBtu/hr
1st liquid / Total liquid:		

At the bottom of the window, there is a status bar with the text "For Help, press F1", the current directory "C:\My Simulations", the file name "NUM", and a "Results Available" button.

How about using PRO/II ?

```
TITLE PROJECT=DISTILLATION, PROBLEM=DEWP, USER=JHCHO, DATE=08/28/00
  PRINT INPUT=ALL
  SEQUENCE PROCESS
COMPONENT DATA
  LIBID 1,C2/2,C3/3,NC4
THERMODYNAMIC DATA
  METHOD SYSTEM=SRK
STREAM DATA
  PROPERTY STREAM=1, TEMPERATURE=100, PRESSURE=300, PHASE=M, &
    RATE (M) =100, COMPOSITION (M) =1,13.27/2,84.51/3,2.22
UNIT OPERATIONS
  FLASH UID=F01
    FEED 1
    PROD V=1V, L=1L
    DEW TEMP=130
END
```

ASPEN PLUS Keyword Input File



```
TITLE 'Dew Pressure Calculation at the Condenser Pressure'  
IN-UNITS ENG  
DEF-STREAMS CONVEN ALL  
DESCRIPTION "  
    General Simulation with English Units :  
    F, psi, lb/hr, lbmol/hr, Btu/hr, cuft/hr.  
    Property Method: None  
    Flow basis for input: Mole  
    Stream report composition: Mole flow "  
DATABANKS PURE10 / AQUEOUS / SOLIDS / INORGANIC / &  
    NOASPENPCD  
PROP-SOURCES PURE10 / AQUEOUS / SOLIDS / INORGANIC  
COMPONENTS  
    C2 C2H6 /  
    C3 C3H8 /  
    NC4 C4H10-1  
FLOWSHEET  
    BLOCK DEW IN=1 OUT=2 3  
PROPERTIES RK-SOAVE  
STREAM 1  
    SUBSTREAM MIXED TEMP=130. VFRAC=0. MOLE-FLOW=1.  
    MOLE-FRAC C2 0.1327 / C3 0.8451 / NC4 0.0222  
BLOCK DEW FLASH2  
    PARAM TEMP=130. VFRAC=1.
```


FLASH ID	F01
FEEDS	1
PRODUCTS VAPOR	1V
LIQUID	1L
TEMPERATURE, F	130.000
PRESSURE, PSIA	298.857
PRESSURE DROP, PSI	1.143
MOLE FRAC VAPOR	1.00000
MOLE FRAC LIQUID	.00000
DUTY, MM BTU/HR	.58994
FLASH TYPE	DEW-T

Dew Pressure Calculation Results

	ASPEN PLUS	PRO/II
Condenser Type	Partial	Partial
Condenser Operating Temperature	130°F	130°F
Condenser Operating Pressure	298.736 psia	298.857 psia
Condenser Pressure Drop	4 psia (assumed)	4 psia (assumed)
Column Pressure Drop	5 psia (assumed)	5 psia (assumed)

- Next step is to determine the minimum number of stages & minimum reflux ratio for separation using “SHORTCUT” model.

Shortcut Modeling using ASPEN PLUS

Aspen Plus - DSTWU-200 - [Stream 1 (MATERIAL) - Data Browser]

File Edit View Data Tools Run Plot Library Window Help

Grid 0.1

1

ENGAS

Specifications Flash Options PSD Component Attr.

Substream name: **MIXED**

State variables

Temperature: 225 F

Pressure: 320 psi

Total flow: Mole

1000 kmol/hr

Solvent:

Composition

Mole-Flow: kmol/hr

Component	Value
C2	30
C3	200
NC4	370
NC5	350
NC6	50

Total: 1000

Input Complete

For Help, press F1

C:\My Simulations CAP NUM Required Input Incomplete

Shortcut Modeling using ASPEN PLUS

The screenshot shows the Aspen Plus Data Browser interface for Block B1. The left pane displays a tree view of the simulation data, with 'Streams' and 'Block B1' expanded. The main pane shows the 'Specifications' tab for the 'ENGGAS' block. The 'Specifications' tab is active, and the 'Reflux ratio' is set to -2. The 'Pressure' section shows 'Condens' at 299 psi and 'Reboiler' at 308 psi. The 'Key component recoveries' section shows 'Light key' as C3 with a recovery of 0.955, and 'Heavy' as NC4 with a recovery of 0.0134. The 'Condenser specifications' section shows 'Partial condenser with all vapor distillate' selected, and 'Distillate vapor' set to 1. The status bar at the bottom indicates 'Input Complete' and 'Required Input Complete'.

Aspen Plus - DSTWU-200 - [Block B1 (DSTWU) - Data Browser]

File Edit View Data Tools Run Plot Library Window Help

Grid 0.1

B1 ENGGAS

Specifications Calculation Options Convergence

Column specifications

Reflux ratio: -2

Pressure

Condens: 299 psi

Reboiler: 308 psi

Key component recoveries

Light key:

Comp: C3

Recov: 0.955

Heavy

Comp: NC4

Recov: 0.0134

Condenser specifications

Partial condenser with all vapor distillate

Distillate vapor: 1

Partial condenser, with vapor distillate only.

Input Complete

For Help, press F1

C:\My Simulations CAP NUM Required Input Complete

Shortcut Modeling using ASPEN PLUS

The screenshot displays the Aspen Plus Data Browser interface for Block B1. The window title is "Aspen Plus - DSTWU-200 - [Block B1 (DSTWU) - Data Browser]". The menu bar includes File, Edit, View, Data, Tools, Run, Plot, Library, Window, and Help. The toolbar contains various icons for file operations and simulation control. The left pane shows a tree view with "Streams" (1, 2, 3) and "Blocks" (B1). The right pane shows the "Results" tab for Block B1, displaying a table of simulation results.

Results		
Minimum reflux ratio:	3.20841305	
Actual reflux ratio:	6.4168261	
Minimum number of stages:	10.9105896	
Number of actual stages:	14.6787254	
Feed stage:	8.1556041	
Number of actual stages above	7.1556041	
Reboiler heating required:	22.9341228	MMBtu/hr
Condenser cooling required:	16.9470622	MMBtu/hr
Distillate temperature:	130.012782	F
Bottom temperature:	282.721311	F
Distillate to feed fraction:	0.22595694	

Results Available
For Help, press F1
C:\My Simulations CAP NUM Results Available

DSTWU (Shortcut in Aspen Plus) modeling Case Study

R/R _{min}	Number of Tray	Reflux Ratio	Feed Tray	Condenser Duty	Reboiler Duty	Utility
1.00	Infinite	3.21	-	-	-	-
1.05	38.3	3.37	19.7	3.82	6.54	10.36
1.10	26.1	3.53	13.7	4.06	6.77	10.83
1.50	17.9	4.81	9.7	5.67	8.39	14.06
2.00	14.7	6.42	8.0	7.69	10.40	18.09
2.50	13.8	8.02	7.7	9.67	12.39	22.06
5.00	12.1	16.04	6.9	19.60	22.32	41.92
Infinite	10.9	Infinite	-	-	-	-

- **Minimum Reflux Ratio = 3.21**
- **Minimum Number of Stages = 10.9**

Shortcut Modeling using PRO/II



```
TITLE PROBLEM=DEWP, PROJECT=DISTILLATION, USER=JHCHO
PRINT INPUT=ALL, PERC=M, RATE=M
COMPONENT DATA
  LIBID 1, C2/2, C3/3, NC4/4, NC5/5, NC6
THERMODYNAMIC DATA
  METHOD SYSTEM=SRK
STREAM DATA
  PROP STREAM=1, TEMP=225, PRES=320, RATE=1000, &
    COMP=1, 30/2, 200/3, 370/4, 350/5, 50
UNIT OPERATION DATA
  SHORTCUT UID=S01
  FEED 1
  PROD STREAM=2, CUTP=0.3, PRES=299
  PROD STREAM=3, PRES=308
  COND TYPE=PART, TEMP=130
  EVAL MODEL=CONV, KEYL=2, KEYH=3, RRMIN=1.75
  SPEC STREAM=2, COMP=3, RATE, RATIO, STREAM=1, VALUE=0.0135
  SPEC STREAM=3, COMP=2, RATE, RATIO, STREAM=1, VALUE=0.0450
END
```

Shortcut Modeling using PRO/II



----- TOTAL STREAM RATES -----						
STREAM + PHASE		MOLES LB-MOL/HR	WEIGHT LB/HR	LIQUID VOL FT3/HR	NORM VAPOR (1) FT3/HR	NUM SECTION TRAYS
2	V	226.00	9615.25	314.56	85762.74	1 12.51
3	L	774.00	51173.86	1340.37	293720.69	
TOTALS		1000.00	60789.11	1654.93	379483.44	12.51

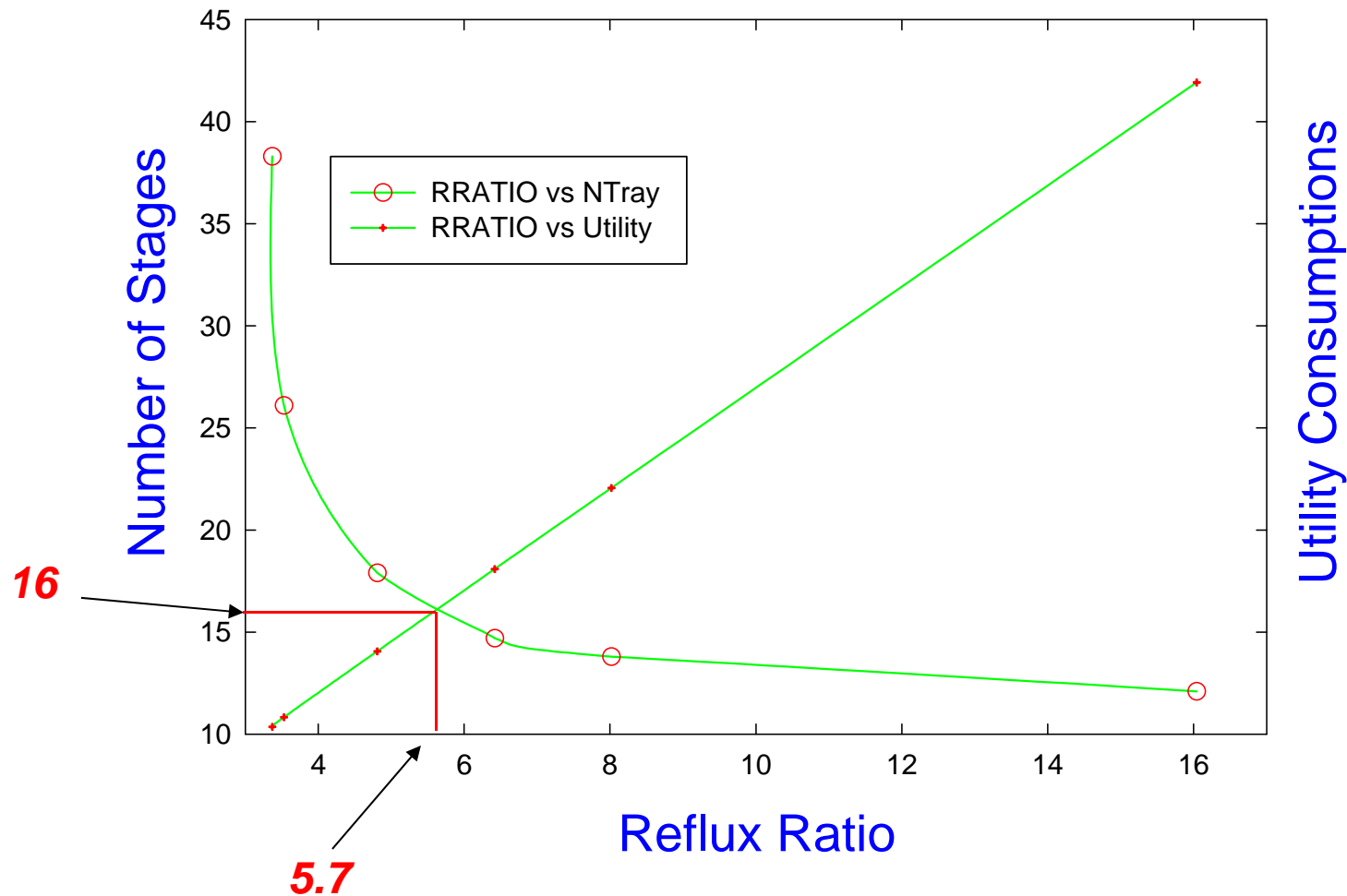
SPECIFICATIONS

PARAMETER TYPE	COMP. NUM	SPECIFICATION TYPE	SPECIFIED VALUE	CALCULATED VALUE
STRM 2	3	MOL RATIO	1.350E-02	1.350E-02
STRM 3	2	MOL RATIO	4.500E-02	4.500E-02

SUMMARY OF UNDERWOOD CALCULATIONS

MINIMUM REFLUX RATIO **2.94575**
FEED CONDITION Q **1.07172**
FENSKE MINIMUM TRAYS **12.51173**

Reflux Ratio vs. # of Stages & Utility Consumptions



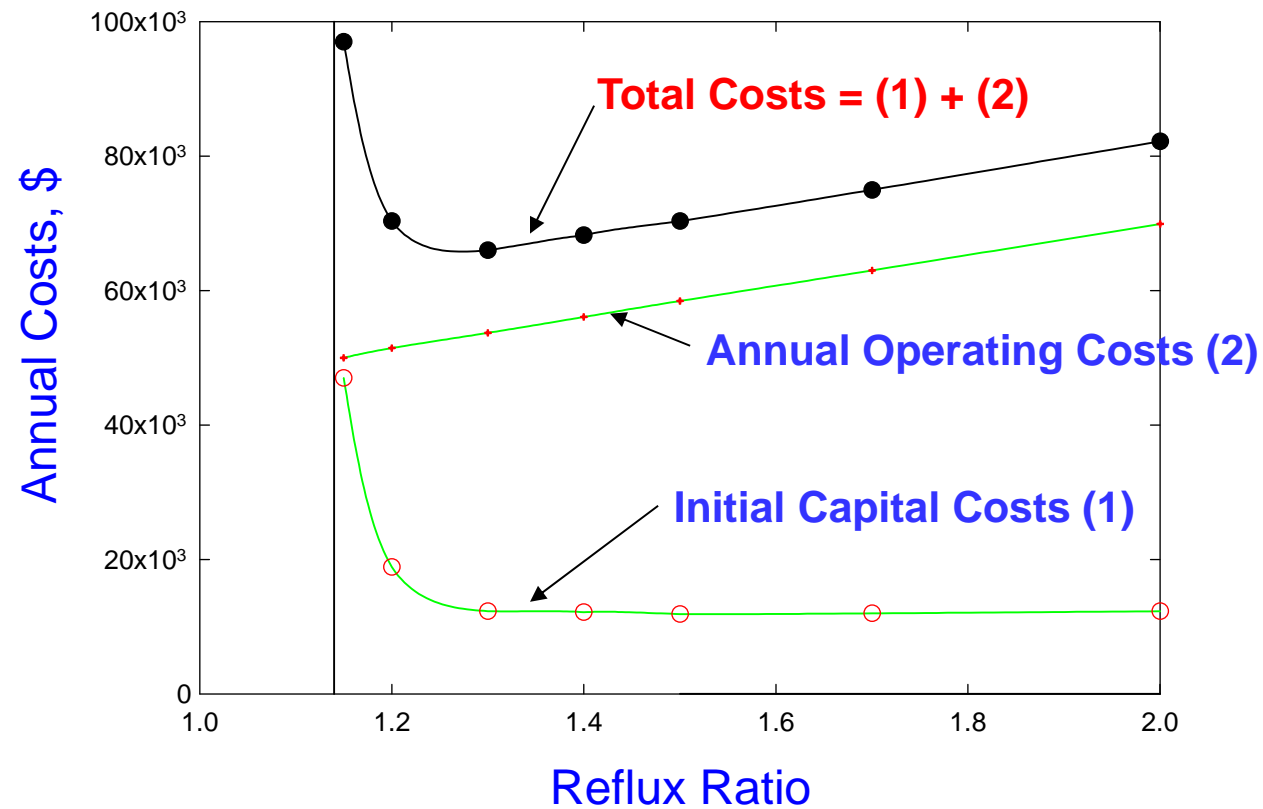
Determination of Optimum Reflux Ratio & # of Stages

Feed rate	700 lb mole/hr
Feed thermal condition	Saturated liquid
Feed composition	45 % mol benzene, 55 % mol toluene
Column pressure	1 atm
Distillate composition	92 mole % benzene
Bottoms composition	95 mole % toluene
Average cooling-water temp in condenser	90 °F
Gain in cooling-water temp in condenser	50 °F
Steam to reboiler	Saturated, at 60 psia
Max allowable vapor velocity in tower	2.5 ft/sec
Stage efficiency	70% (overall)

Determination of Optimum Reflux Ratio & Number of Stages

Reflux Ratio	No of Actual Stages	Column Diameter (feet)	Annual Cost					Total Annual Cost
			Fixed Charges			Operating		
			Column	Condenser	Reboiler	c/w	Steam	
1.14	Infinitive	6.7	\$ Inf.	\$ 1810	\$ 3960	\$ 5780	\$ 44300	\$ Infinitive
1.2	29	6.8	8930	1910	4040	5940	45500	66,320
1.3	21	7.0	6620	1950	4130	6200	47500	66,400
1.4	18	7.1	5920	2000	4240	6470	49600	68,230
1.5	16	7.3	5490	2050	4340	6740	51700	70,320
1.7	14	7.7	5290	2150	4540	7290	55700	74,970
2.0	13	8.0	5210	2280	4800	8100	61800	82,190

Total Variable Annual Cost for Benzene-toluene Distillation as a Function of Reflux Ratio



Overall Tray Efficiencies

COLUMN TYPE	TYPICAL ACTUAL TRAYS	TYPICAL EFFICIENCY, % (THEOTICAL TRAYS)
ABSORBER/STRIPPER	15 – 25	20 – 30
SIDE STRIPPER(STEAM)	4 – 6	(2)
SIDE STRIPPER(REB)	6 – 8	(3 – 4)
REBOILED ABSORBER	25 – 40	45 – 55
DEETHANIZER	30 – 35	65 – 70
DEPROPANIZER	35 – 40	70 – 80
DEBUTANIZER	38 – 45	85 – 90
NAPHTHA SPLITTER	30 – 35	70 – 75
C2 SPLITTER	110 – 130	95 – 100
C3 SPLITTER	200 – 250	95 – 100
C4 SPLITTER	70 – 80	85 – 90
AMINE CONTACTOR	20 – 24	(4 – 5)
AMINE ABSORBER	20 – 24	(9 – 12)
CRUDE COLUMN	35 – 45	ABOUT 50 – 55

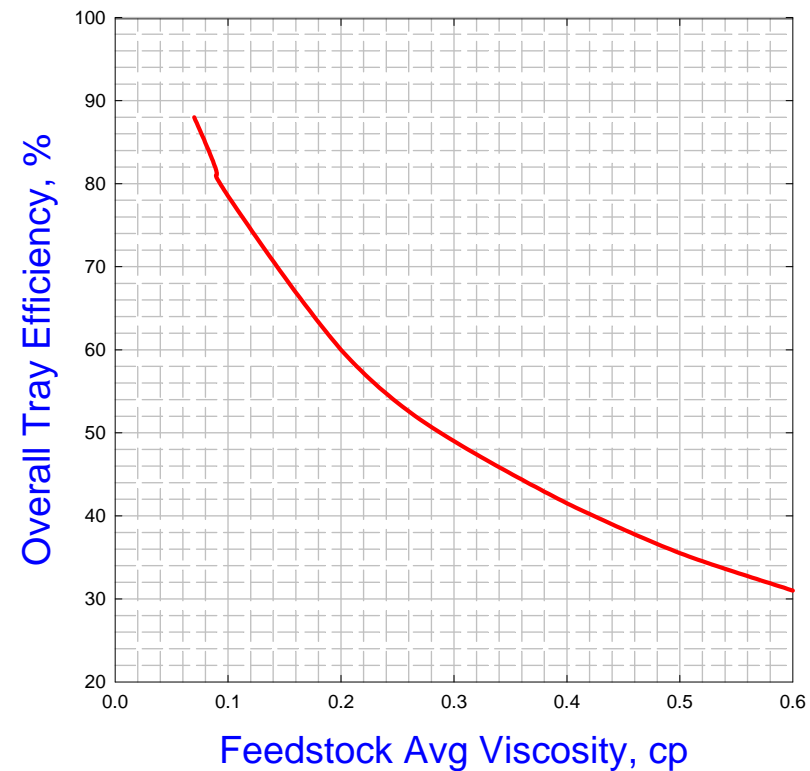
Overall Tray Efficiencies

Method of Drickamer & Bradford ¹

Notes:

- 1) Based on 54 refinery columns.
- 2) Viscosity is average of feed as liquid at top & bottom temperatures of the column.
- 3) For Absorbers, use rich oil at exit temperature.
- 4) Efficiency is for key components.

¹ Tran. Am. Inst. Chem. Engrs, 39, 319 (1943).



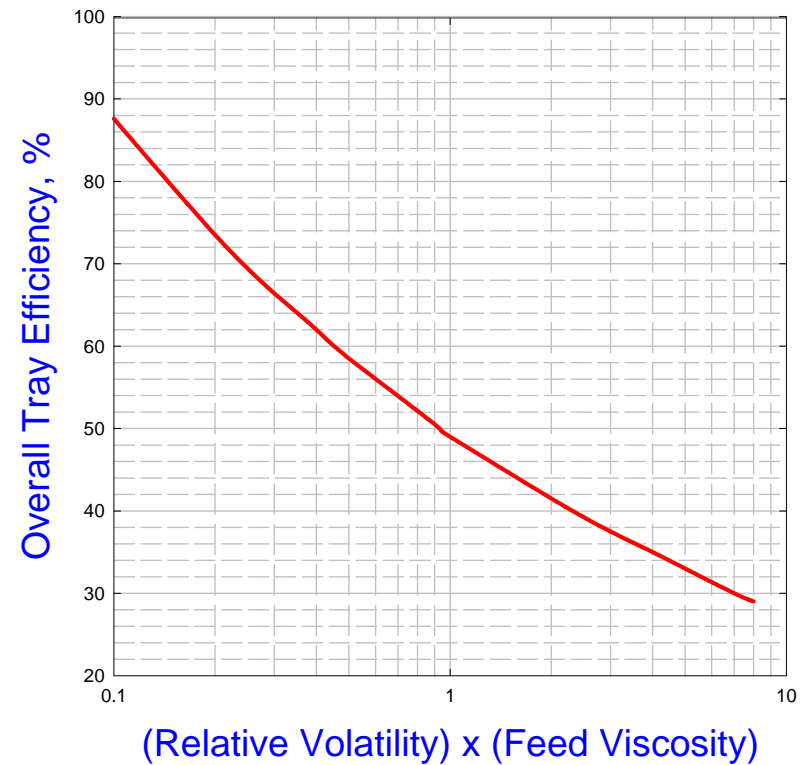
Overall Tray Efficiencies

Method of O'Connell ¹

Notes:

- 1) Evaluate alpha and viscosity columns average conditions.
- 2) Better for columns with high alphas than Drickamer et al.
- 3) O'Connell states that efficiency may be different for different components in a mixture.
- 4) Based on commercial and laboratory column data.

¹ Tran. Am. Inst. Chem. Engrs, 42, 741 (1946).



Determination of DeC3 Column Efficiency

Method I : From experience, 70 – 80% efficiency

- Typical DeC3 Column with condenser, reboiler and 40 trays
- At 75% (70 – 80%) efficiency, 30 theoretical stages
- Add stages for condenser and reboiler → 32 total

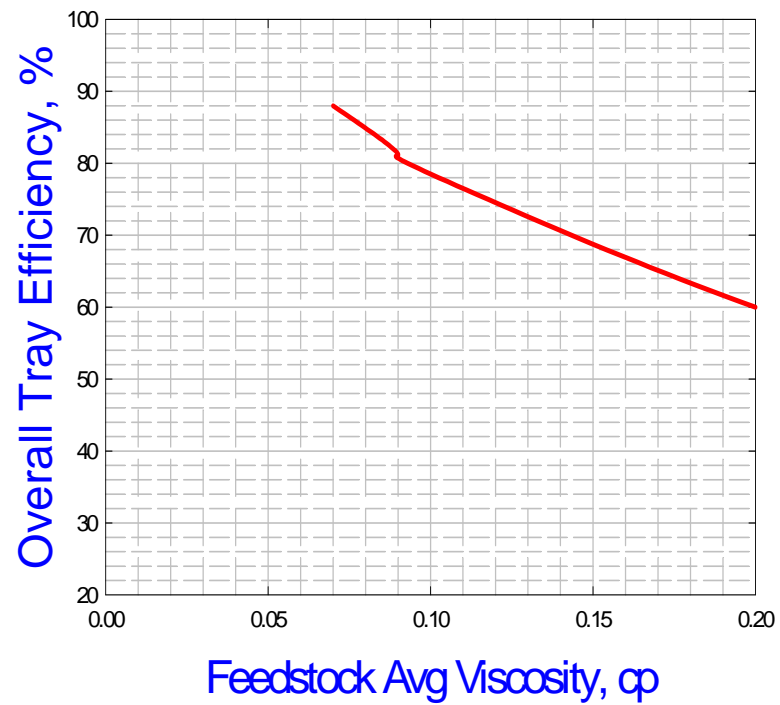
Method II : Method of Drickamer & Bradford

- Feed average viscosity is 0.09 cp, so tray efficiency is 80%.

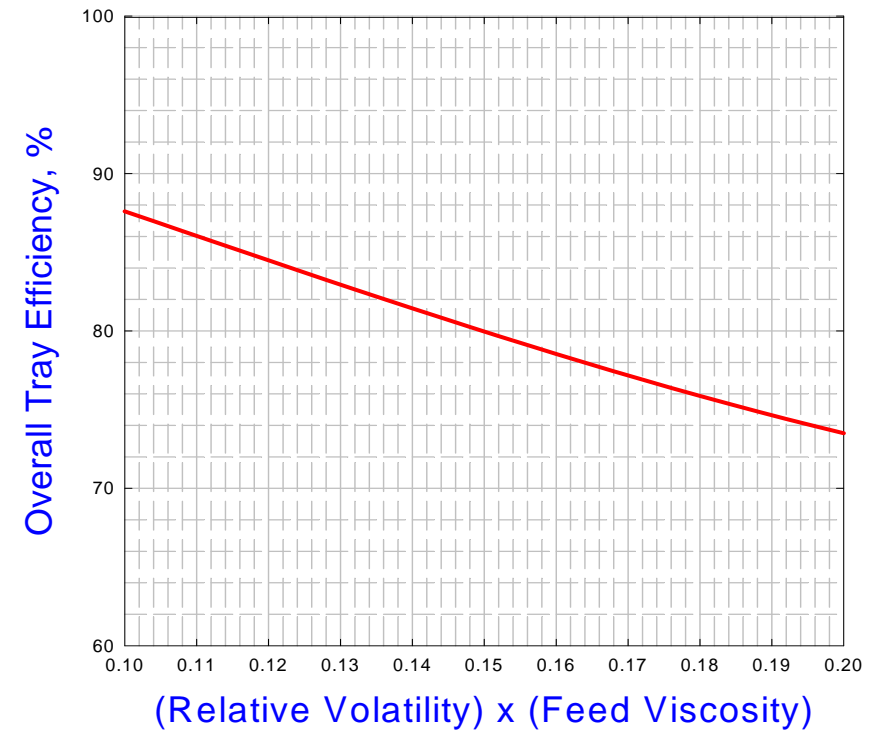
Method III : Method of O'Connell

- Relative volatility between key components is 1.95 and feed viscosity is 0.09 cp, so tray efficiency is 76%.

Method II



Method III

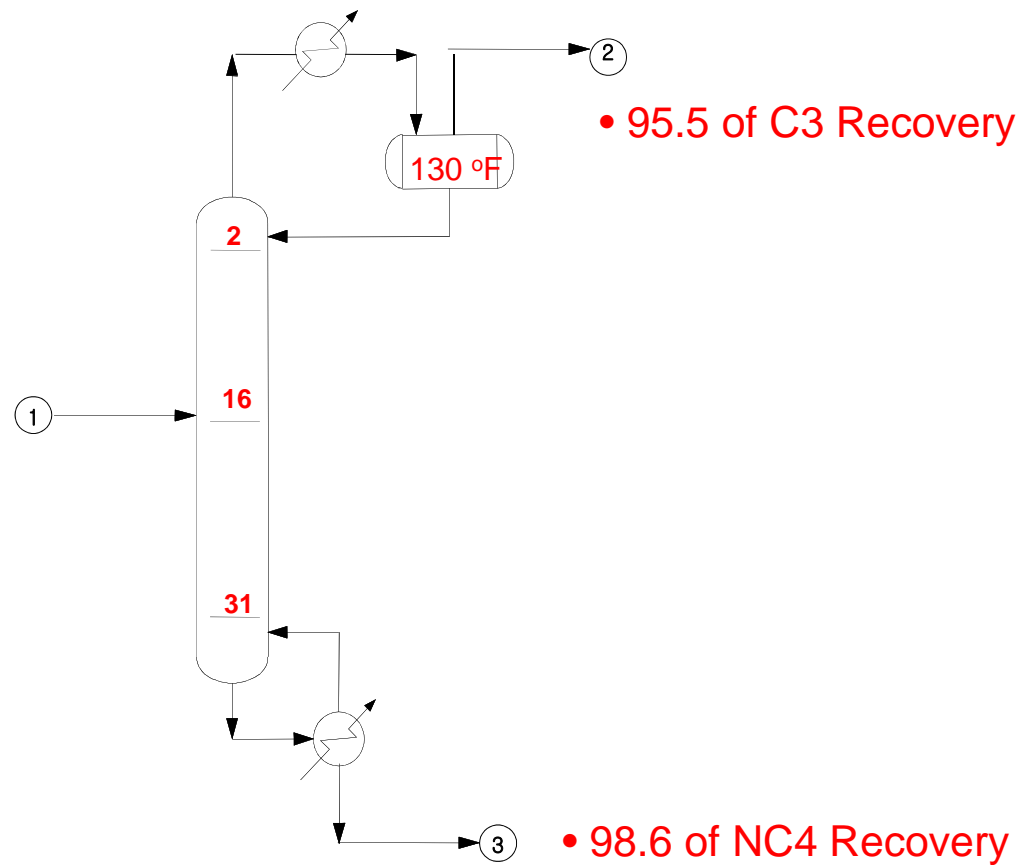


Rigorous Simulation of DeC3 Column using ASPEN PLUS & PRO/II

Feed, lbmole/hr	
C2	30
C3	200
NC4	370
NC5	350
NC6	50
Total	1000
Press.	320 psia
Temp.	225 °F

LK → **C3**

HK → **NC4**



RadFrac Modeling using ASPEN PLUS Configuration

Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) - Data Browser]

File Edit View Data Tools Run Plot Library Window Help

Grid 0.1

B1

ENG GAS

Configuration Streams Pressure Condenser Reboiler 3-P

Setup options

Number of stages: 32

Condenser: Partial-Vapor

Reboiler: Kettle

Valid phases: Vapor-Liquid

Convergence: Standard

Operating specifications

Distillate rate: Mole 230 kmol/hr

Reflux ratio: Mole 5

Free water reflux: need basis

For Help, press F1

C:\My Simulations CAP NUM Required Input Incomplete

RadFrac Modeling using ASPEN PLUS

Streams

Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) - Data Browser]

File Edit View Data Tools Run Plot Library Window Help

Grid 0.1

B1

ENGAS

Configuration Streams Pressure Condenser Reboiler 3-P

Feed streams

	Name	Stage	Convention
▶ 1		16	Above-Stage

Product streams

	Name	Stage	Phase	Basis	Flow	Unit
2		1	Vapor	Mole		MMscd
3		32	Liquid	Mole		MMscd

For Help, press F1

C:\My Simulations NUM Required Input Incomplete

RadFrac Modeling using ASPEN PLUS

Pressure

The screenshot displays the Aspen Plus Data Browser for a RadFrac column. The interface includes a menu bar (File, Edit, View, Data, Tools, Run, Plot, Library, Window, Help), a toolbar with various icons, and a main workspace. On the left, a tree view shows the column configuration options, with 'Pressure' selected. The main workspace is divided into tabs: Configuration, Streams, Pressure, Condenser, Reboiler, and 3-P. The 'Pressure' tab is active, showing the following settings:

- View: Top / Bottom
- Top stage / Condenser pressure: Stage 1 / Condenser: 299 psi
- Stage 2 pressure (optional):
 - Stage 2 pressure: [] psi
 - Condenser pressure drop: 4 psi
- Pressure drop for rest of column (optional):
 - Stage pressure drop: [] psi
 - Column pressure drop: 5 psi

At the bottom, the status bar shows 'For Help, press F1', 'C:\My Simulations', 'NUM', and 'Required Input Complete'.

RadFrac Modeling using ASPEN PLUS

Design Spec.1: Specifications

The screenshot displays the Aspen Plus software interface for a RadFrac column. The window title is "Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) Design Specs 1 - Data Browser]". The menu bar includes File, Edit, View, Data, Tools, Run, Plot, Library, Window, and Help. The toolbar contains various icons for file operations and simulation control. The left pane shows a tree view of the design specifications for block B1, with "Design Specs 1" selected. The right pane shows the "Specifications" tab, where the "Design specification" type is set to "Mole recovery" and the "Target" value is 0.955. A status bar at the bottom indicates "Required Input Incomplete".

Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) Design Specs 1 - Data Browser]

File Edit View Data Tools Run Plot Library Window Help

Grid 0.1

1

ENGAS

Specifications Components Feed/Product Streams Options

Design specification

Type: Mole recovery

Specification

Target: 0.955

Desired value of the specified variable. Units for the design specification are Type units from block units-set.

For Help, press F1

C:\My Simulations NUM Required Input Incomplete

RadFrac Modeling using ASPEN PLUS

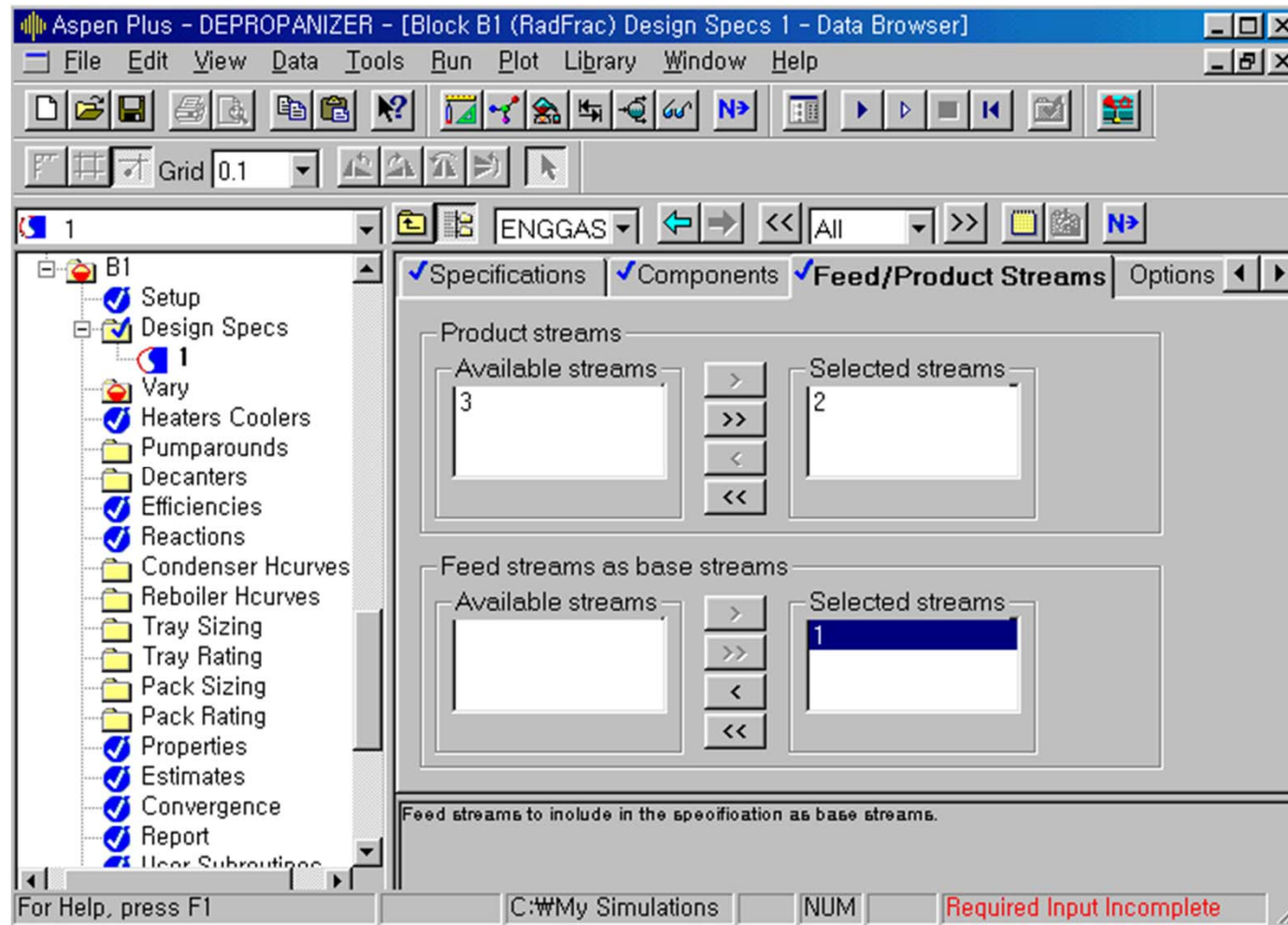
Design Spec.1: Components

The screenshot displays the Aspen Plus software interface for a RadFrac column model. The window title is "Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) Design Specs 1 - Data Browser]". The menu bar includes File, Edit, View, Data, Tools, Run, Plot, Library, Window, and Help. The toolbar contains various icons for file operations and simulation control. The main window is divided into several sections:

- Left Panel:** A tree view showing the project structure. Under "Design Specs", "1" is selected, and its sub-items include "Vary", "Heaters Coolers", "Pumparounds", "Decanters", "Efficiencies", "Reactions", "Condenser Hcurves", "Reboiler Hcurves", "Tray Sizing", "Tray Rating", "Pack Sizing", "Pack Rating", "Properties", "Estimates", "Convergence", "Report", and "User Subroutines".
- Top Panel:** A dropdown menu set to "ENGGAS" and a "Grid 0.1" indicator.
- Right Panel:** The "Design Specs 1 - Data Browser" window with the "Components" tab selected. It contains two sections:
 - Components:** A list of "Available components" (C2, NC4, NC5) and a "Selected components" list (C3). Navigation buttons (>, <, >>, <<) are present between the lists.
 - Base components:** A list of "Available components" (C2, C3, NC4) and an empty "Selected components" list. Navigation buttons (>, <, >>, <<) are present between the lists.
- Bottom Panel:** A status bar with the text "Components to include in the specification." and a red error message "Required Input Incomplete".

RadFrac Modeling using ASPEN PLUS

Design Spec.1: Feed/Product Streams



Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) Design Specs 1 - Data Browser]

File Edit View Data Tools Run Plot Library Window Help

Grid 0.1

1

ENGAS

Specifications Components **Feed/Product Streams** Options

Product streams

Available streams: 3

Selected streams: 2

Feed streams as base streams

Available streams:

Selected streams: 1

Feed streams to include in the specification as base streams.

For Help, press F1

C:\My Simulations NUM Required Input Incomplete

RadFrac Modeling using ASPEN PLUS

Vary1: Reflux Ratio

The screenshot displays the Aspen Plus interface for a simulation titled "DEPROPANIZER - [Block B1 (RadFrac) Vary 1 - Data Browser]". The "Vary" dialog box is open, showing the following configuration:

- Adjusted variable:** Type is set to "Reflux ratio".
- Upper and lower bounds:** Lower bound is 3, and Upper bound is 10.
- Optional:** Maximum step is set to 1.

At the bottom of the dialog, a note states: "Upper bound for the manipulated variable. Units for the upper bound are Type units from the block Units-Set." The status bar at the bottom indicates "C:\My Simulations", "NUM", and "Required Input Complete".

RadFrac Modeling using ASPEN PLUS

Design Spec.2: Specifications

The screenshot displays the Aspen Plus interface for a RadFrac column. The window title is "Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) Design Specs 2 - Data Browser]". The menu bar includes File, Edit, View, Data, Tools, Run, Plot, Library, Window, and Help. The toolbar contains various icons for file operations and simulation control. The left pane shows a tree view for Block B1, with "Design Specs" expanded to show "Spec 2" selected. The right pane is titled "Specifications" and shows a "Design specification" with "Type" set to "Mole recovery" and "Target" set to "0.0134". A status bar at the bottom indicates "Required Input Incomplete".

Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) Design Specs 2 - Data Browser]

File Edit View Data Tools Run Plot Library Window Help

Grid 0.1

2

ENG GAS

Specifications Components Feed/Product Streams Options

Design specification

Type: Mole recovery

Specification

Target: 0.0134

Desired value of the specified variable. Units for the design specification are Type units from block units-set.

For Help, press F1

C:\My Simulations NUM Required Input Incomplete

RadFrac Modeling using ASPEN PLUS

Design Spec.2: Components

The screenshot displays the Aspen Plus software interface for a RadFrac model. The main window title is "Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) Design Specs 2 - Data Browser]". The menu bar includes File, Edit, View, Data, Tools, Run, Plot, Library, Window, and Help. The toolbar contains various icons for file operations and simulation control. The left pane shows a tree view of the design specifications, with "Design Specs 2" selected. The right pane shows the "Components" tab of the "Design Specs 2" dialog box. The "Components" section has two sub-sections: "Components" and "Base components". Each sub-section has an "Available components" list and a "Selected components" list. In the "Components" section, the available list contains C2, C3, and NC5, and the selected list contains NC4. In the "Base components" section, the available list contains C2, C3, and NC4, and the selected list is empty. The status bar at the bottom indicates "Required Input Incomplete".

Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) Design Specs 2 - Data Browser]

File Edit View Data Tools Run Plot Library Window Help

Grid 0.1

2

ENGAS

All

Specifications Components Feed/Product Streams Options

Components

Available components Selected components

C2 C3 NC5

NC4

Base components

Available components Selected components

C2 C3 NC4

Components to include in the specification.

For Help, press F1 C:\My Simulations NUM Required Input Incomplete

RadFrac Modeling using ASPEN PLUS

Design Spec.2: Feed/Product Streams

Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) Design Specs 2 - Data Browser]

File Edit View Data Tools Run Plot Library Window Help

Grid 0.1

2

ENGAS

Specifications Components **Feed/Product Streams** Options

Product streams

Available streams: 3

Selected streams: 2

Feed streams as base streams

Available streams:

Selected streams: 1

Product streams to include in the specification.

For Help, press F1

C:\My Simulations NUM Required Input Complete

RadFrac Modeling using ASPEN PLUS

Vary 2: Distillate rate

The screenshot displays the Aspen Plus Data Browser interface for a RadFrac column. The window title is "Aspen Plus - DEPROPANIZER - [Block B1 (RadFrac) Vary 2 - Data Browser]". The menu bar includes File, Edit, View, Data, Tools, Run, Plot, Library, Window, and Help. The toolbar contains various icons for file operations and simulation control. The left pane shows a tree view with "Design Specs" expanded to "Vary", where two variables are listed: "1" and "2". The right pane is titled "Specifications" and shows the configuration for the selected variable "2".

Specifications

Adjusted variable
Type: Distillate rate

Upper and lower bounds
Lower bound: 100 kmol/hr
Upper: 900 kmol/hr

Optional
Maximum step: []

Lower bound for the manipulated variable. Units for the lower bound are Type units from the block Units=Set.

For Help, press F1 | C:\My Simulations | NUM | Required Input Complete

PRO/II Keyword Input



```
TITLE PROBLEM=DEWP,PROJECT=DISTILLATION,USER=JHCHO
PRINT INPUT=ALL,PERC=M,RATE=M
COMPONENT DATA
  LIBID 1,C2/2,C3/3,NC4/4,NC5/5,NC6
THERMODYNAMIC DATA
  METHOD SYSTEM=SRK,TRANS=PURE
STREAM DATA
  PROP STREAM=1,TEMP=225,PRES=320,RATE=1000,&
    COMP=1,30/2,200/3,370/4,350/5,50
UNIT OPERATION DATA
  COLUMN UID=T01
  PARA TRAY=32,IO=100,DAMP=0.4
  FEED 1,16
  PROD OVHD=2,230,BTMS=3
  COND TYPE=PART,PRES=299
  PSPE TOP=303,DPCOL=5
  ESTI MODEL=CONV
  DUTY 1,1/2,32
  VARY DUTY=1,2
  SPEC STREAM=2,COMP=3,RATE,RATIO,STREAM=1,VALUE=0.0135
  SPEC STREAM=3,COMP=2,RATE,RATIO,STREAM=1,VALUE=0.0450
END
```

DeC3 Column Simulation Results

	ASPEN PLUS	PRO/II
Theoretical Stage	32	32
Feed Stage	16	16
Tray Efficiency (%)	75	75
Condenser Duty (MM Btu/ Hr)	-5.1700	-5.1759
Reboiler Duty (MM Btu/ Hr)	7.8858	7.8767
Top Temperature (°F)	139.3	139.3
Bottom Temperature (°F)	273	273
Condenser Temperature (°F)	130	130
C3 Recovery at OVHD (%)	95.50	95.50
NC4 Recovery at BTMS (%)	98.65	98.65

Tray Sizing for DeC3 Column

- For tray sizing, the diameter of each tray is adjusted to meet the flooding factor criterion (ex. FF = 85).

TSIZE SECTION (1) = 2, 15, SIEVE, FF=85

TSIZE SECTION (2) = 16, 31, SIEVE, FF=85

TRAY SIZING RESULTS

TRAY	VAPOR CFS	LIQUID HOTGPM	VLOAD CFS	-- DESIGN -- DIA, IN	FF	NP
2	5.042	199.2	1.749	41.5	85.0	1
3	5.003	197.6	1.737	41.3	85.0	1
23	5.586	534.5	2.084	57.0	85.0	1
24	5.658	542.2	2.124	57.5	85.0	1

Tray Sizing for DeC3 Column

- The entire section is then re-rated at the largest required diameter.

TSIZE SECTION (1) = 2, 15, SIEVE, FF=85

TSIZE SECTION (2) = 16, 31, SIEVE, FF=85

TRAY RATING AT SELECTED DESIGN TRAYS

TRAY	VAPOR CFS	VLOAD CFS	DIAM IN	FF	NP	PRES DROP PSI
2	5.042	1.749	42.	83.4	1	.064
3	5.003	1.737	42.	82.8	1	.063
22	5.515	2.045	66.	60.3	1	.054
23	5.586	2.084	66.	61.4	1	.054



연락처

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끝