

Tray에서 Packing으로 교체를 통한 환류비 감소 및 단수 증가로 인한 에너지 절감 및 생산성 향상 효과

2017년 10월 21일(토)

공주대학교 화학공학부

조 정 호

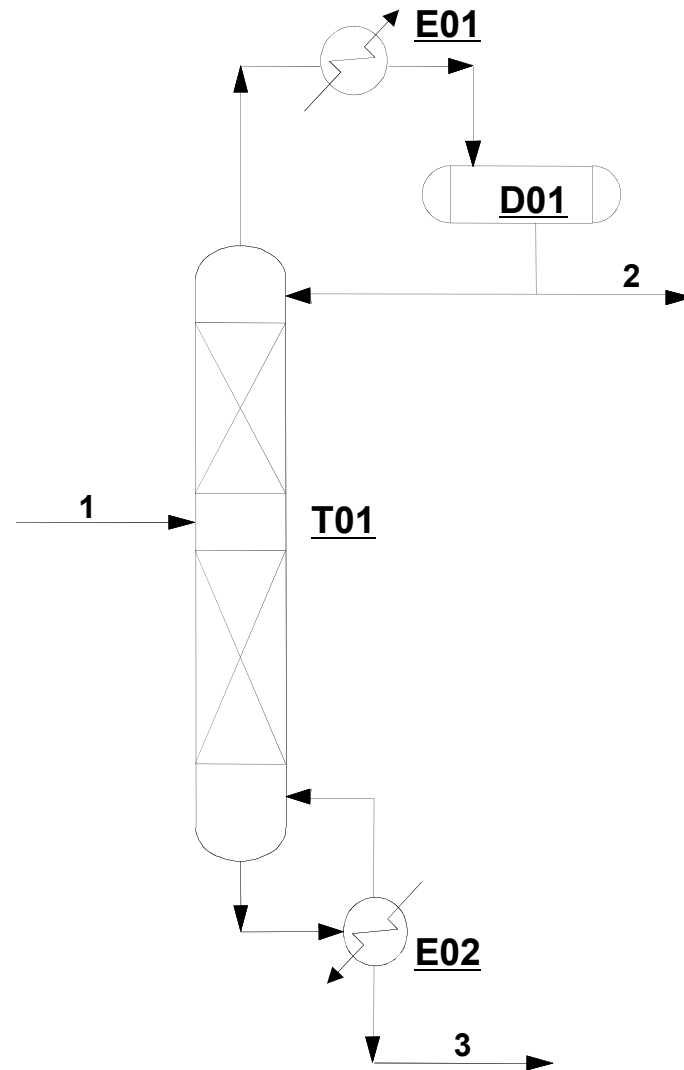
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Problem Definition

Flow Sheet for Methanol Recovery Column:



Feedstock Characterization:

➤ Feedstock compositions are as:

Feedstock Characterization		
Flow, Kg/hr	554	
	Flowrate (Kg/hr)	Flowrate (K-mole/hr)
Methanol	227	7.09
Water	227	12.62
Temperature (°C)	35.00	
Pressure (Kg/cm ² G)	< 1.0	

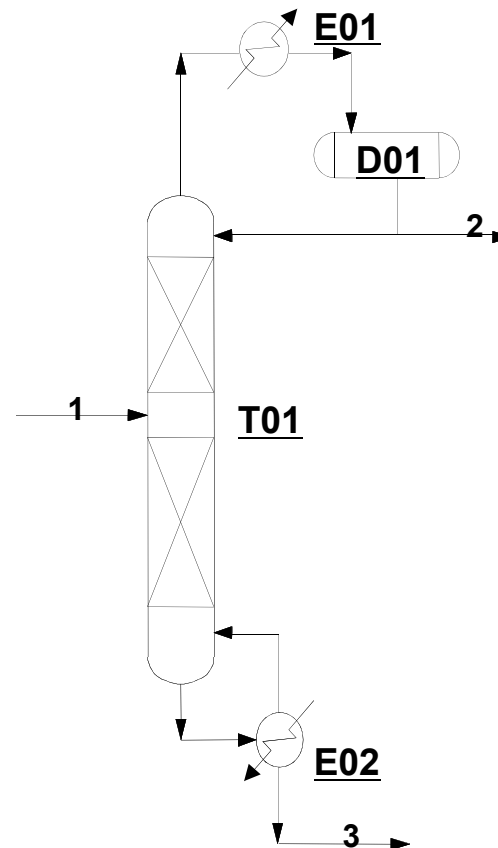
Product Specifications:

- Final target of the methanol recovery column is to recovery 98% of methanol as a column top product.
- Distilled methanol purity at column top is 99.8 % by mole.
- Methanol content at column bottom should be less than 1.0 % by mole.

Selection of Proper Thermodynamic Model:

- The objective of this column is to obtain a purified methanol product at column top and demethanolized stream as a bottom product before releasing into the environment.

Feed Characterization	
CH ₃ OH	50 wt %
Water	50 wt %
Temp.	20 °C
Press.	1.0 Kg/cm ² G



Results of Waste Water Releasing Simulation:

- Three thermodynamic models were tested with the 'Rigorous' column model for the same theoretical number of stages & reflux ratio.

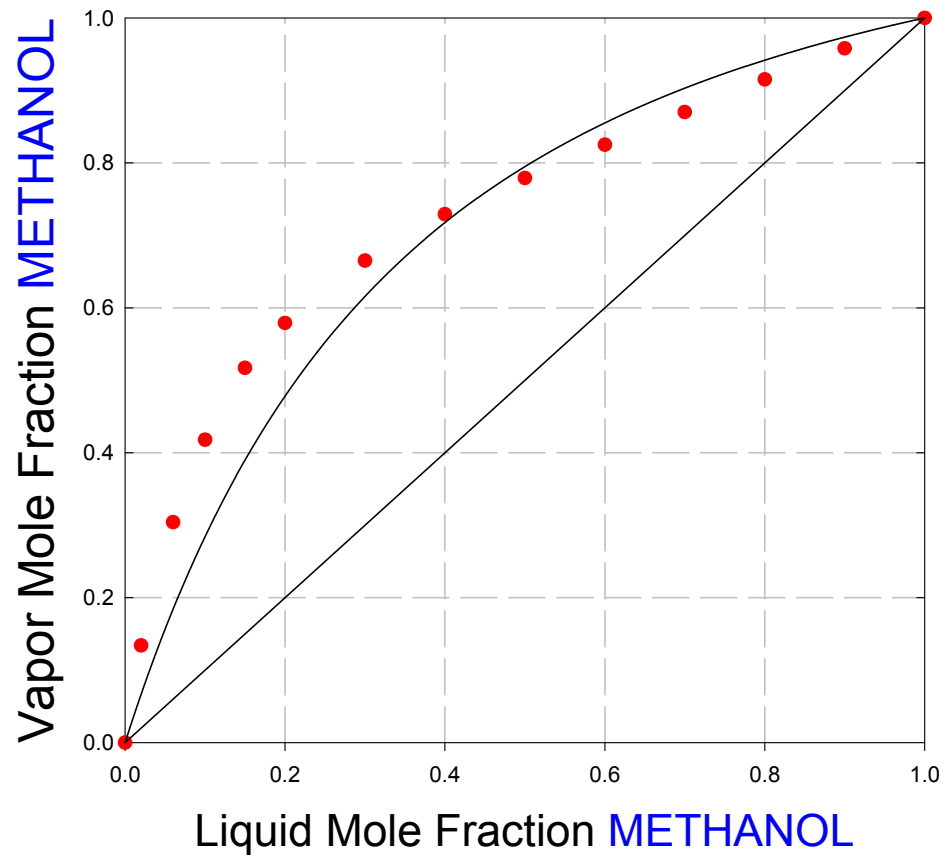
Property Model	Mole Fraction <u>Methanol in Bottoms</u>
Ideal Raoult's Law	8,000 ppm
SRK (EOS)	10 ppm
NRTL (with BIP's)	152 ppm

Q: Which thermodynamic model is most suitable for this simulation?

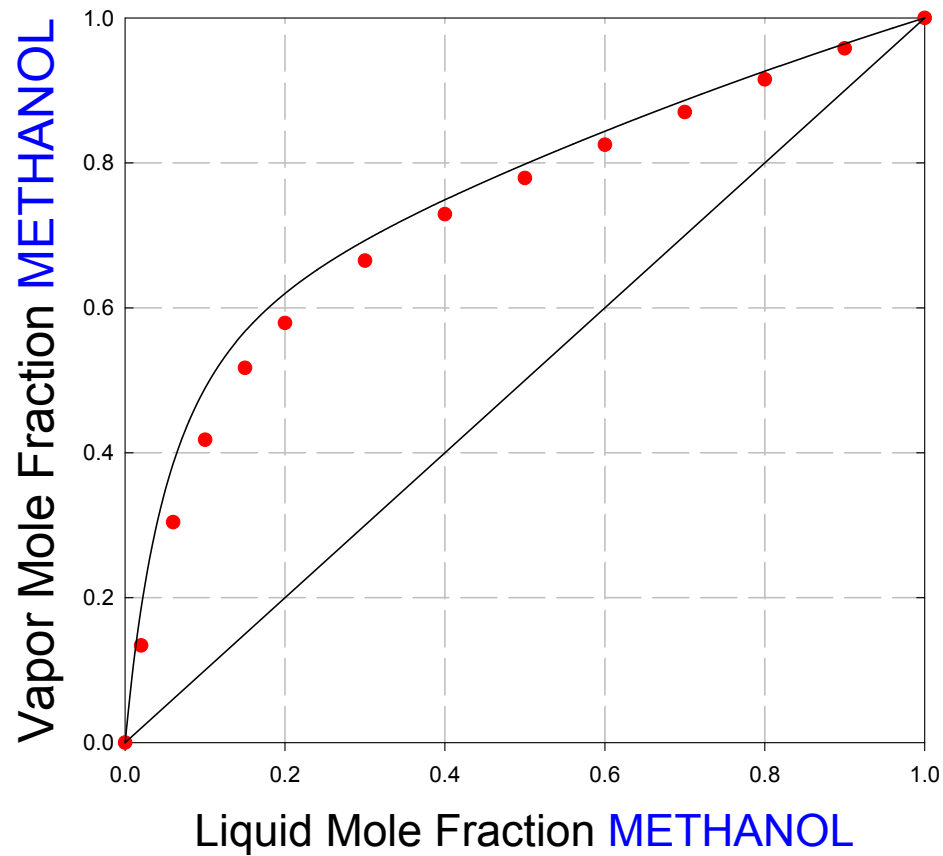
A: The best answer is NRTL !!!

Why?....

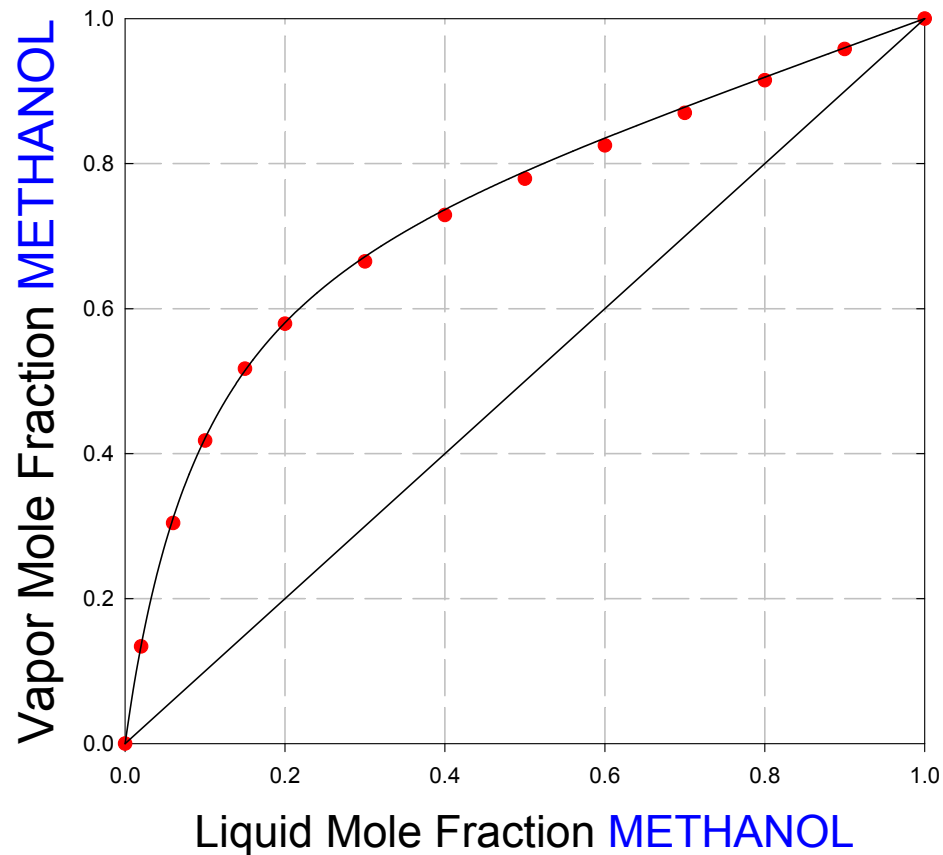
Ideal Raoult's Law:



SRK Equation of State:



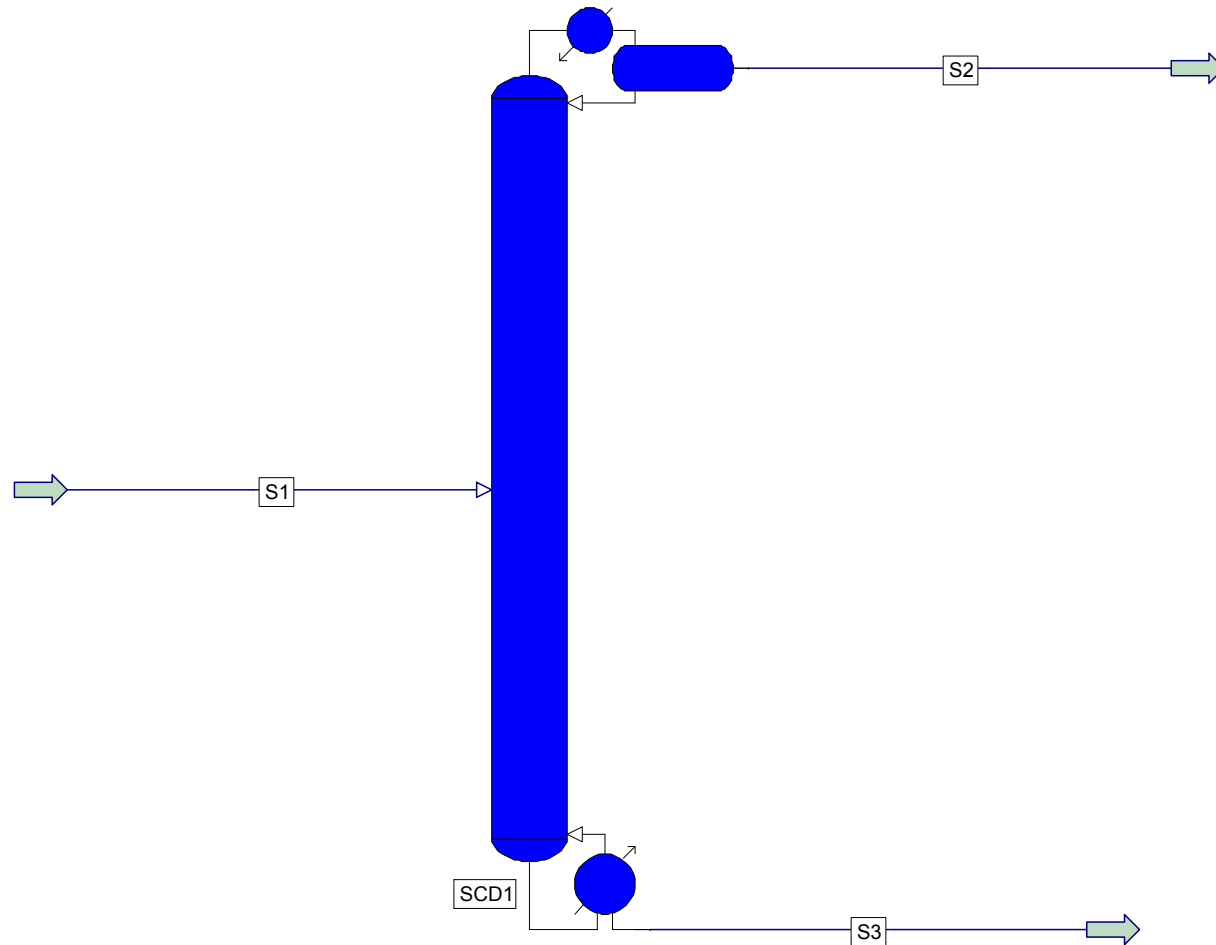
NRTL Liquid Activity Coefficient Model:



2

Shortcut Modeling

Shortcut Modeling Using PRO/II with PROVISION:



Step 1: Units of Measure

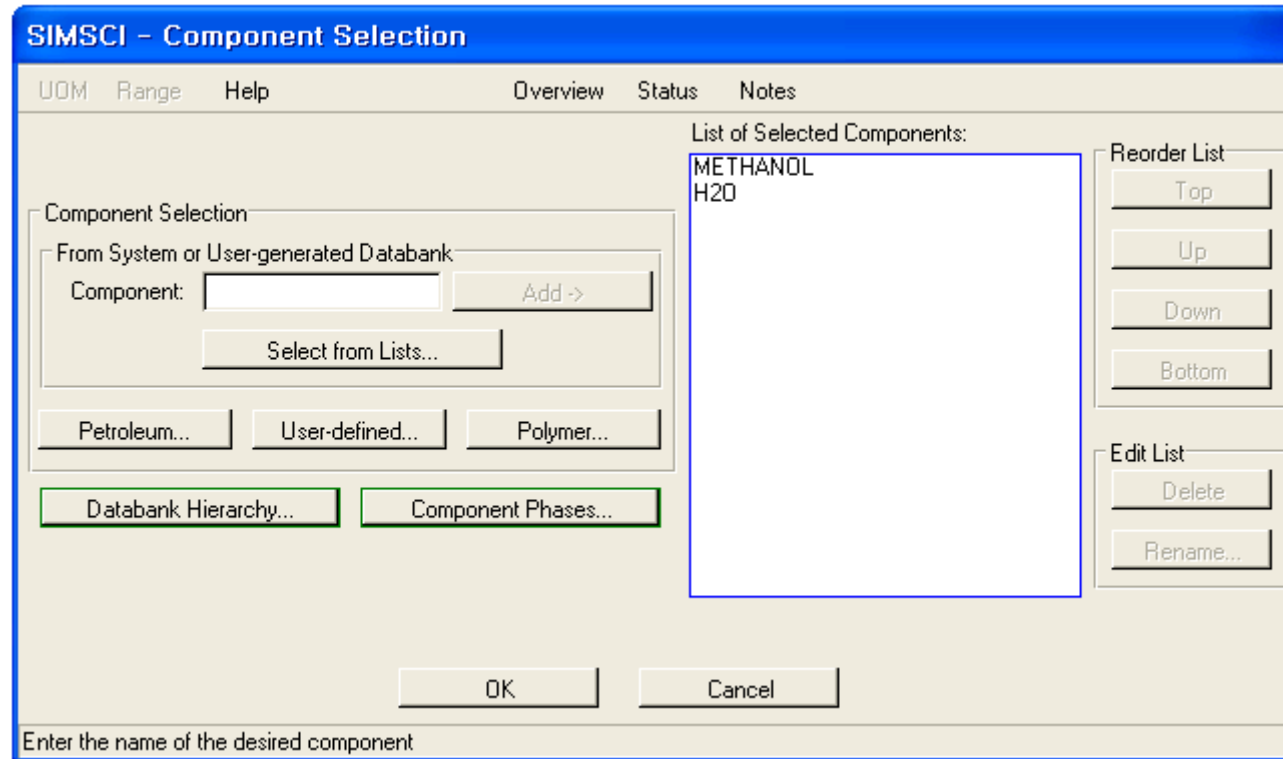
The image shows two overlapping software windows. The foreground window is titled "Initialize Units of Measure from UOM Library". It contains a warning message: "WARNING: The selected set will override all the current default units of measure". Below the warning is a dropdown menu labeled "Initialize from:" with "METRIC-SET1" selected. There are "OK" and "Cancel" buttons at the bottom. A footer note says "Choose a set from the sets defined in the UOM library".

The background window is titled "Problem Data Input". It has a button "Initialize from UOM Library..." at the top right. The main area is titled "Default Units of Measure for Problem Data Input" and contains a grid of dropdown menus for various physical properties. The units are as follows:

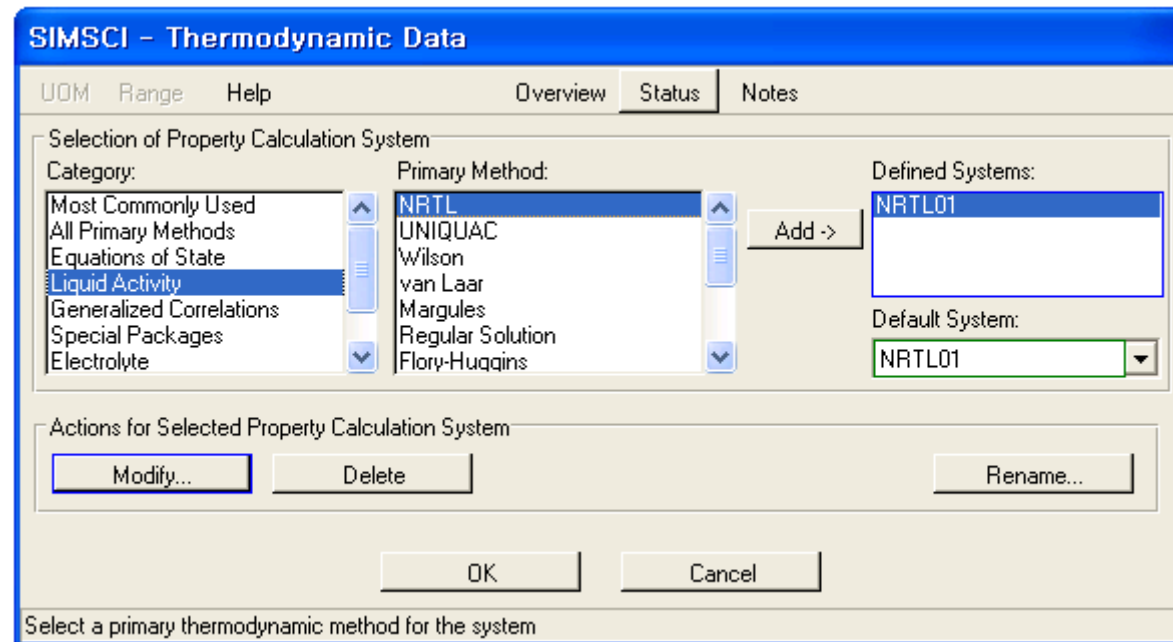
Property	Unit	Property	Unit
Temperature:	Celsius	Energy:	Kilocalorie
Pressure:	Kilogram/centimeter ²	Duty:	Energy/Time
Time:	Hour	Work:	Kilowatt
Weight (wt.):	Kilogram	Length:	Meter
Liquid Volume:	Meter ³	Fine Length:	Millimeter
Vapor Volume:	Meter ³	Heat Trans. Coefficient:	Kilocalorie/hour-m ² -K
Specific Liquid Volume:	Liquid volume/Molar wt.	Fouling Coefficient:	Hour-meter ² -C/kcal
Specific Vapor Volume:	Vapor volume/Molar wt.	Viscosity:	Centipoise
Liquid Density:	Weight/Liquid volume	Kinematic Viscosity:	Centistoke
Vapor Density:	Weight/Vapor volume	Thermal Conductivity:	Kilocalorie/hour-m-C
Petroleum Density:	same as liquid density	Surface Tension:	Dyne/centimeter

Below the grid are two buttons: "Standard Vapor Conditions..." and "TVP and RVP Conditions...". At the bottom are "OK" and "Cancel" buttons. A footer note says "Override current units of measure by units of measure defined in library".

Step 2: Component Selection



Step 3: Thermodynamic Data Selection



Step 4: Stream Data

The image shows two overlapping windows from the PRO/II software. The background window is titled "PRO/II - Stream Data" and the foreground window is titled "Stream Data - Flowrate and Composition".

PRO/II - Stream Data

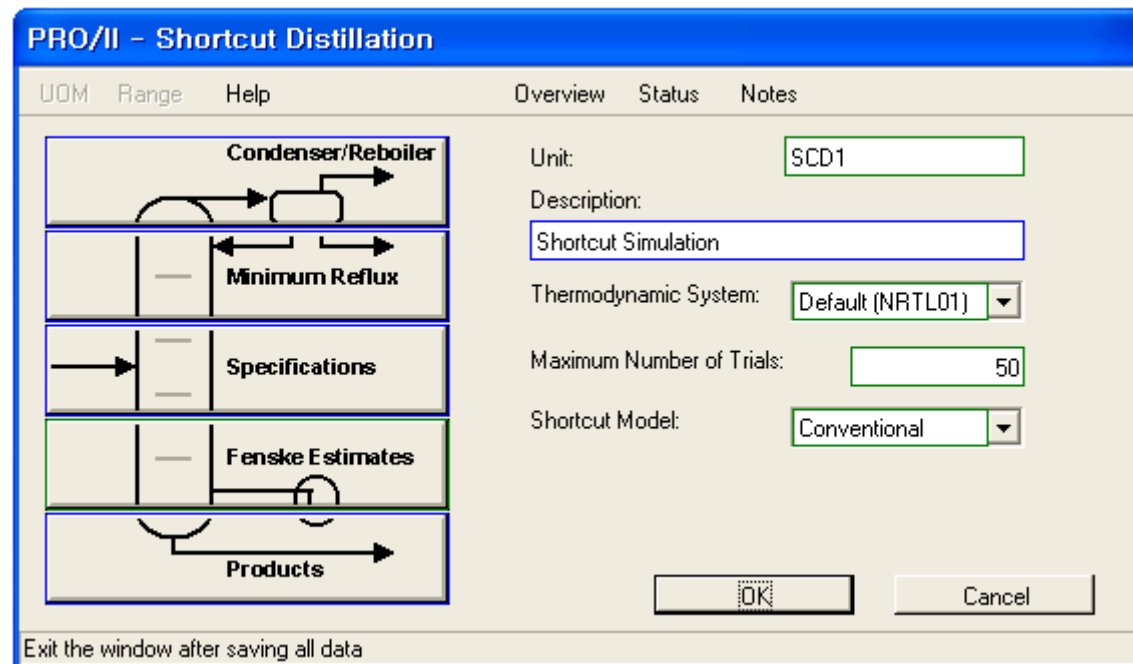
- Stream: S1
- To Unit: SCD1
- Stream Type: Composition Defined (selected), Petroleum Assay, Referenced to Stream, Solids Only Stream
- Buttons: Flowrate and Composition..., Stream Solids Data..., Stream Polymer Data...
- Thermal Condition:
 - First Specification: Temperature 20.00 C
 - Second Specification: Pressure 1.0000 at
- Thermodynamic System: Determined From Connectivity
- Buttons: OK, Cancel
- Footer: Exit the window after saving all data

Stream Data - Flowrate and Composition

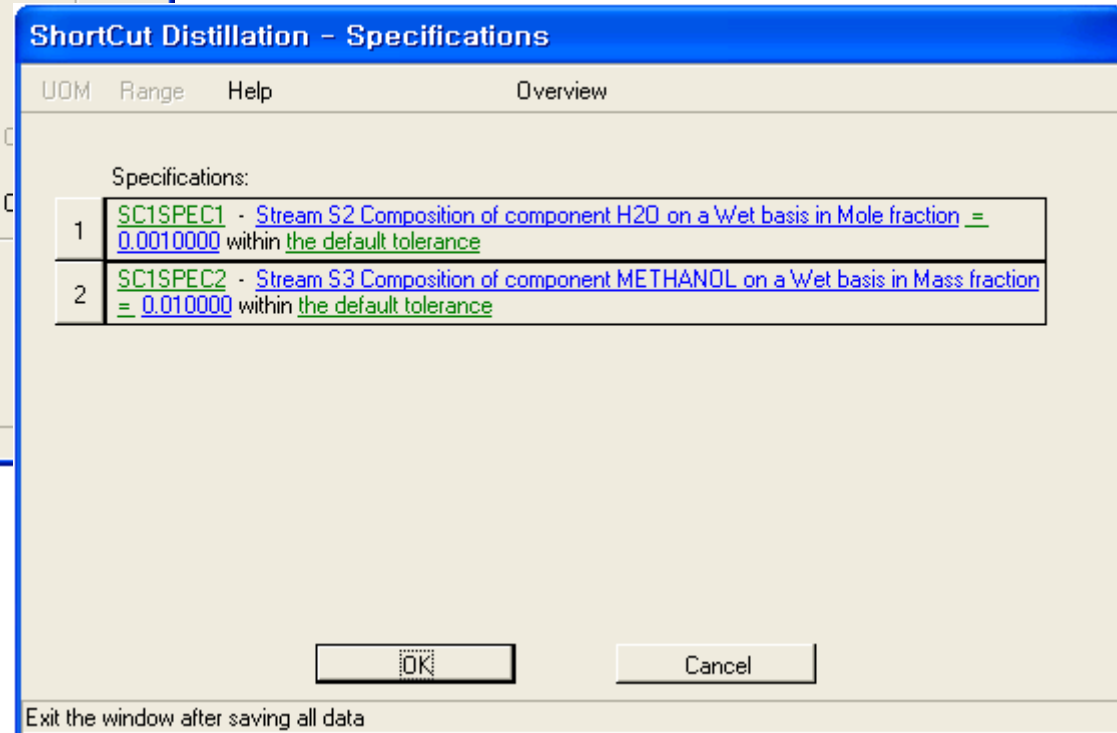
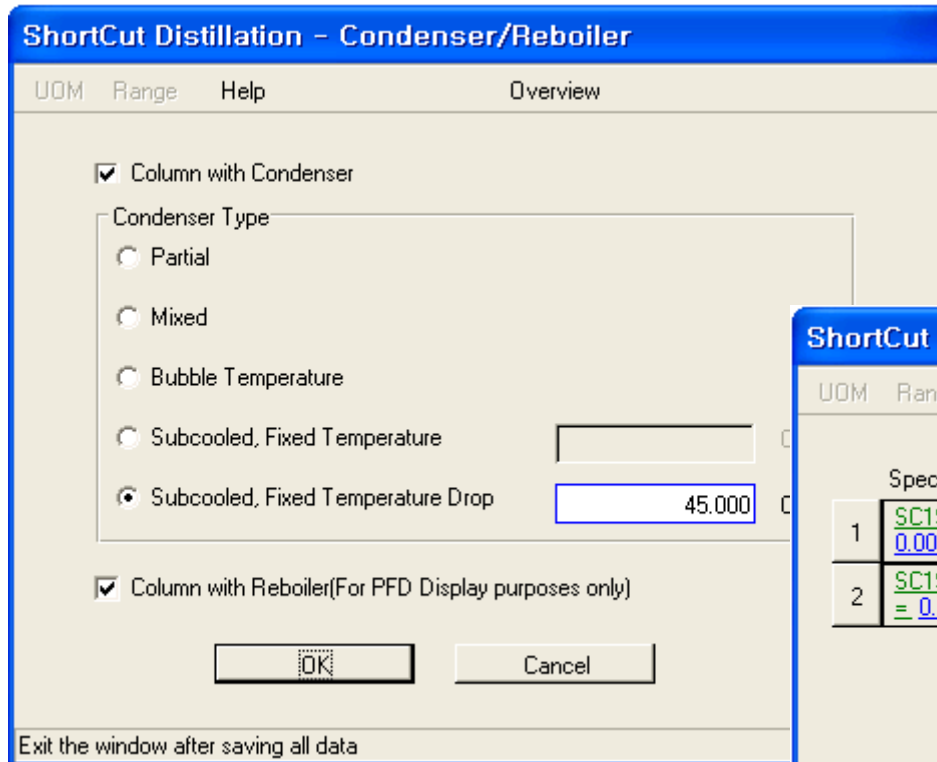
- Specify flowrate and composition for stream S1
- Fluid Flowrate Specification:
 - Total Fluid Flowrate: 454.00 kg/hr (selected)
 - Individual Component Flowrates
- Table:

Component	Composition Mass
METHANOL	227.00
H2O	227.00
- Normalize Component Flowrates Based on Specified Fluid Flowrate (checked)
- Buttons: Clear Compositions, Total: 454.00, OK, Cancel
- Footer: Exit the window after saving all data

Step 5: Shortcut Distillation



Step 5: Shortcut Distillation



PRO/II Keyword Input File for Shortcut Distillation

```
TITLE
  PRINT INPUT=ALL,RATE=M,WT,FRACTION=M,WT,PERCENT=M,WT
  DIMENSION METRIC, PRES=ATE
COMPONENT DATA
  LIBID 1,METHANOL/2,H2O
THERMODYNAMIC DATA
  METHOD SYSTEM=NRTL, TRANSPORT=PURE
STREAM DATA
  PROP STRM=S1,TEMP=20,PRES=1.0,RATE(WT)=454,COMP(WT)=1,227/2,227
UNIT OPERATIONS
  SHORTCUT UID=SCD1, NAME=Shortcut Simulation
  FEED S1
  PRODUCT STREAM=S2, RATE(WT)=227, PHASE=L, PRESSURE=0.1
  PRODUCT STREAM=S3, PHASE=L, DP=0.3
  CONDENSER TYPE=DTB, DT=45
  EVALUATE MODEL=CONV, TRIAL=50, KEYLIGHT=1, KEYHEAVY=2, RRMIN=2
  FINDEX 2
  SPEC STREAM=S2,FRACTION, COMP=2,WET, VALUE=0.001
  SPEC STREAM=S3,FRACTION(WT), COMP=1,WET, VALUE=0.01
END
```

PRO/II Output Summary for Shortcut Distillation

----- TOTAL STREAM RATES -----

STREAM + PHASE	MOLES KG-MOL/HR	WEIGHT KG/HR	LIQUID VOL M3/HR	NORM VAPOR(1) M3/HR	SECTION	NUM TRAYS
S2 L	7.02	224.84	0.28	157.35	1	7.27
S3 L	12.67	229.16	0.23	283.88		
TOTALS	19.69	454.00	0.51	441.22		<u>7.27</u>

SPECIFICATIONS

PARAMETER TYPE	COMP. NUM	SPECIFICATION TYPE	SPECIFIED VALUE	CALCULATED VALUE
STRM S2	2	MOL FRACTION	1.000E-03	1.000E-03
STRM S3	1	WT FRACTION	1.000E-02	9.998E-03

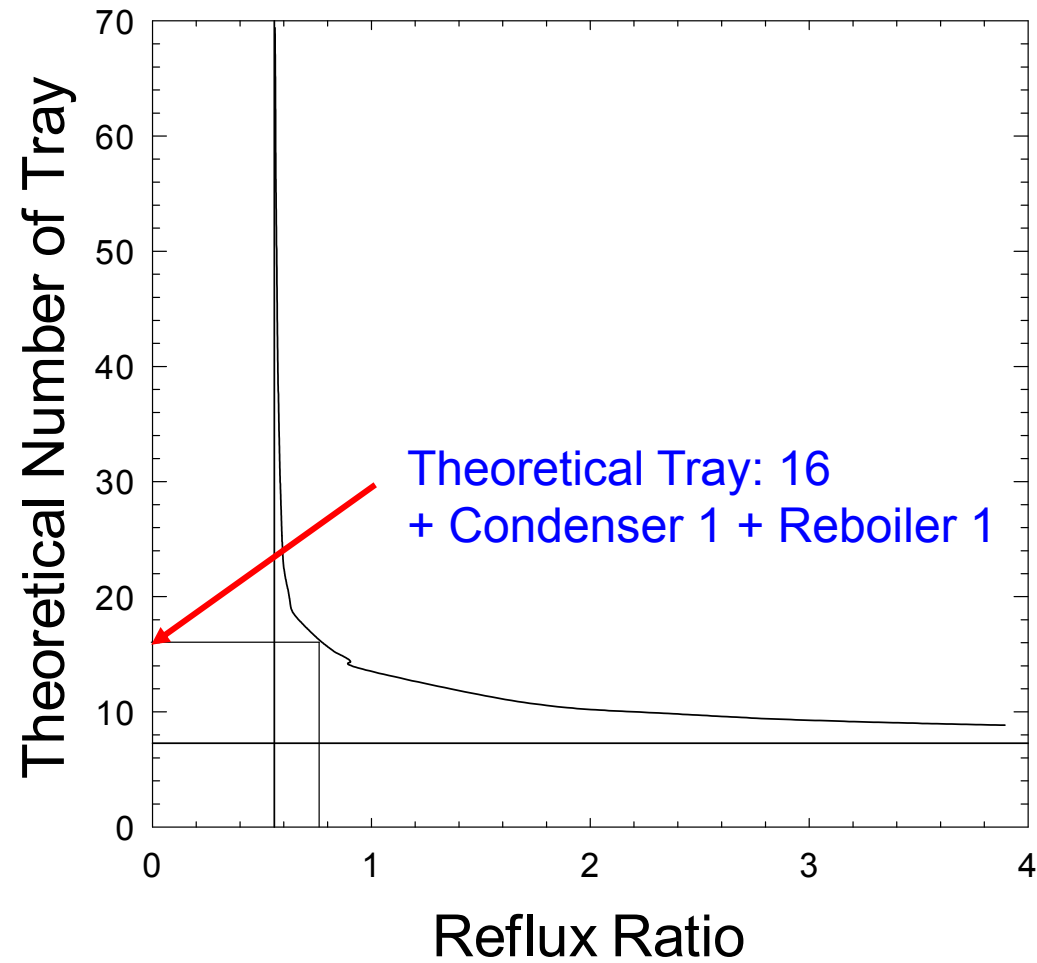
SUMMARY OF UNDERWOOD CALCULATIONS

MINIMUM REFLUX RATIO	<u>0.55642</u>
FEED CONDITION Q	1.16541
FENSKE MINIMUM TRAYS	<u>7.27097</u>

PRO/II Output Summary for Shortcut Distillation

STREAM ID	S1	S2	S3
NAME			
PHASE	LIQUID	LIQUID	LIQUID
FLUID RATES, KG-MOL/HR			
1 METHANOL	7.0845	7.0129	0.0715
2 H2O	12.6006	7.0221E-03	12.5936
TOTAL RATE, KG-MOL/HR	19.6851	7.0200	12.6651
TEMPERATURE, C	20.0000	21.9051	108.3561
PRESSURE, ATE	1.0000	0.1000	0.4000
ENTHALPY, M*KCAL/HR	7.1668E-03	2.8564E-03	0.0248
MOLECULAR WEIGHT	23.0632	32.0280	18.0942
MOLE FRAC VAPOR	0.0000	0.0000	0.0000
MOLE FRAC LIQUID	1.0000	1.0000	1.0000

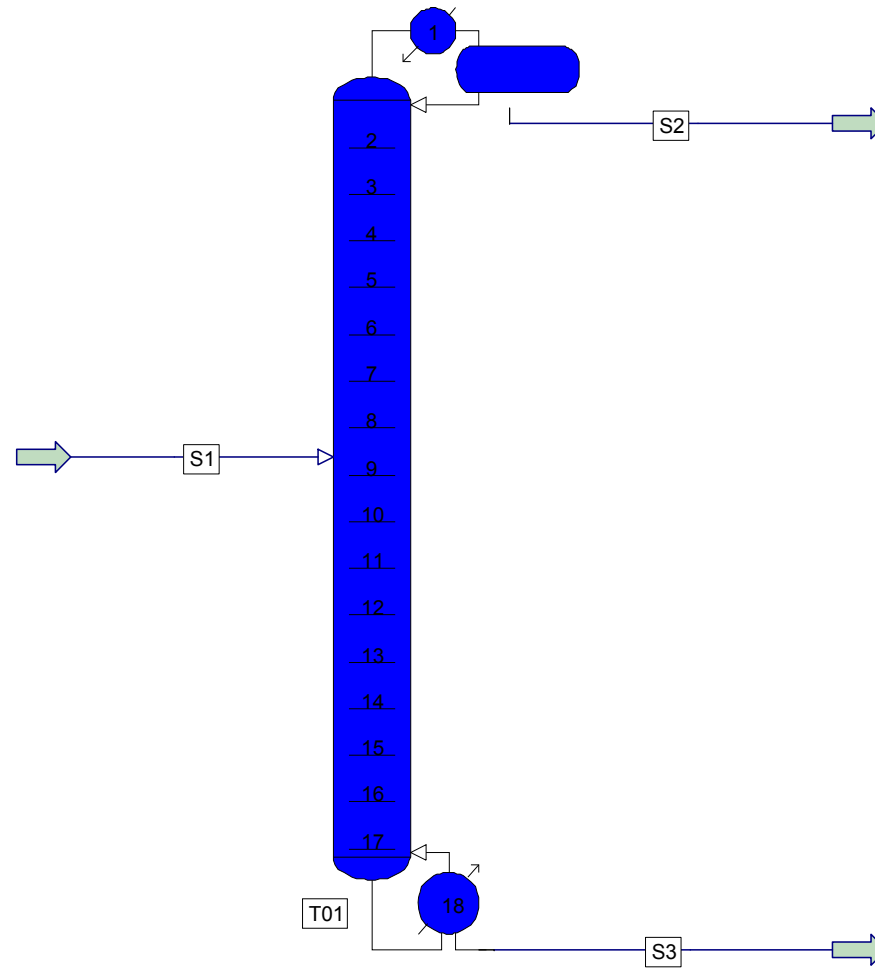
Determination of Optimum Number of Tray:



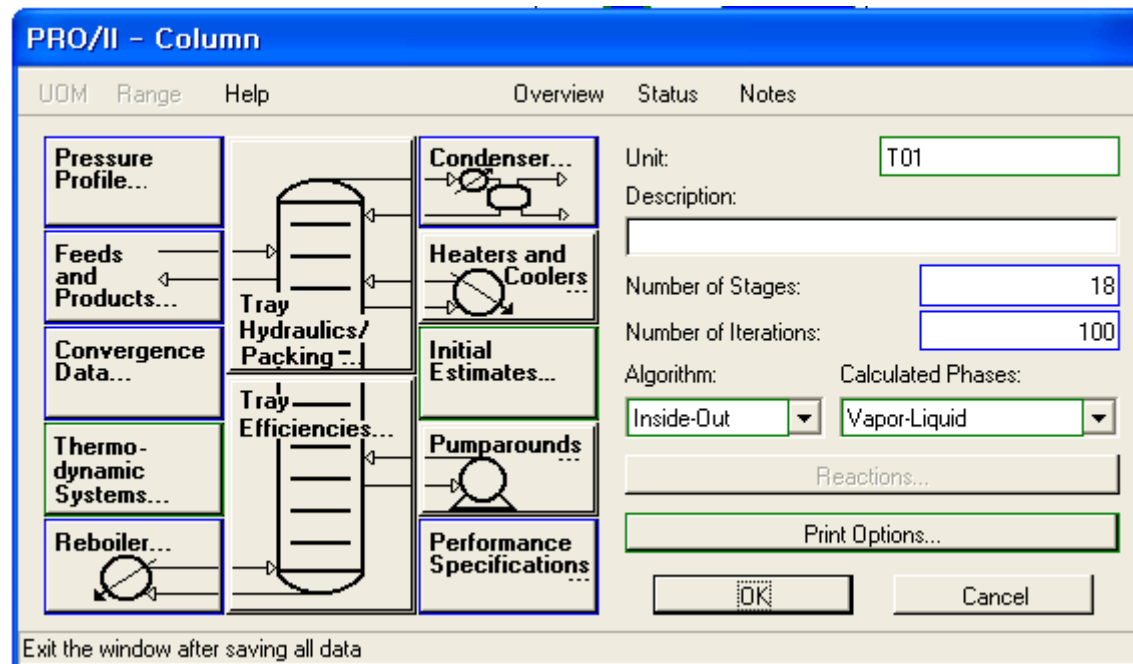
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Rigorous Modeling

Rigorous Simulation Using PRO/II with PROVISION:



Step 6: Rigorous Distillation



Step 6: Rigorous Distillation

Column - Specifications and Variables

UDM Range Help Overview

Add Specifications and Variables

Specifications:

		Active:
1	COL1SPEC1 - Stream S2 Composition of component H2O on a Wet basis in Mole fraction = 0.0010000 within the default tolerance	<input checked="" type="checkbox"/>
2	COL1SPEC2 - Stream S3 Composition of component METHANOL on a Wet basis in Mass fraction = 0.010000 within the default tolerance	<input checked="" type="checkbox"/>

Variables:

1	Column T01 Duty of Heater CONDENSER
2	Column T01 Duty of Heater REBOILER

The number of active specifications, 2 equals the number of Variables, 2

Exit the window after saving all data

PRO/II Keyword Input File for Rigorous Distillation

```
TITLE DATE=04/09/05
PRINT INPUT=ALL,RATE=M,WT,FRACTION=M,WT, PERCENT=M,WT
DIMENSION METRIC, PRES=ATE
COMPONENT DATA
LIBID 1,METHANOL/2,H2O
THERMODYNAMIC DATA
METHOD SYSTEM=NRTL,TRANSPORT=PURE
STREAM DATA
PROP STRM=S1,TEMP=20,PRES=1.0,RATE(WT)=454,COMP(WT)=1,227/2,227
UNIT OPERATIONS
COLUMN UID=T01
PARAMETER TRAY=18,IO=100 DAMPING=0.4
FEED S1,9
PRODUCT OVHD(WT)=S2,227, BTMS(M)=S3
CONDENSER TYPE=TFIX,PRESSURE=0.1,TEMPERATURE=45
DUTY 1,1,,CONDENSER/2,18,,REBOILER
PSPEC PTOP=1.2,DPCOLUMN=0.2
ESTIMATE MODEL=CONVENTIONAL,RRATIO=3
SPEC STREAM=S2,FRACTION,COMP=2,WET,VALUE=0.001
SPEC STREAM=S3,FRACTION(WT),COMP=1,WET,VALUE=0.01
VARY DUTY=1,2
REBOILER TYPE=KETTLE
END
```

Column Summary:

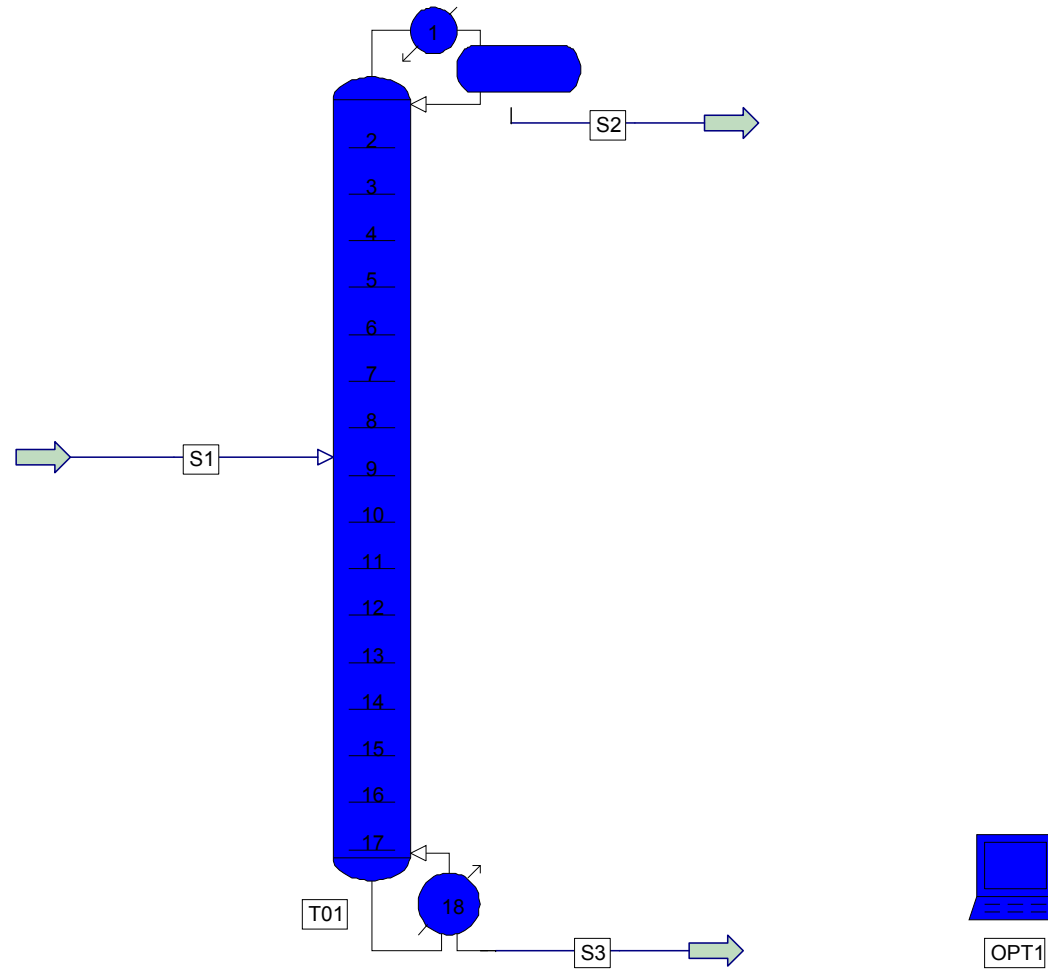
COLUMN SUMMARY

TRAY	TEMP DEG C	PRESSURE ATE	NET FLOW RATES			HEATER DUTIES M*KCAL/HR
			LIQUID	VAPOR	FEED PRODUCT	
			KG-MOL/HR			
1C	45.0	0.10	57.9		7.0L	-0.5814
2	85.5	1.20	64.2	64.9		
3	85.7	1.21	64.2	71.2		
4	85.9	1.23	64.1	71.2		
5	86.2	1.24	64.0	71.2		
6	86.6	1.25	63.9	71.1		
7	87.2	1.26	63.5	70.9		
8	88.4	1.27	62.7	70.5		
9	90.5	1.29	86.0	69.8	19.7L	
10	90.7	1.30	86.0	73.3		
11	90.9	1.31	85.9	73.3		
12	91.3	1.33	85.8	73.3		
13	92.0	1.34	85.2	73.1		
14	93.6	1.35	83.9	72.6		
15	97.8	1.36	80.9	71.3		
16	107.8	1.38	77.6	68.3		
17	119.9	1.39	77.1	64.9		
18R	124.8	1.40		64.5	12.7L	0.6088

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Finding Optimal Feed Tray Location

Finding Optimum Feed Tray Location:



Column Summary: Optimization

COLUMN SUMMARY

TRAY	TEMP DEG C	PRESSURE ATE	NET FLOW RATES			HEATER DUTIES M*KCAL/HR
			LIQUID	VAPOR	FEED PRODUCT	
			KG-MOL/HR			
1C	45.0	0.10	15.6			7.0L
2	85.5	1.20	17.3	22.6		
3	85.7	1.21	17.3	24.3		
4	85.9	1.23	17.3	24.3		
5	86.1	1.24	17.3	24.3		
6	86.4	1.25	17.3	24.3		
7	86.7	1.26	17.2	24.3		
8	87.0	1.27	17.2	24.3		
9	87.5	1.29	17.1	24.2		
10	88.2	1.30	17.0	24.1		
11	89.2	1.31	16.8	24.0		
12	90.6	1.33	16.6	23.9		
13	92.9	1.34	16.2	23.6		
14	96.6	1.35	15.7	23.2		
15	102.1	1.36	37.8	22.7	19.7L	
16	111.4	1.38	37.0	25.2		
17	120.8	1.39	37.0	24.4		
18R	124.8	1.40		24.3		12.7L
						0.2301

Material Balance: (1)

STREAM ID	S1	S2	S3
NAME			
PHASE	LIQUID	LIQUID	LIQUID
FLUID RATES, KG-MOL/HR			
1 METHANOL	7.0845	7.0129	0.0715
2 H2O	12.6006	7.0199E-03	12.5936
TOTAL RATE, KG-MOL/HR	19.6851	7.0200	12.6651
TEMPERATURE, C	20.0000	45.0000	122.1405
PRESSURE, ATE	1.0000	0.1000	1.2090
ENTHALPY, M*KCAL/HR	7.1668E-03	6.0555E-03	0.0280
MOLECULAR WEIGHT	23.0632	32.0280	18.0942
MOLE FRAC VAPOR	0.0000	0.0000	0.0000
MOLE FRAC LIQUID	1.0000	1.0000	1.0000

Material Balance: (2)

STREAM ID		S1	S2	S3
NAME				
PHASE		LIQUID	LIQUID	LIQUID
FLUID MOLAR PERCENTS				
1	METHANOL	35.9890	99.9000	0.5647
2	H2O	64.0110	0.1000	99.4353
TOTAL RATE, KG-MOL/HR		19.6851	7.0200	12.6651
TEMPERATURE, C		20.0000	45.0000	122.1405
PRESSURE, ATE		1.0000	0.1000	1.2090
ENTHALPY, M*KCAL/HR		7.1668E-03	6.0555E-03	0.0280
MOLECULAR WEIGHT		23.0632	32.0280	18.0942
MOLE FRAC VAPOR		0.0000	0.0000	0.0000
MOLE FRAC LIQUID		1.0000	1.0000	1.0000

5

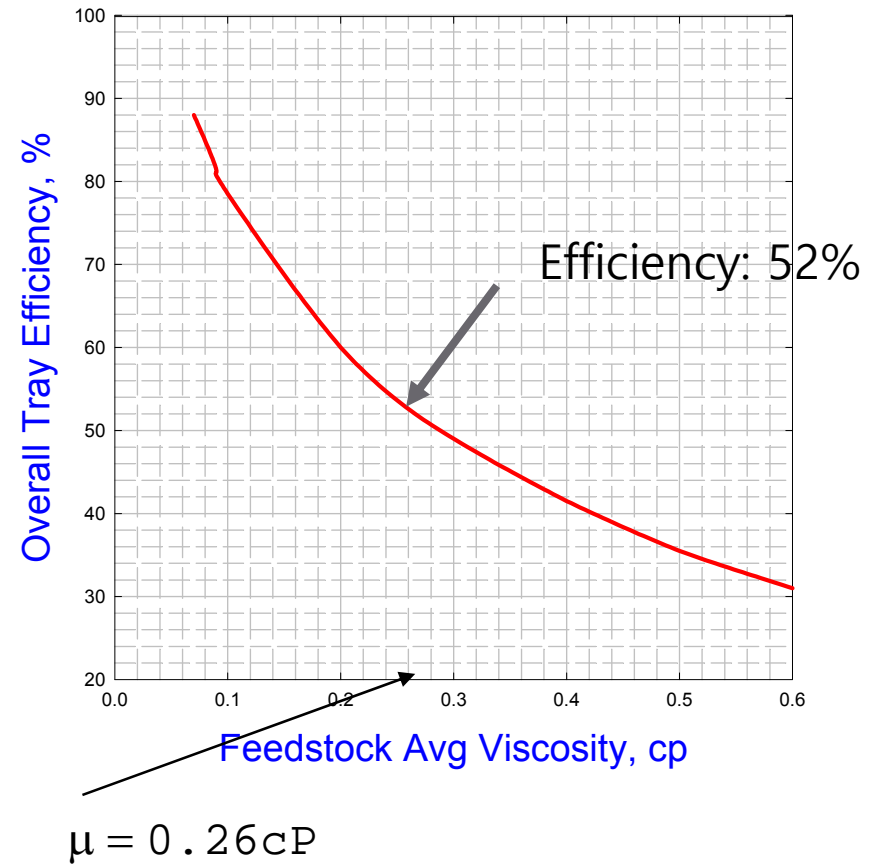
Valve Tray Sizing

Overall Tray Efficiency:

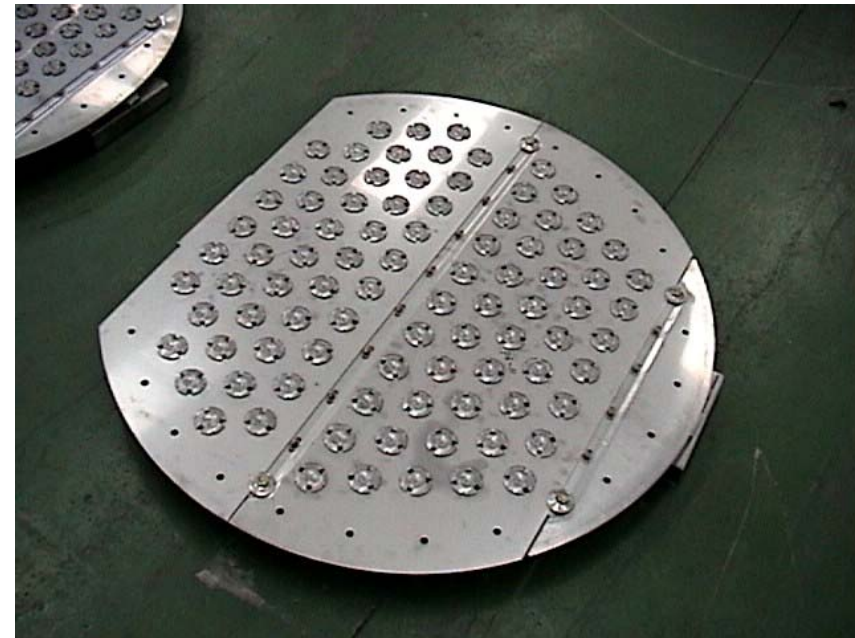
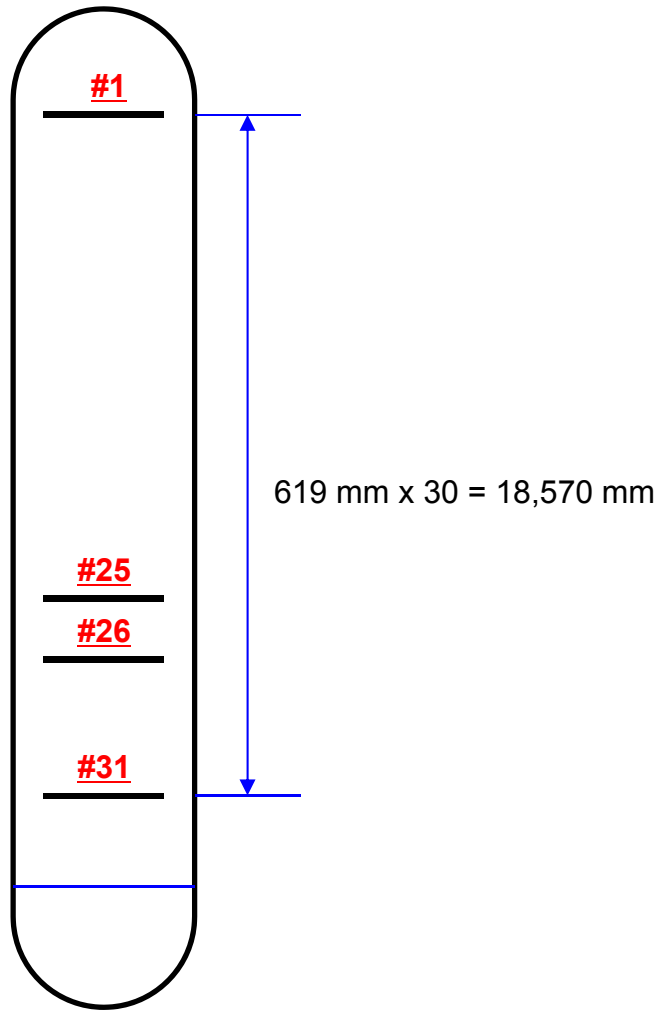
Notes:

- 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).



Valve Tray Sizing:



Valve Tray

6

Packing을 적용한 Simulation

Revamping of Tray into Packing:

➤ Revamping of Trays into Packing Type:

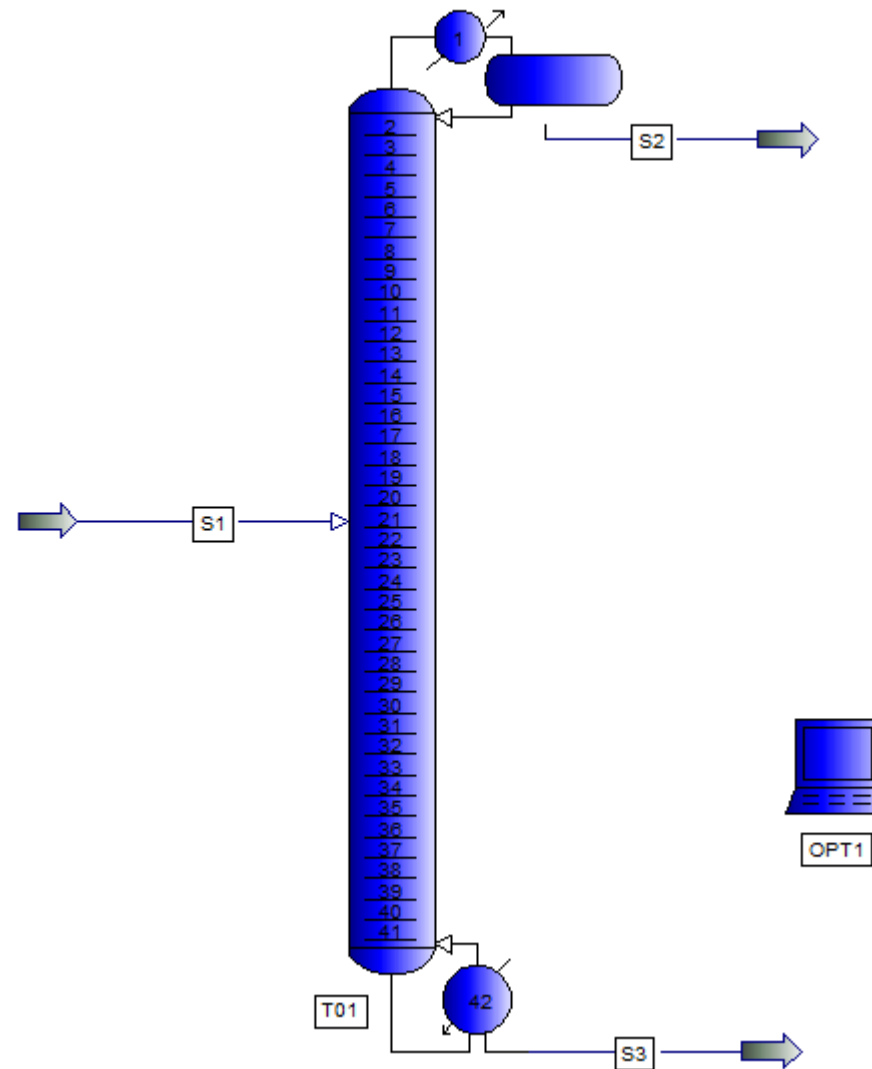
- Tray type은 기본적으로 downcomer(Liquid가 column 하부로 내려가는 길) 부분이 있어서 용량에 제한을 받는다.
- 이것을 Packing type으로 변경하면, downcomer가 없기 때문에 처리 용량이 늘어난다.
- Tray의 경우 한단 사이의 간격인 Tray spacing이 460mm~610mm 인데, Packing의 경우에는 이론단수 한 단에 해당하는 실제 Packing height인 HETP가 200 ~ 450mm (여기에서는 350 mm 적용)정도이므로, Tray에서 Packing으로 교체하면 기존 Column에 대해서 단수 증가효과가 있기 때문에 환류비 감소로 인한 에너지 절감효과를 얻을 수 있다.
- Sieve tray보다 Packing material이 가격이 비싸긴 하지만 동일한 중량 대비는 유사하다.
- 에너지 절감효과는 10~30% 정도를 얻을 수 있으므로, 투자회수기간은 4개월에서 1년 이내에 거둘 수 있다.

Revamping of Tray into Packing:

Packing으로 변경할 경우에 이론단수 40단 + 2단(응축기 + 재비기) 적용 가능



Rigorous Simulation: Packing 이론단수 적용



Column Summary: Optimization

COLUMN SUMMARY

TRAY	TEMP DEG C	PRESSURE ATE	NET FLOW RATES			HEATER DUTIES M*KCAL/HR
			LIQUID	VAPOR	FEED PRODUCT	
			KG/HR			
1C	45.0	0.10	234.3			224.8L
2	85.5	1.20	259.7	459.2		
3	85.6	1.21	259.5	484.5		
4	85.6	1.21	259.3	484.3		
27	91.4	1.32	218.0	448.3		
28	92.2	1.33	211.8	442.8		
29	93.1	1.33	205.0	436.7		
30	94.1	1.34	197.7	429.9		
31	95.3	1.34	190.0	422.5		
32	96.5	1.35	182.3	414.8		
33	97.8	1.35	737.1	407.2	454.0L	
34	97.9	1.36	736.7	507.9		
35	98.0	1.36	735.2	507.5		
36	98.2	1.37	730.8	506.1		
37	98.9	1.37	717.9	501.6		
38	100.6	1.38	684.3	488.8		
39	105.2	1.38	620.1	455.1		
40	113.7	1.39	559.1	390.9		
41	121.4	1.39	533.5	330.0		
42R	124.8	1.40		304.3		229.2L
						<u>0.1553</u>

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Conclusions

Revamping of Tray into Packing:

➤ 물-메탄올 분리탑에 적용해 본 결과:

- 초기에 재비기의 heat duty가 0.6088×10^6 kcal/h 이었으나, 원료 주입단의 위치를 최적화하여 0.2301×10^6 kcal/h 로 줄였으며, 다시 Valve tray에서 Structured Packing으로 변경함으로써 0.1553×10^6 kcal/h 까지 줄일 수 있었다.



THANK YOU

