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

2017년 10월 21일(토)

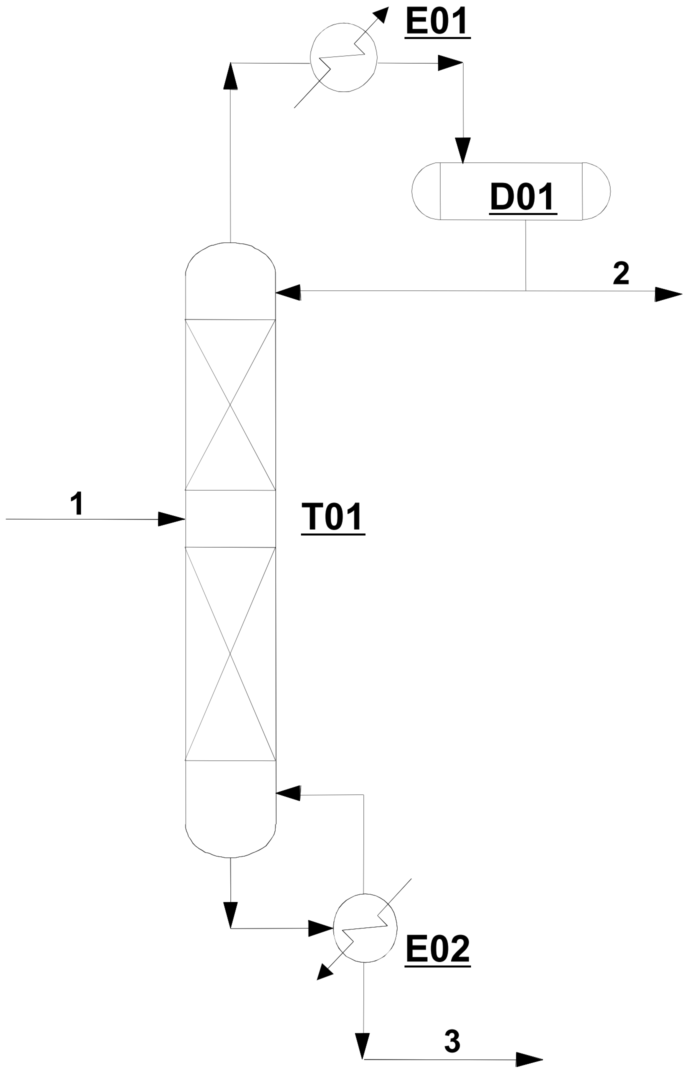
공주대학교 화학공학부

조 정 호

CONTENTS

1 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 (^{o}C)	35.00	
Pressure (Kg/cm^2G)	< 1.0	

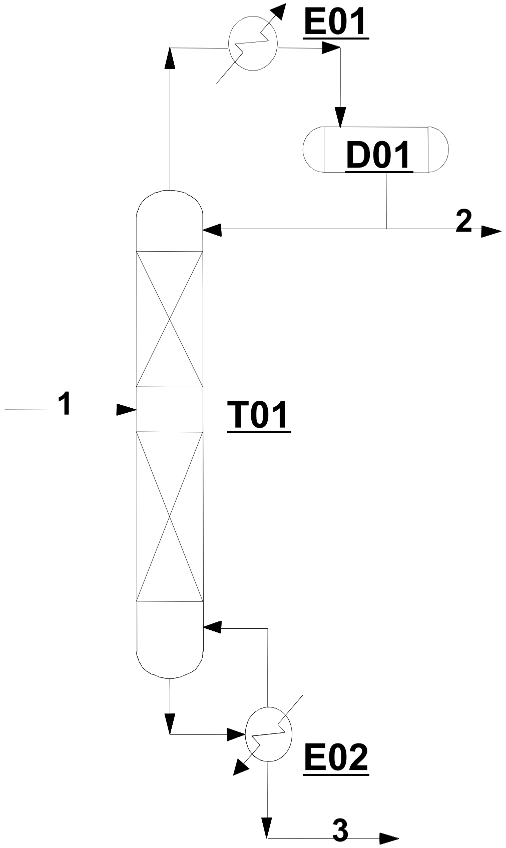
Product Specifications:

- 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	
CH3OH	50 wt %
Water	50 wt %
Temp.	20 °C
Press.	1.0 Kg/cm²G



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.

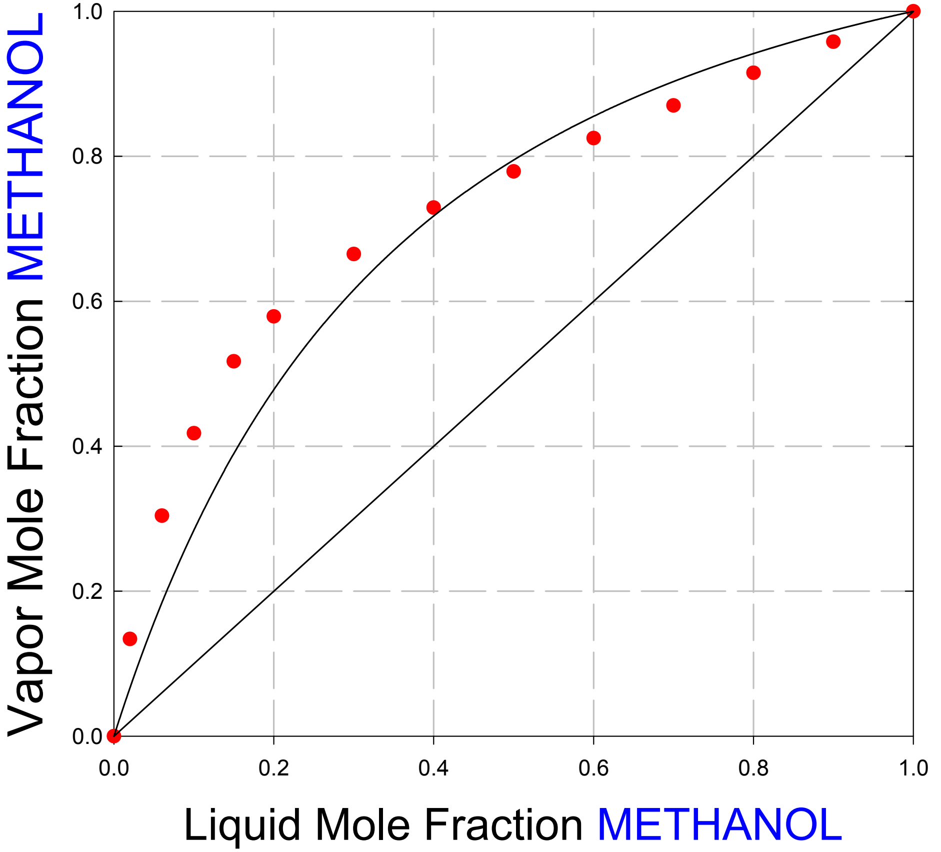
Property Model	Mole Fraction Methanol in Bottoms
Ideal Raoult's Law	8,000 ppm
SRK (EOS)	10 ppm
NRTL (with BIP's)	152 ppm

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

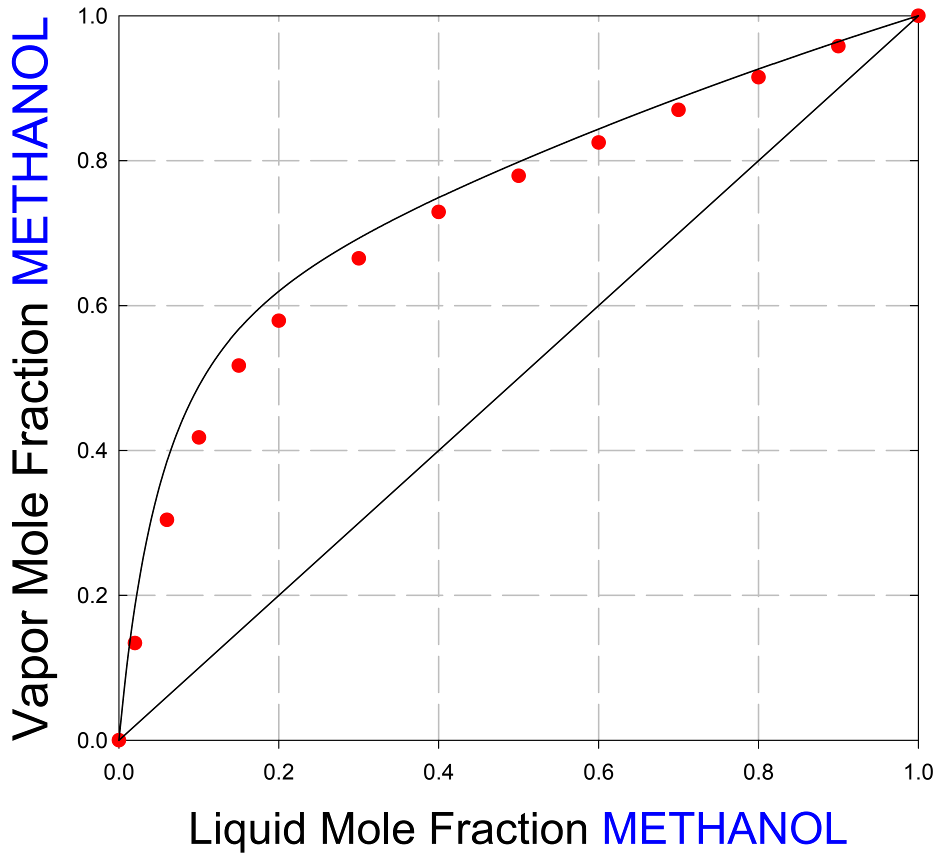
A: The best answer is NRTL !!!

Why?….

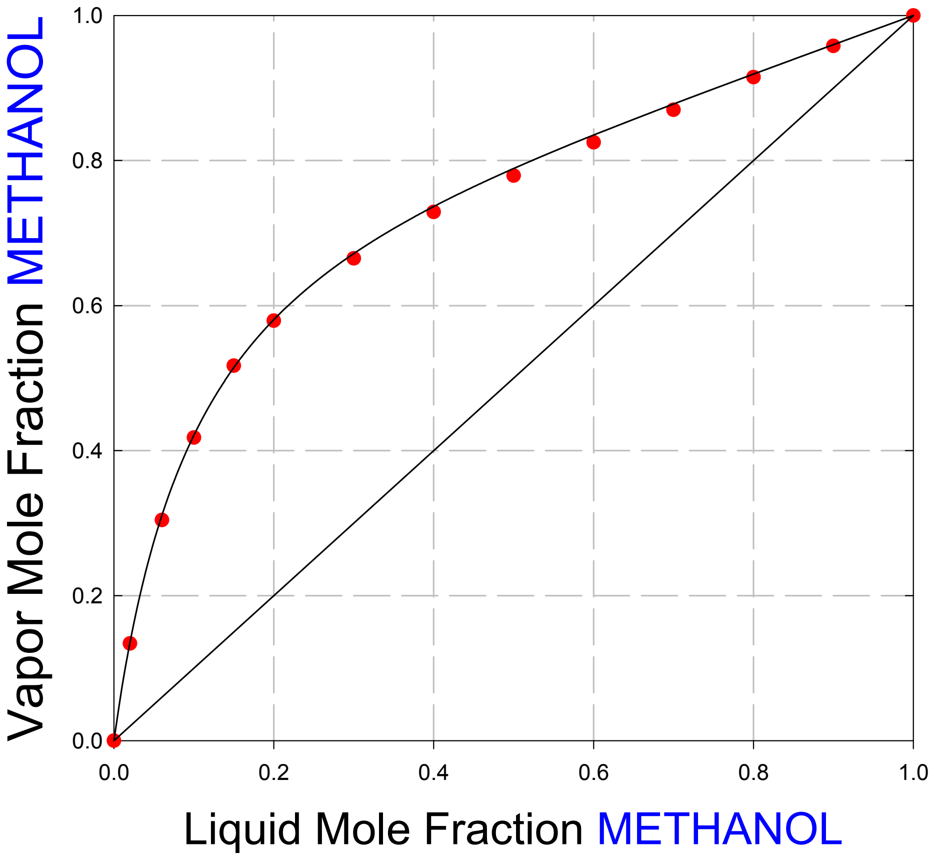
Ideal Raoult's Law:



SRK Equation of State:

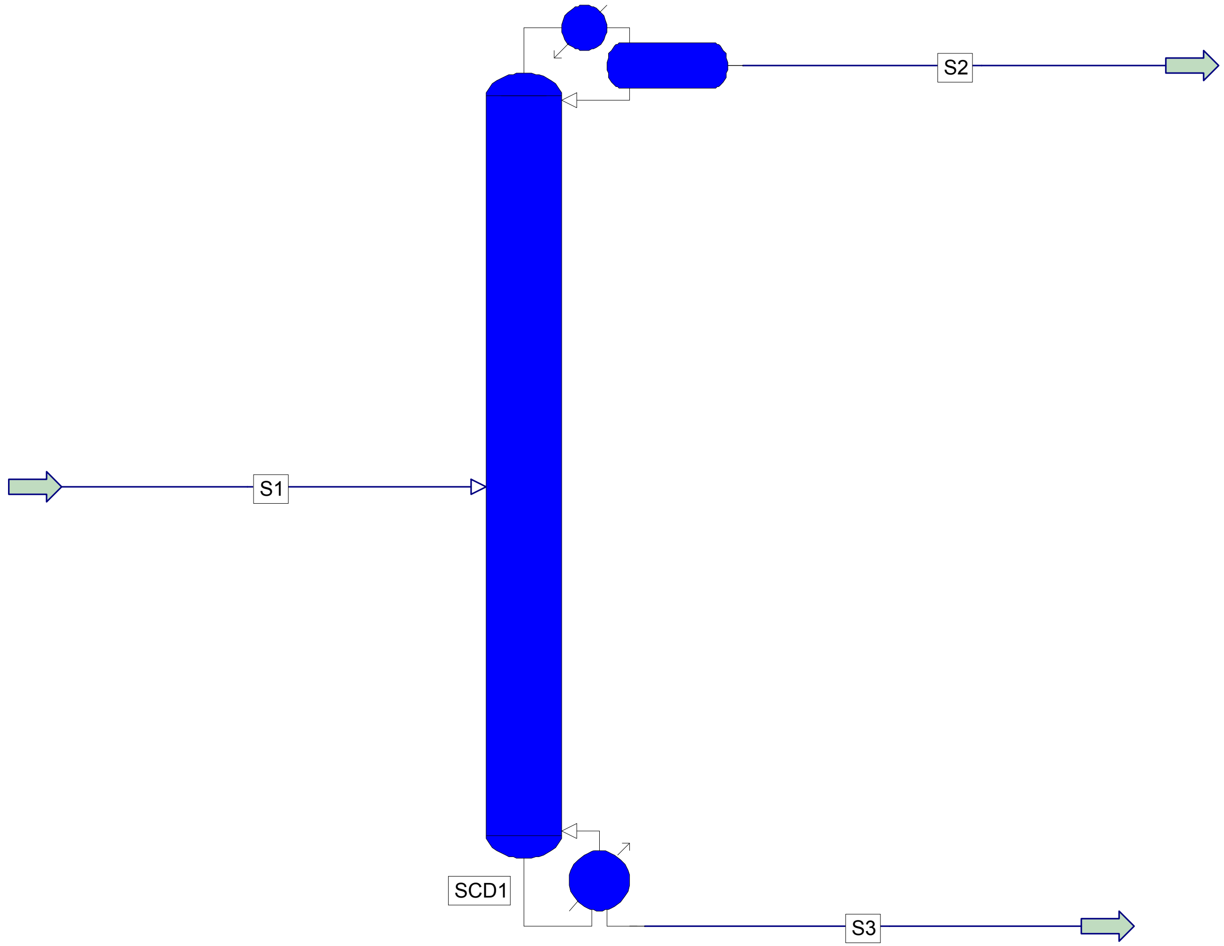


NRTL Liquid Activity Coefficient Model:

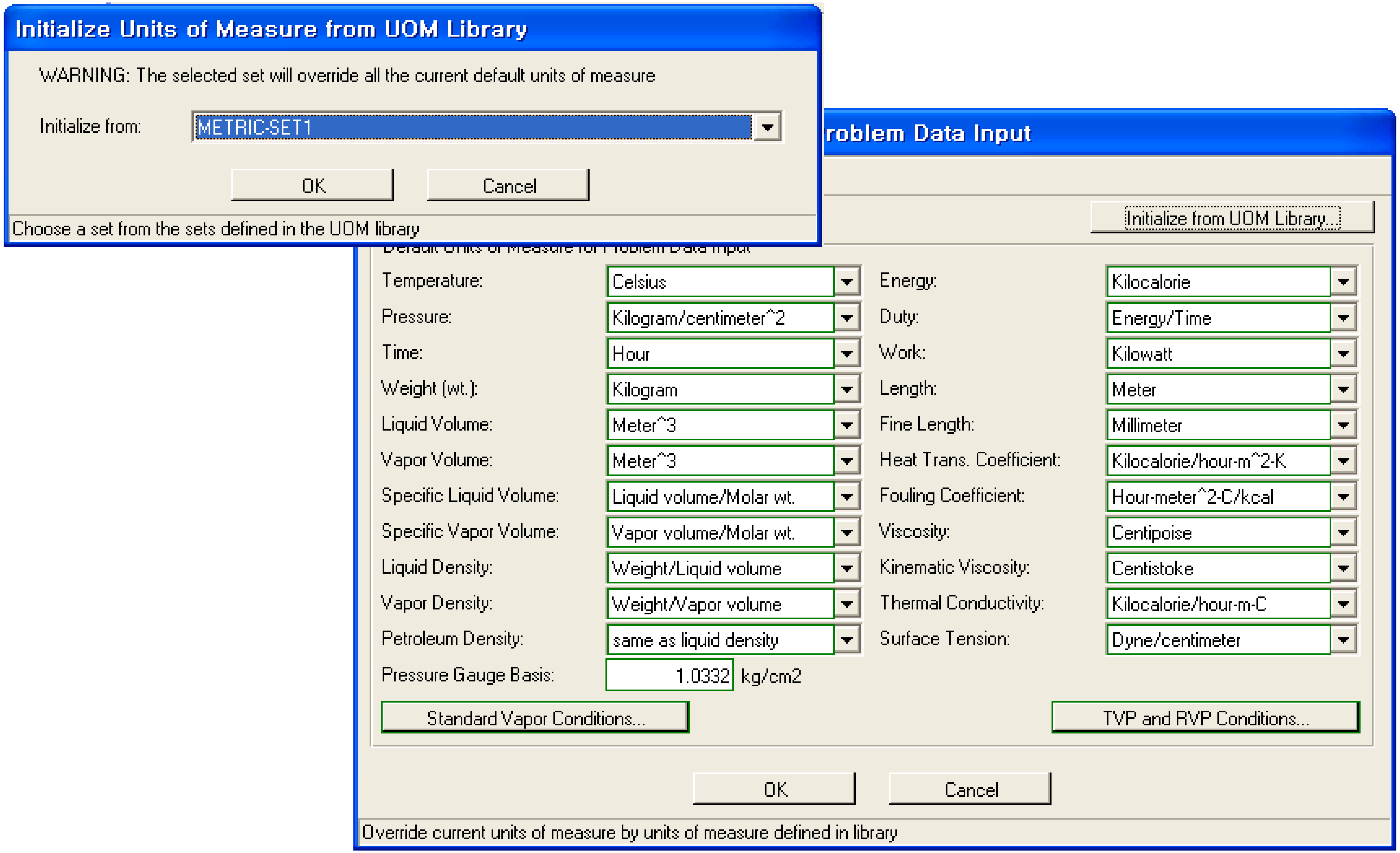


2 Shortcut Modeling

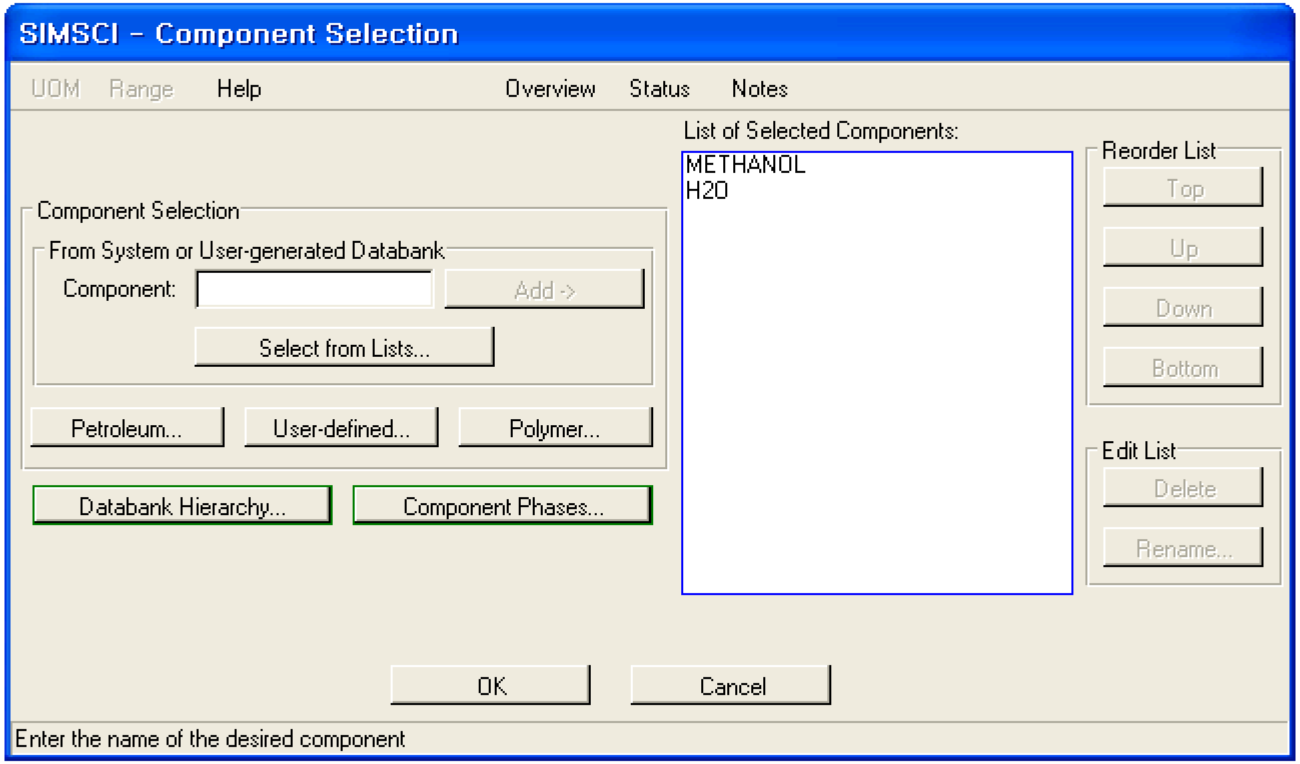
Shortcut Modeling Using PRO/II with PROVISION:



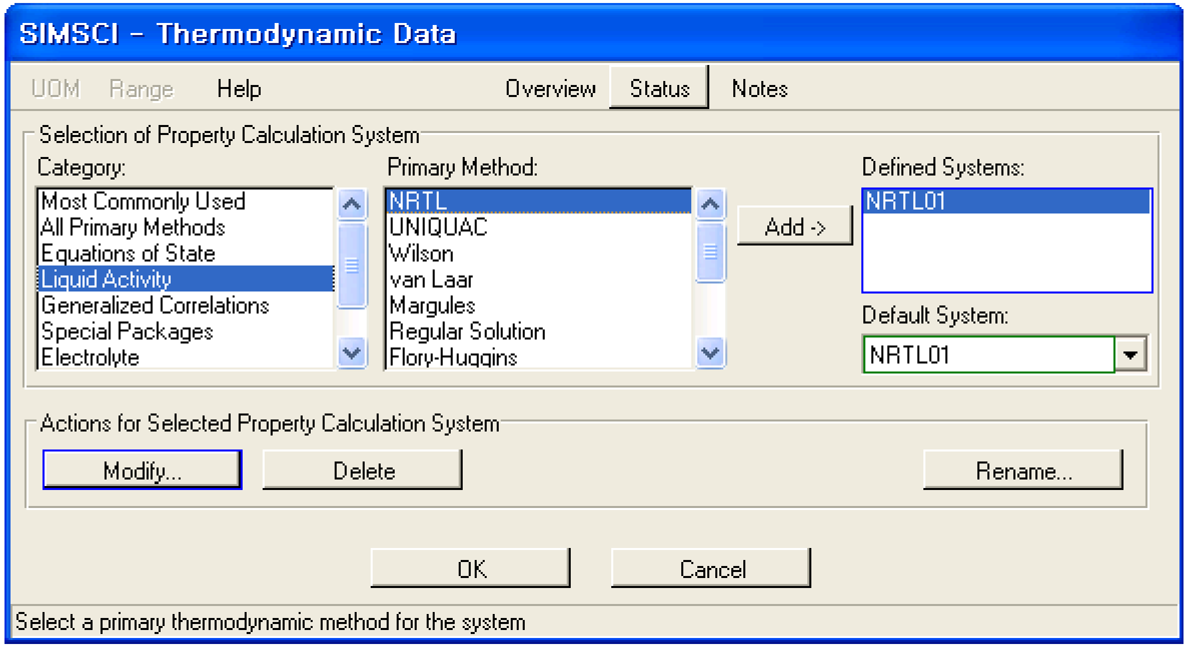
Step 1: Units of Measure



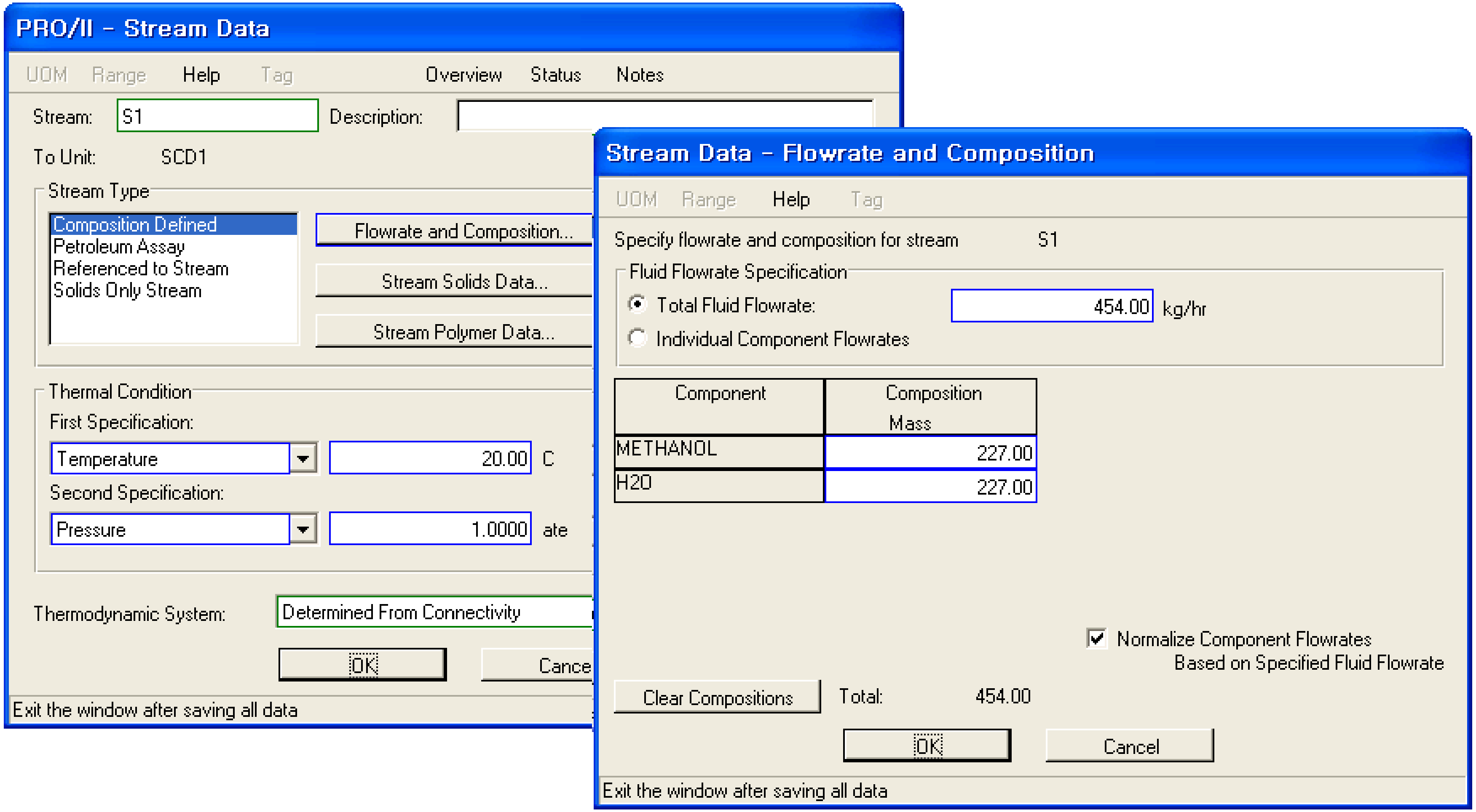
Step 2: Component Selection



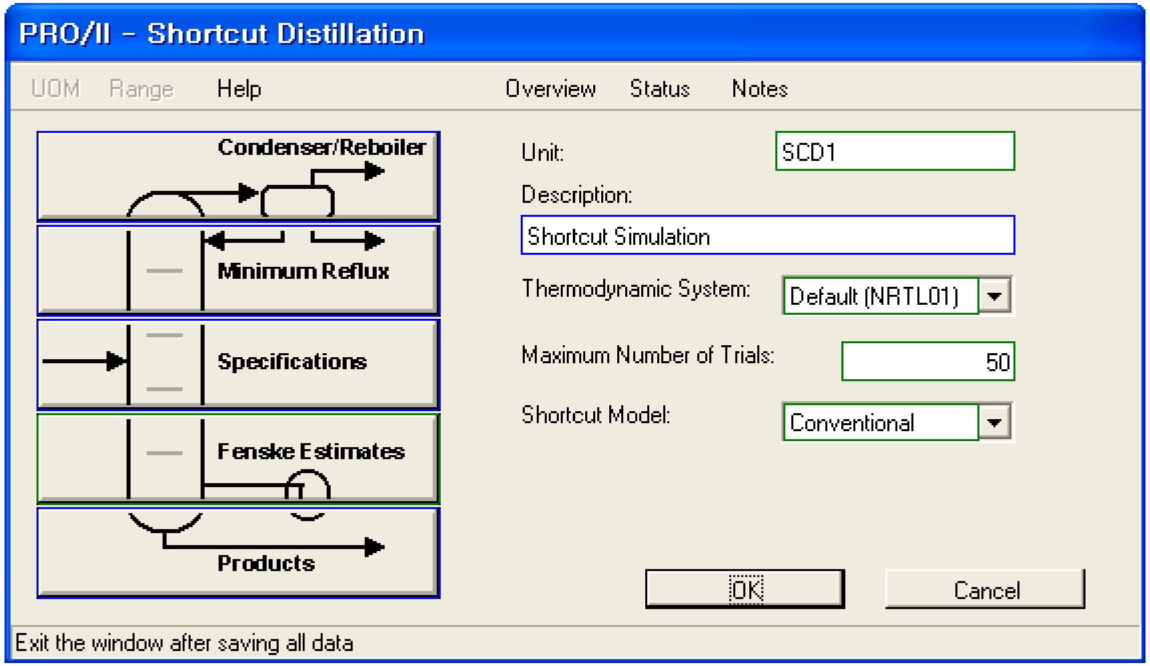
Step 3: Thermodynamic Data Selection



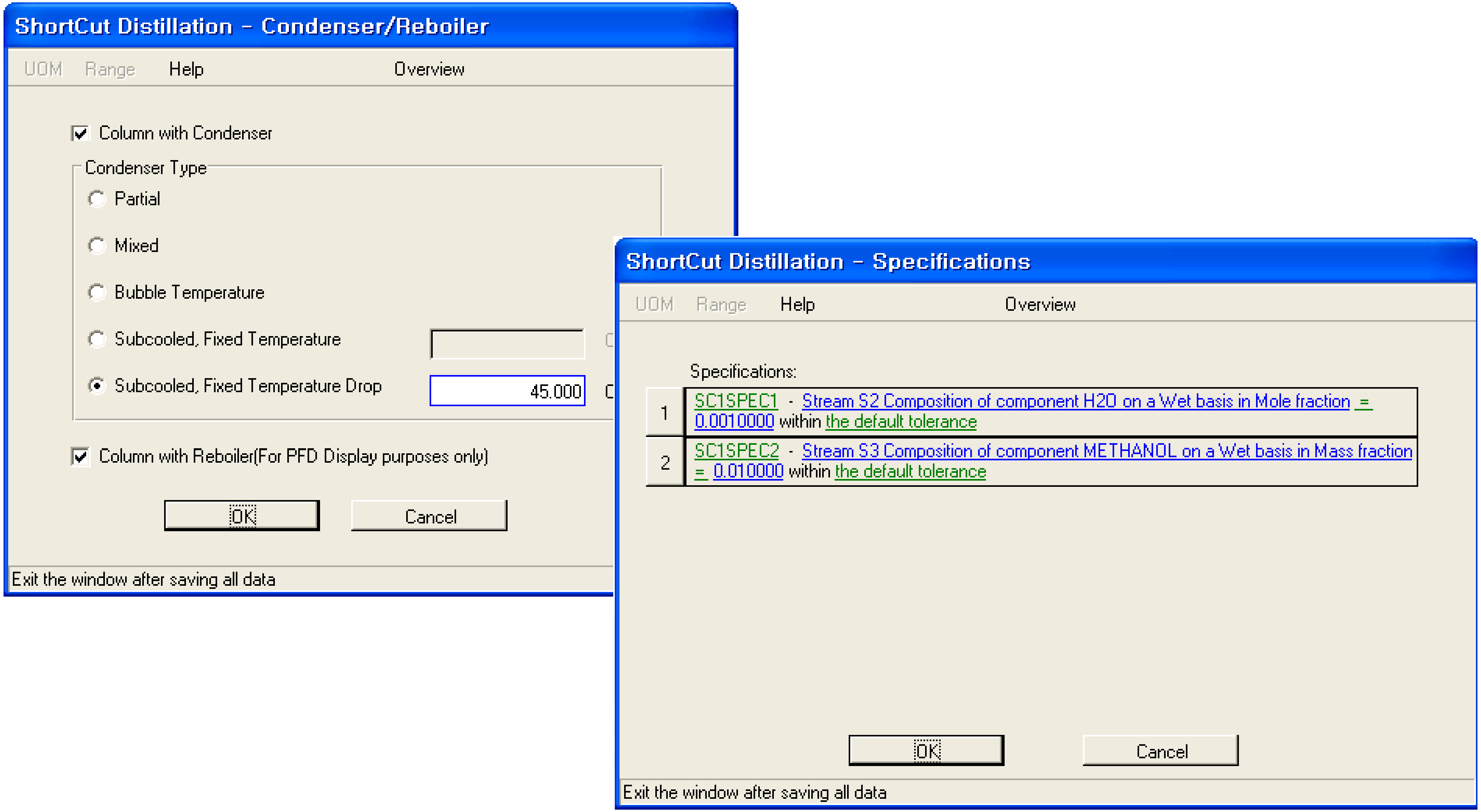
Step 4: Stream Data



Step 5: Shortcut Distillation



Step 5: Shortcut Distillation



PRO/II Keyword Input File for Shortcut Distillation

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 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
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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		**7.27**

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

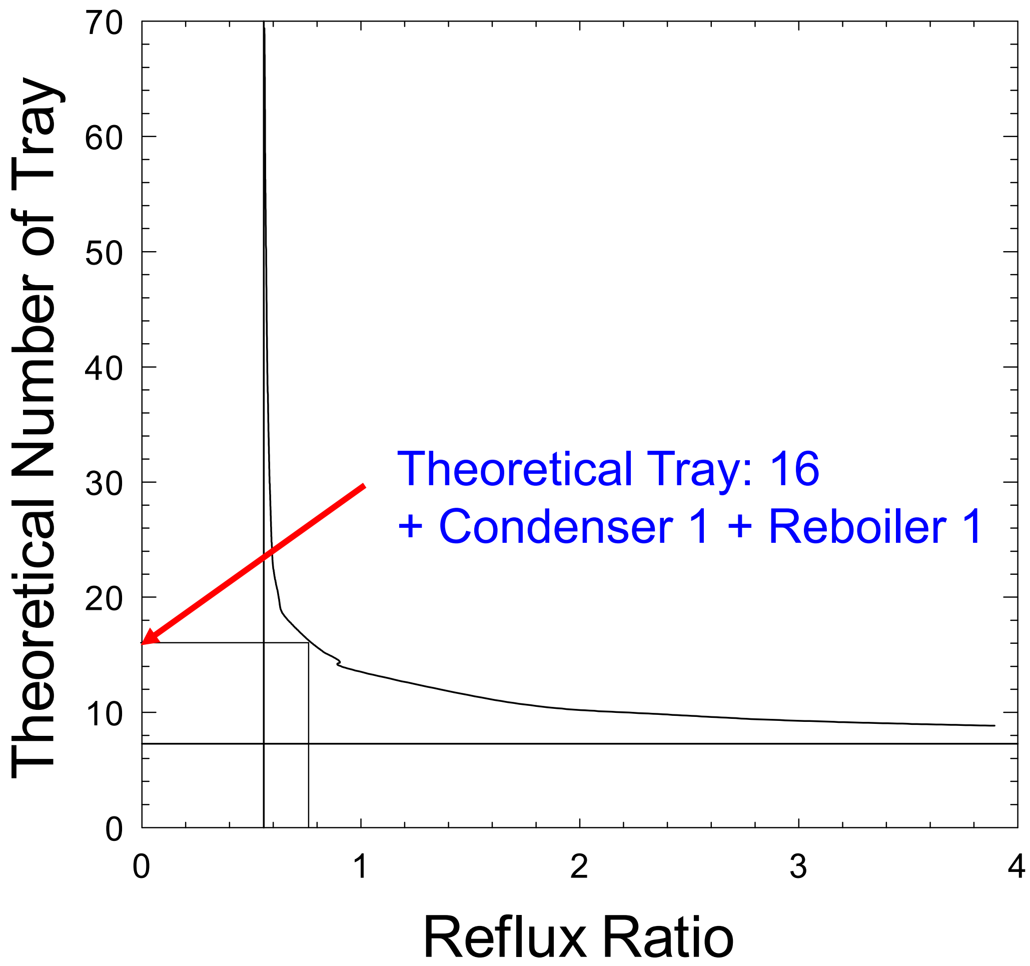
SUMMARY OF UNDERWOOD CALCULATIONS

MINIMUM REFLUX RATIO	**0.55642**
FEED CONDITION Q	1.16541
FENSKE MINIMUM TRAYS	**7.27097**

PRO/II Output Summary for Shortcut Distillation

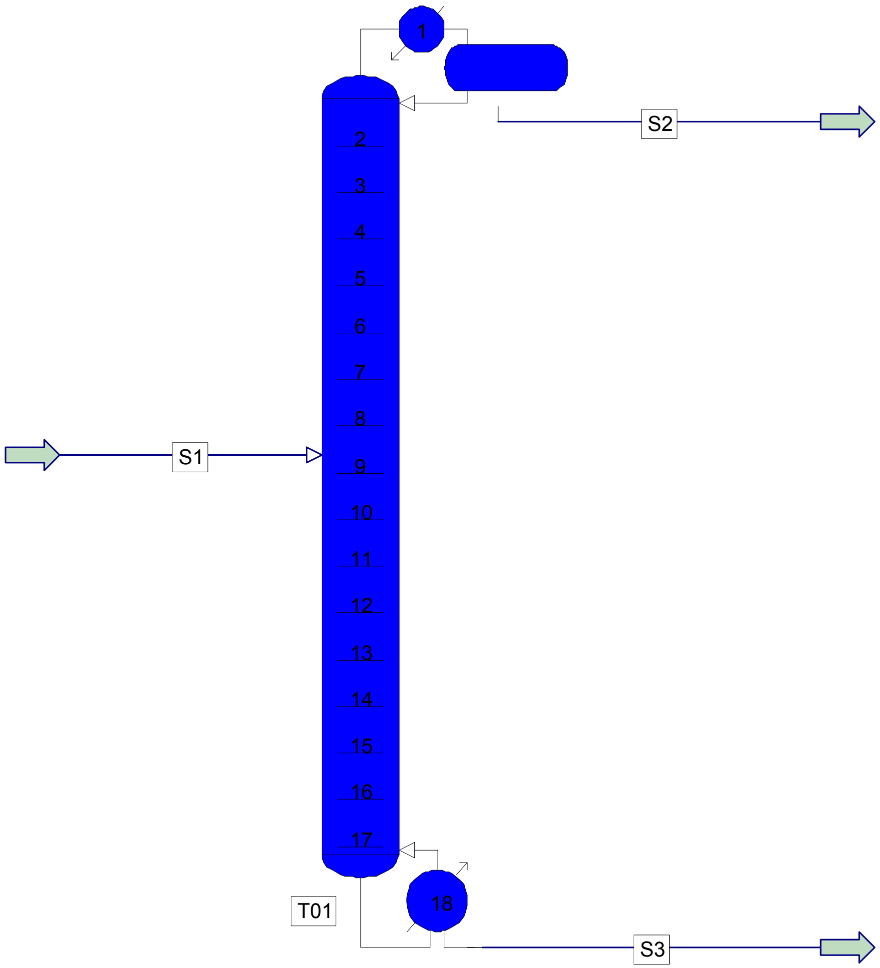
STREAM ID	S1	S2	S3
NAME			
PHASE	LIQUID	LIQUID	LIQUID
FLUID RATES, KG-MOL/HR			
1 METHANOL	7.0845	7.0129	0.0715
2 H2O	12.6006	7.0221E-03	12.5936
TOTAL RATE, KG-MOL/HR	19.6851	7.0200	12.6651
TEMPERATURE, C	20.0000	21.9051	108.3561
PRESSURE, ATE	1.0000	0.1000	0.4000
ENTHALPY, M*KCAL/HR	7.1668E-03	2.8564E-03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

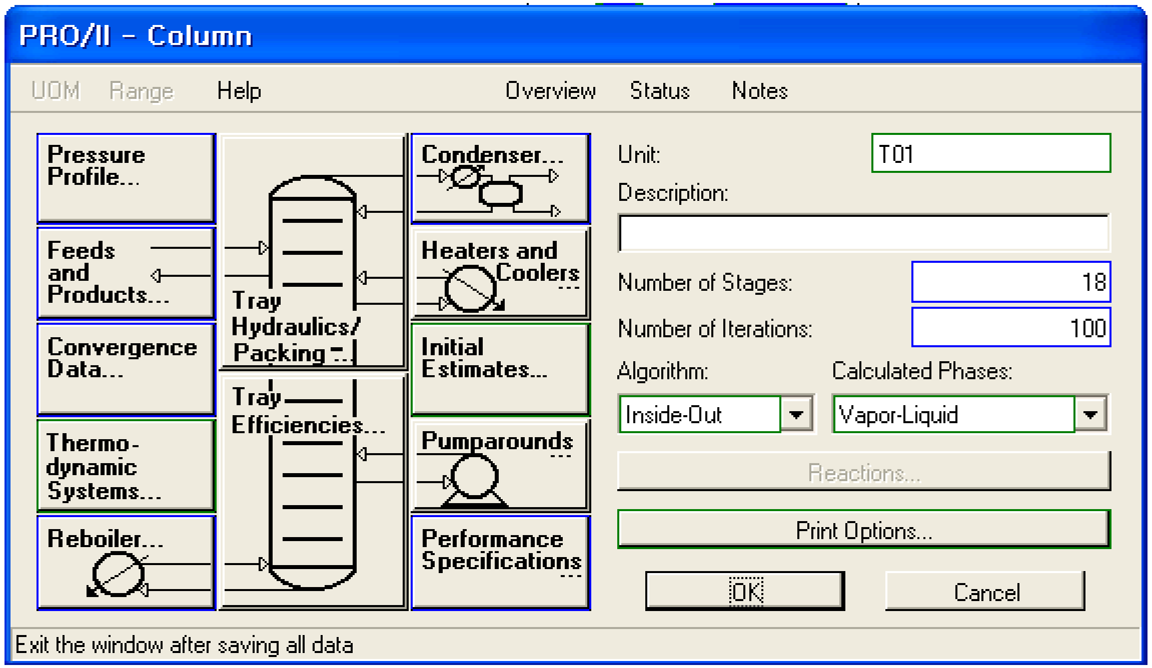


3 Rigorous Modeling

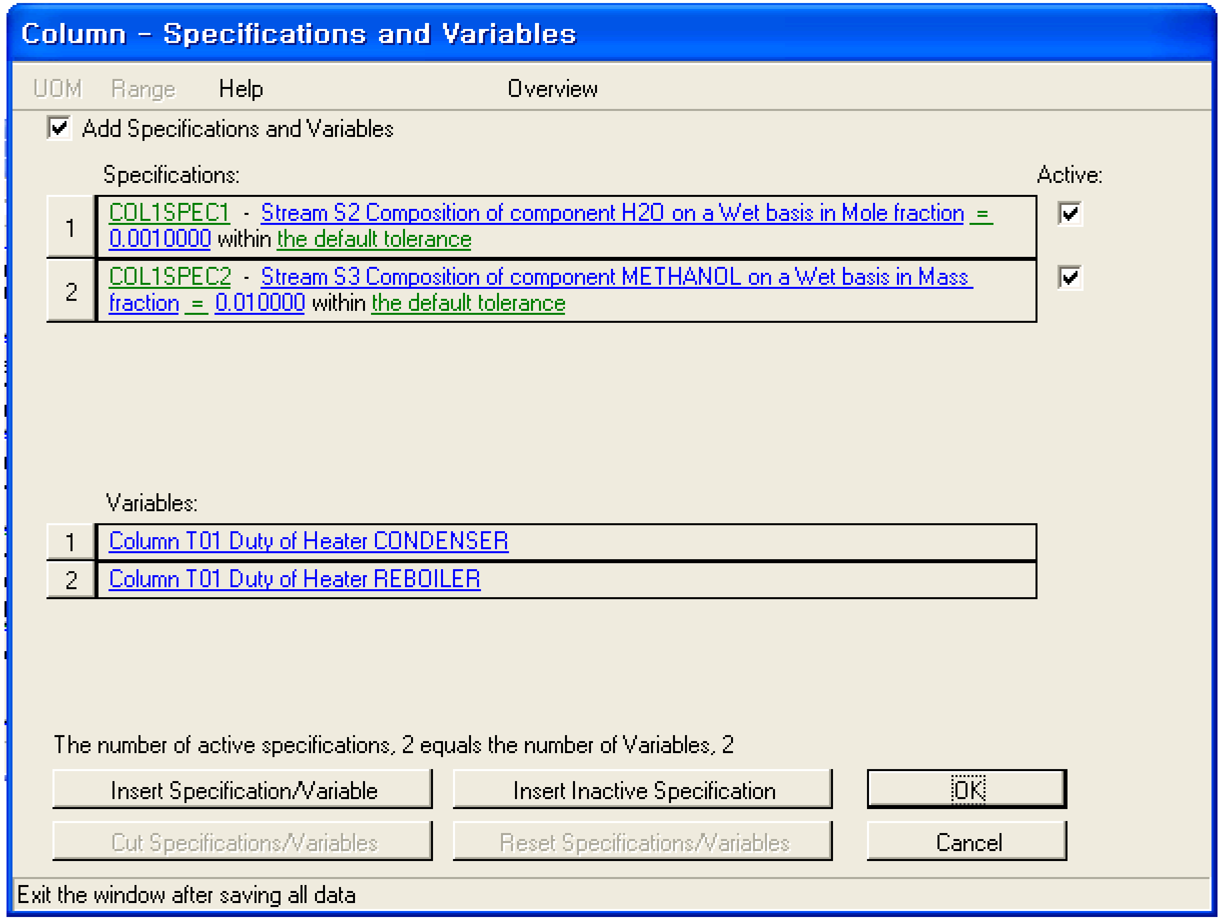
Rigorous Simulation Using PRO/II with PROVISION:



Step 6: Rigorous Distillation



Step 6: Rigorous Distillation



PRO/II Keyword Input File for Rigorous Distillation

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 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
```

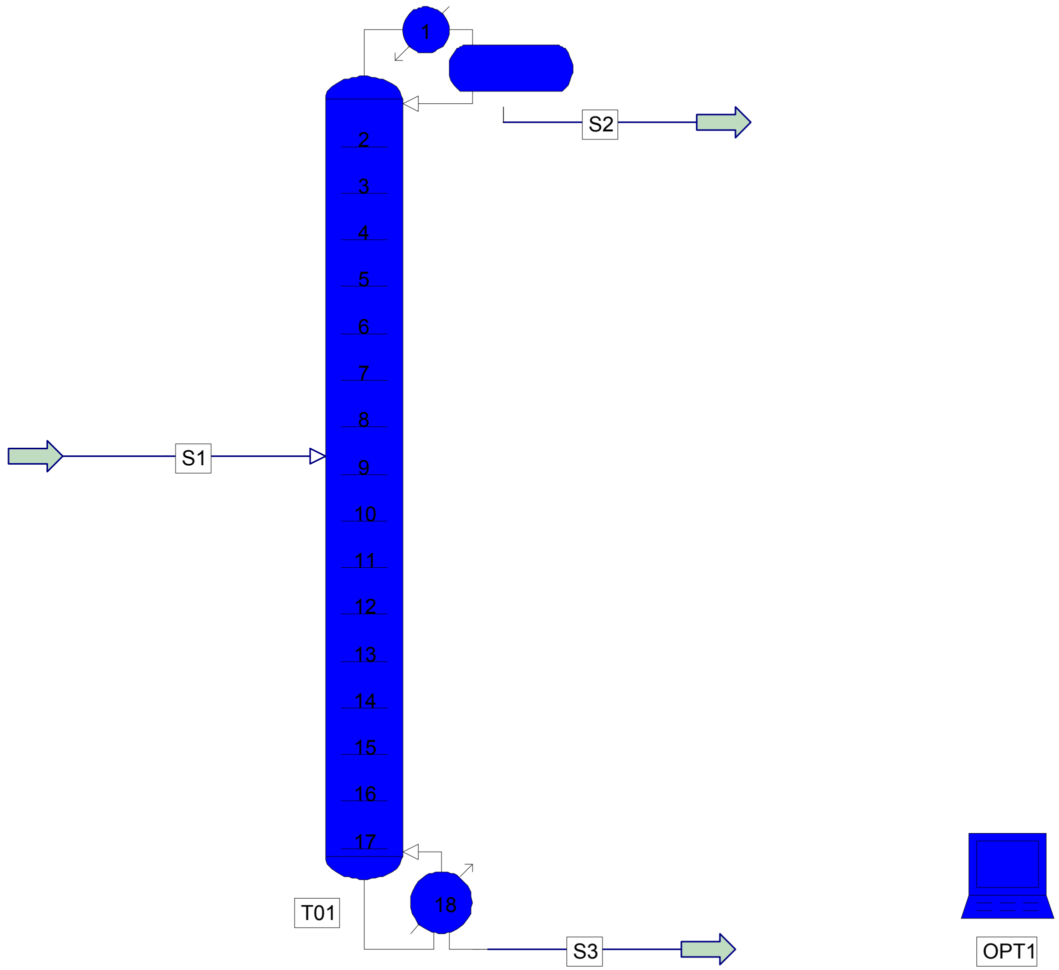
Column Summary:

COLUMN SUMMARY

TRAY	TEMP DEG C	PRESSURE ATE	NET FLOW RATES (KG-MOL/HR) LIQUID	VAPOR	FEED	PRODUCT	HEATER DUTIES M*KCAL/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**

4 Finding Optimal Feed Tray Location

Finding Optimum Feed Tray Location:



Column Summary: Optimization

COLUMN SUMMARY

TRAY	TEMP DEG C	PRESSURE ATE	LIQUID (NET FLOW RATES, KG-MOL/HR)	VAPOR	FEED	PRODUCT	HEATER DUTIES M*KCAL/HR
1C	45.0	0.10	15.6			7.0L	-0.2026
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

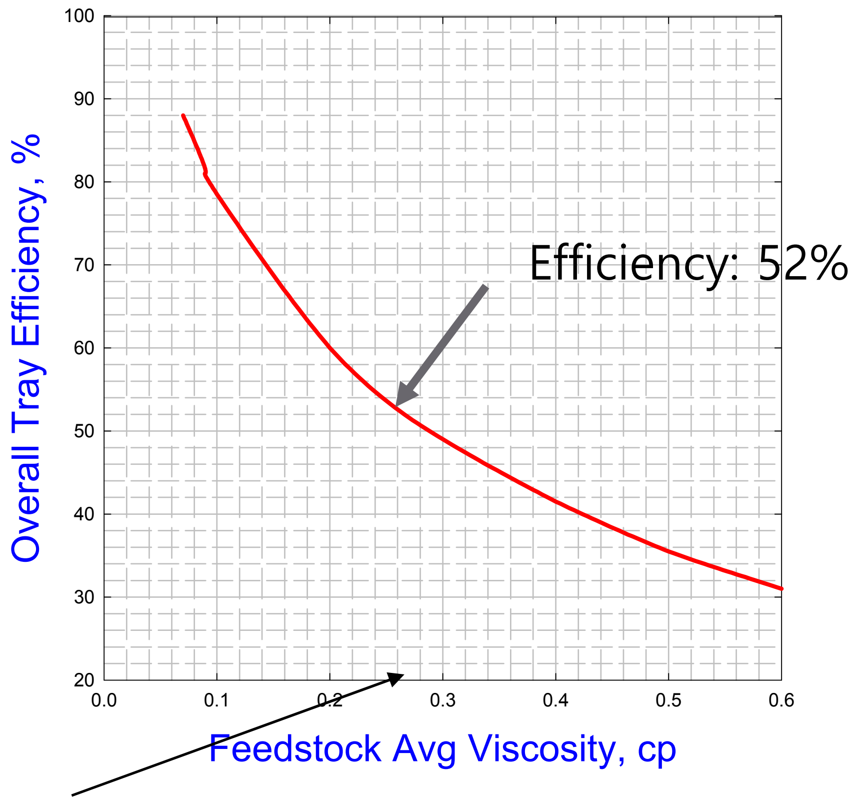
5 Valve Tray Sizing

Overall Tray Efficiency:

Notes:

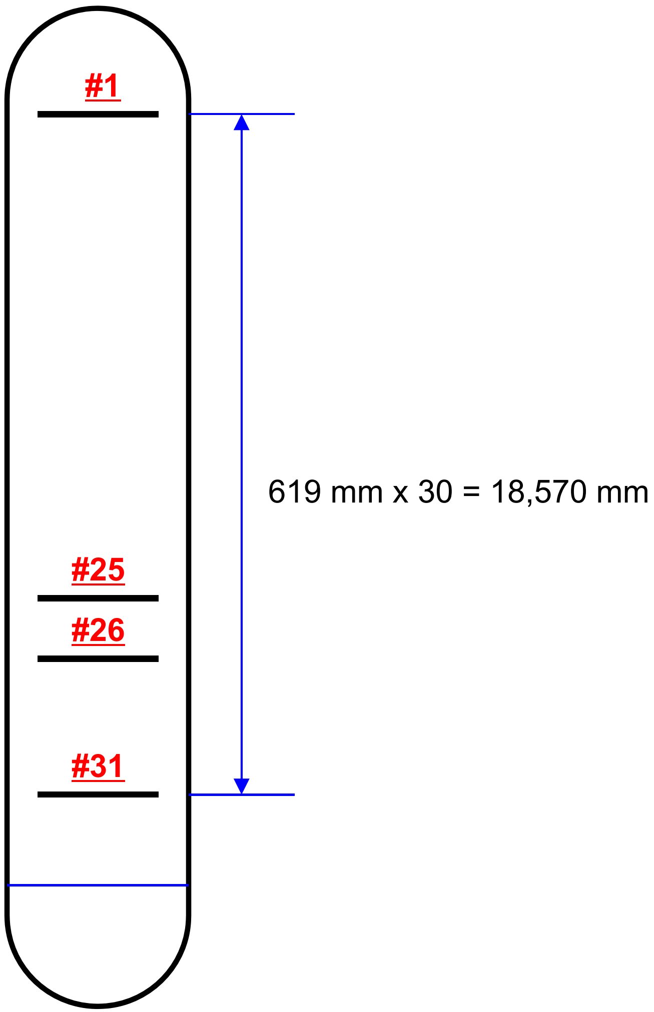
1) Based on 54 refinery columns.
2) Viscosity is average of feed as liquid at top & bottom temperatures of the column.
3) For Absorbers, use rich oil at exit temperature.
4) Efficiency is for key components.

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



$\mu = 0.26 cP$

Valve Tray Sizing:



Valve Tray

6 Packing을 적용한 Simulation

Revamping of Tray into Packing:

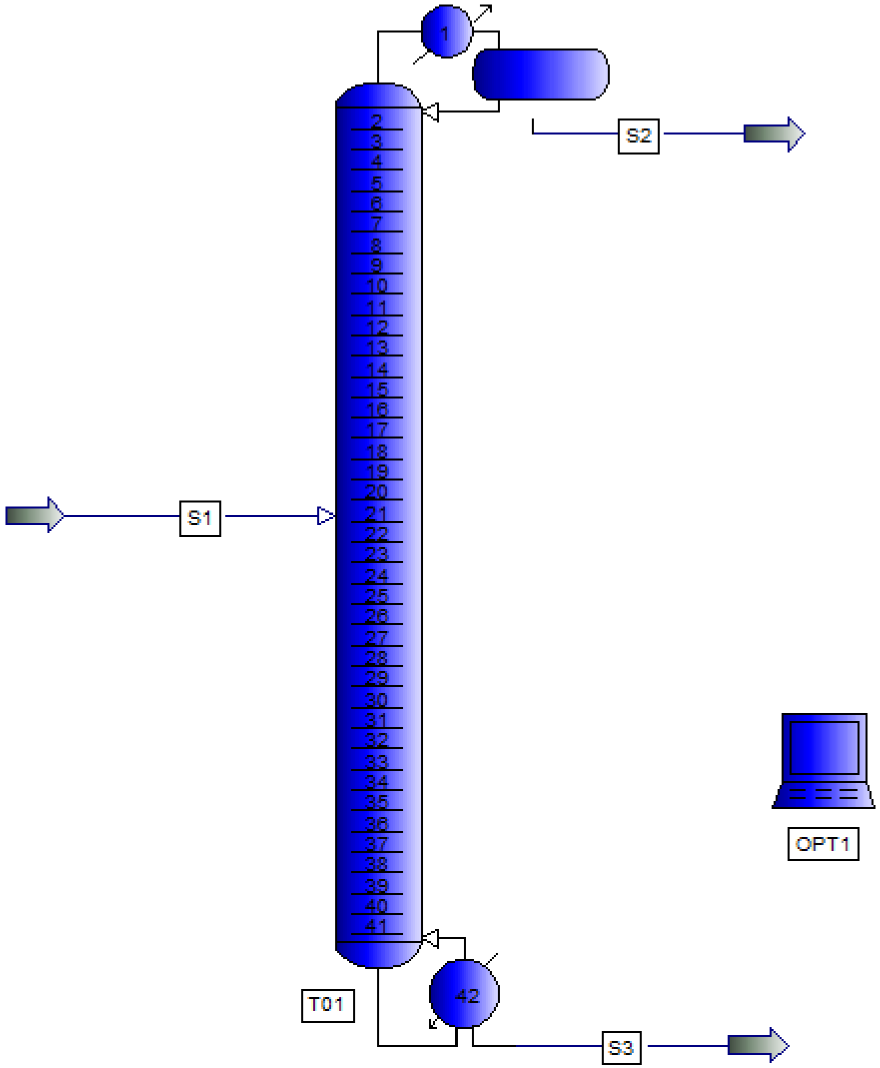
➢ Revamping of Trays into Packing Type:

- 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

			---------- NET FLOW RATES			-----------	HEATER
TRAY	TEMP	PRESSURE	LIQUID	VAPOR	FEED	PRODUCT	DUTIES
	DEG C	ATE		KG/HR			M*KCAL/HR
1C	45.0	0.10	234.3			224.8L	-0.1278
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	**0.1553**

7 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