CL-402: Chemical Process Technology

July-November session, 2018

7th semester, Department of Chemical Engineering

Indian Institute of Technology Guwahati, Guwahati

Tutorial 4

Use Aspen Plus V8.8 to solve all the problems.

Problem-1: Rigorous Distillation Calculations: RadFrac

A feed consisting of 40 mol% propane and 60 mol% isobutane is to be separated by distillation. Feed flowrate is 1 kmol/s and the feed temperature is 322 K. Condenser is operating at 16.8 atm pressure while stage pressure drop is 0.0068 atm. Use CHAO–SEAD thermodynamic model. Assume that the specification of the heavy impurity in the distillate (isobutane) is 2 mol% and that the specification of the light impurity in the bottoms (propane) is 1 mol%.

a. Design a distillation to accomplish the separation i.e. find number of stages, feed stage, diameter and height of the column.

b. Investigate the effect of feed stage on reboiler heat duty.

c. Perform the steady-state economic optimization of the distillation column based on total annual cost (TAC) using the following data:

Parameter	Value
Condensers	
Heat Transfer Coefficient	0.852 kW/K.m^2
Differential Temperature	13.9 K
Capital Cost	7296 (area in m^2)$^{0.65}$
Reboiler	
Heat Transfer Coefficient	0.568 kW/K.m^2
Differential Temperature	34.8 K
Capital Cost	7296 (area in m^2)$^{0.65}$
Column Vessel Capital Cost	17640 [diameter (*D*) in meters)$^{1.066}$ [length (*L*) in meters)$^{0.802}$
Energy Cost	\$4.7/10^6 kJ

$$TAC = \frac{capital\ cost}{payback\ period} + energy\ cost$$

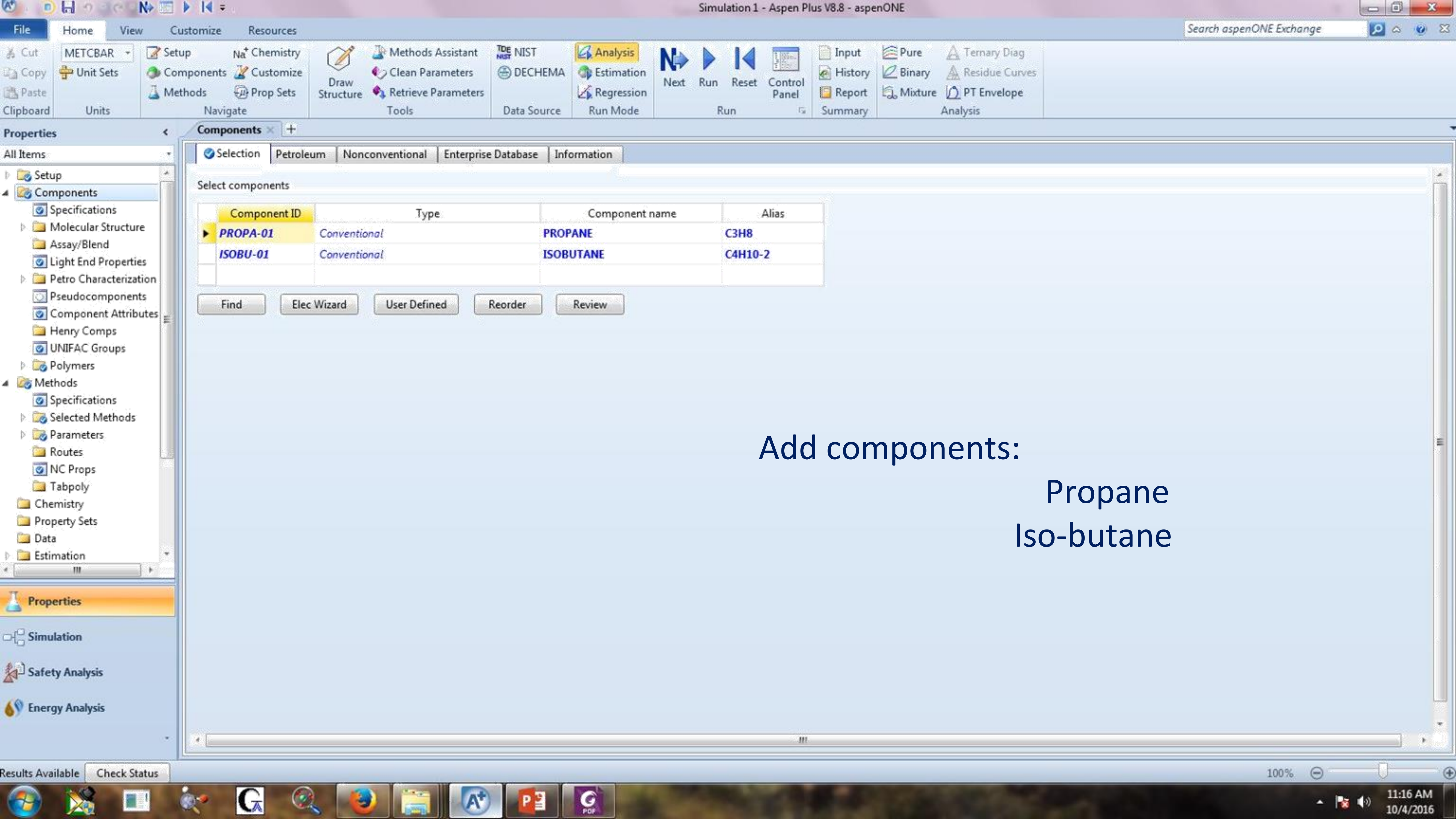
Payback Period	3 years

In Tutorial-3, we have used DSTWU and RadFrac models to design a separation process.

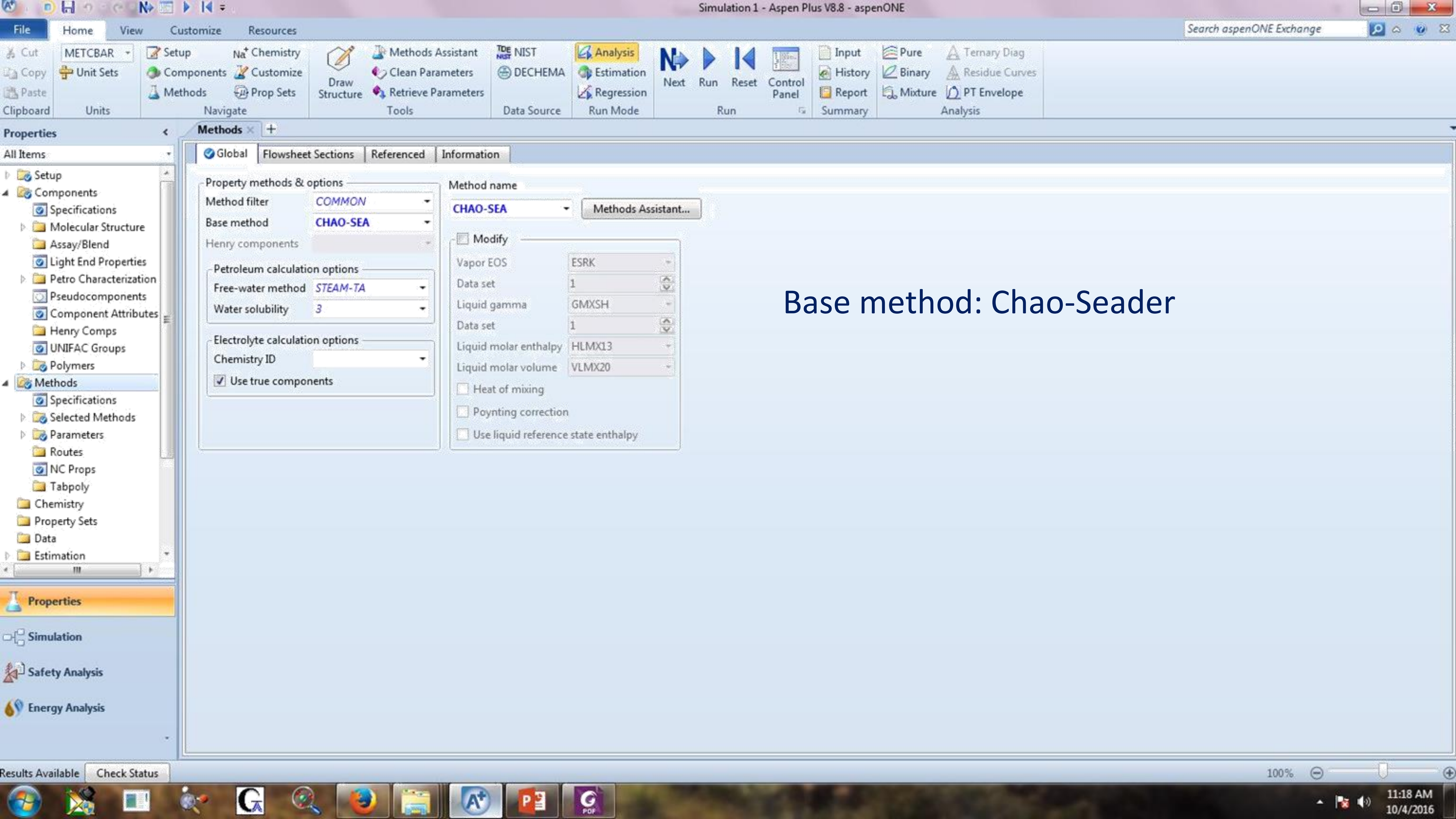
As we have seen, various configurations are possible which can meet the desired specifications. So the question is which one of the many possible configurations should be used. To answer that question, one has to bring other factors. If costs were the only consideration, then there would be a trade-off between capital costs and operating (heat and cooling) costs.

In this Tutorial, we will Perform the steady-state economic optimization of the distillation column based on total annual cost (TAC).

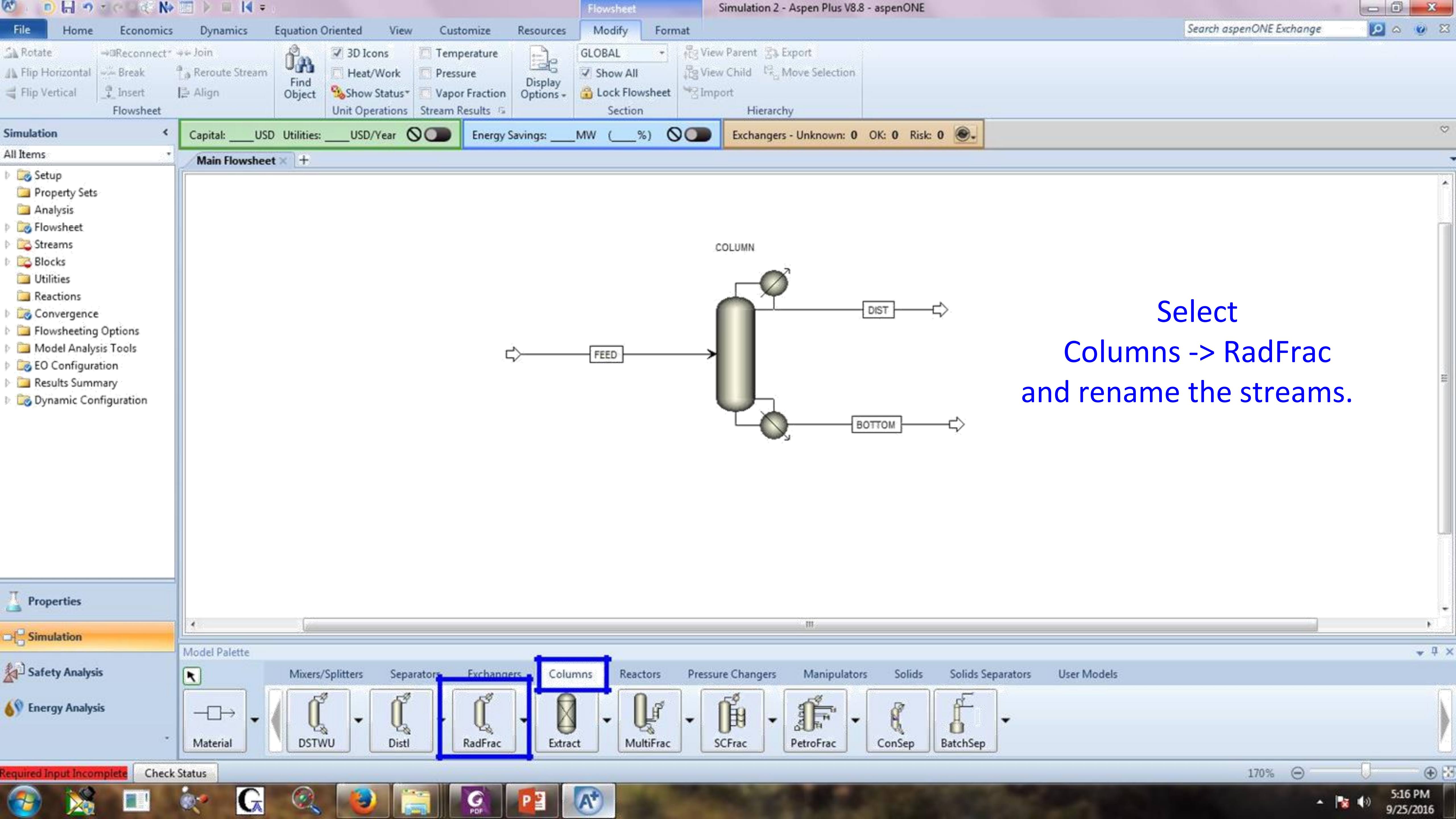
Problem 1



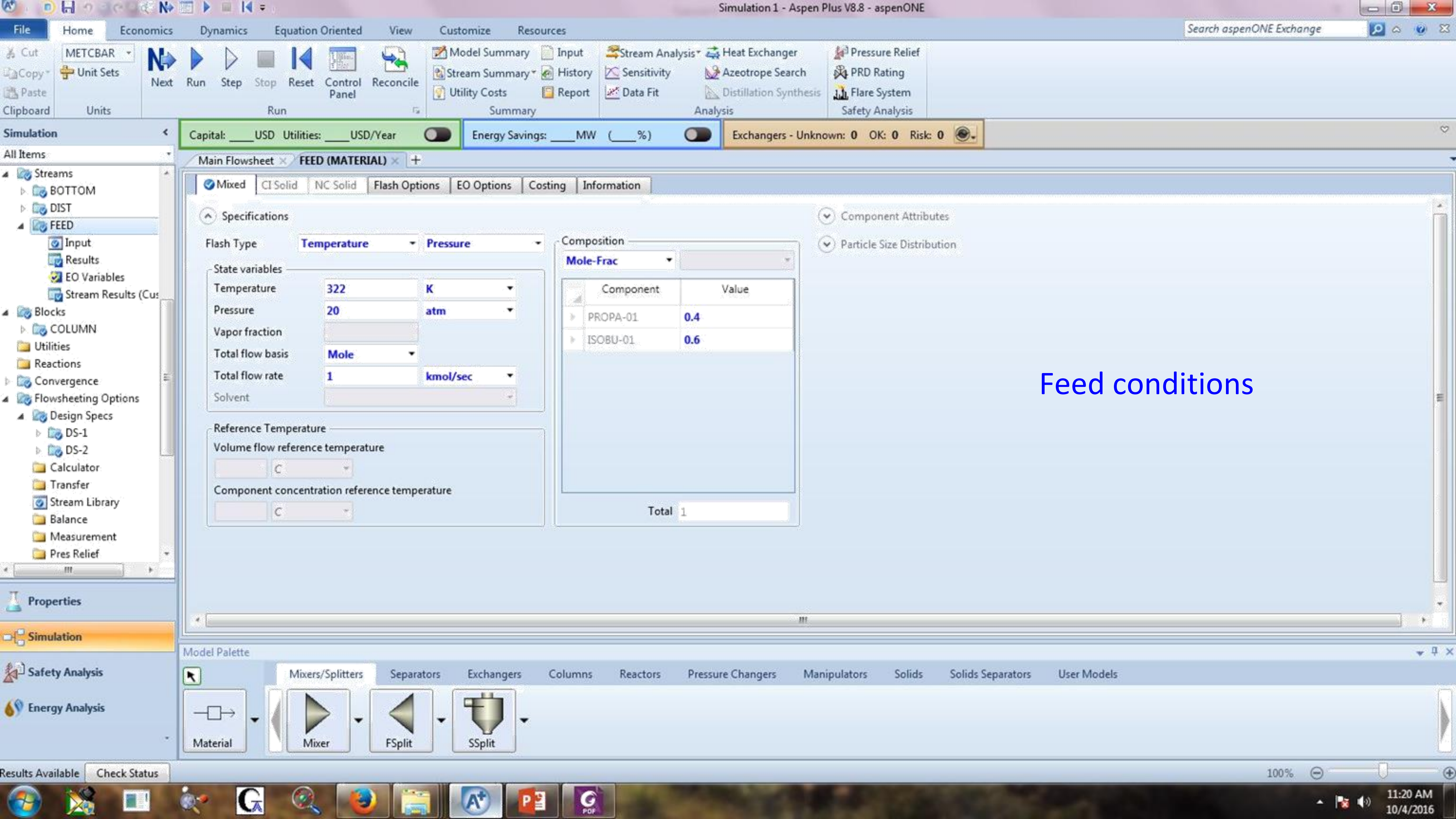
Simulation 1 - Aspen Plus V8.8 - aspenONE
Components
Selection
Petroleum
Nonconventional
Enterprise Database
Information
Select components
Component ID | Type | Component name | Alias
PROPA-01 | Conventional | PROPANE | C3H8
ISOBU-01 | Conventional | ISOBUTANE | C4H10-2
Find
Elec Wizard
User Defined
Reorder
Review
Add components:
Propane
Iso-butane



Base method: Chao-Seader

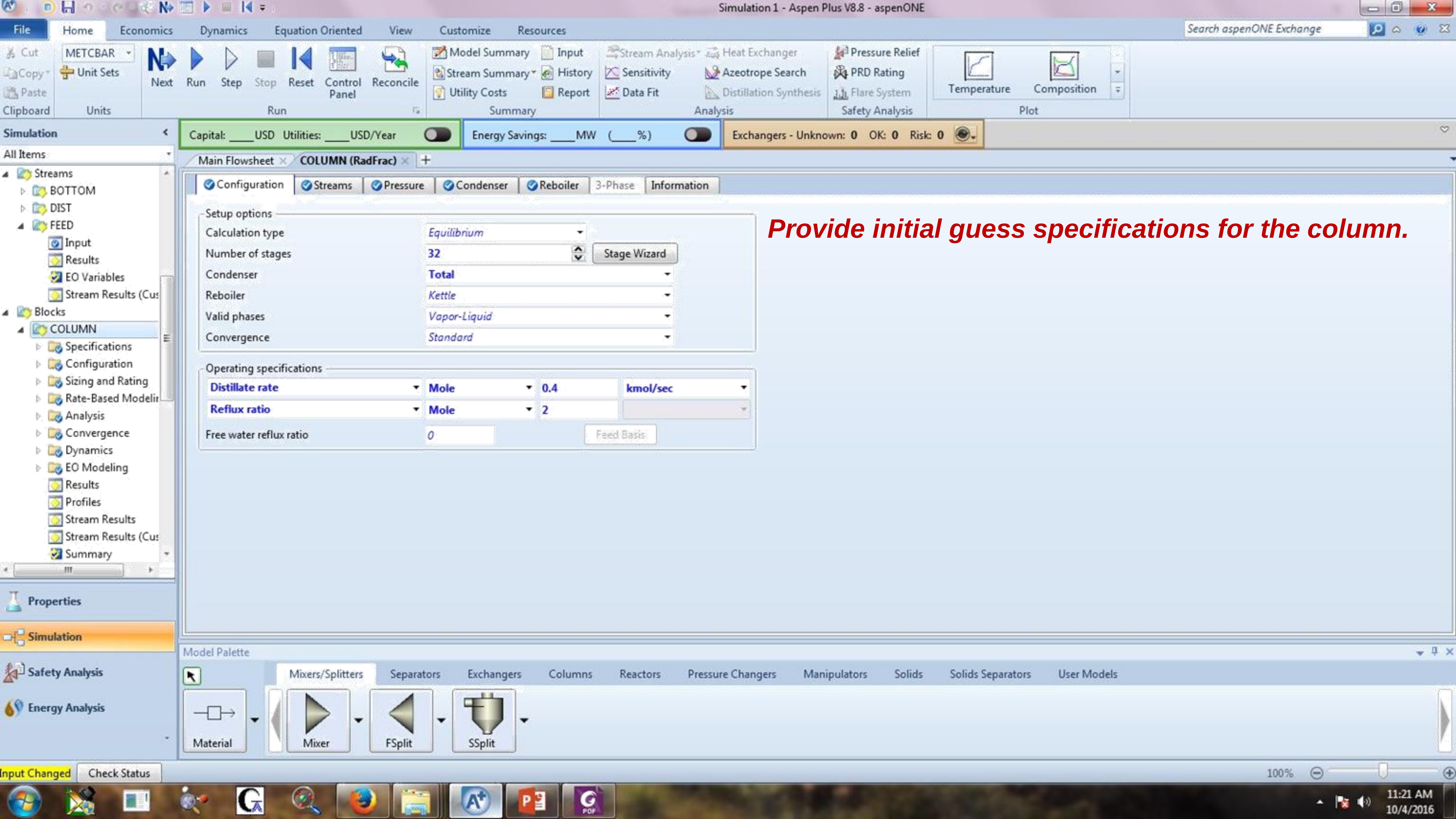


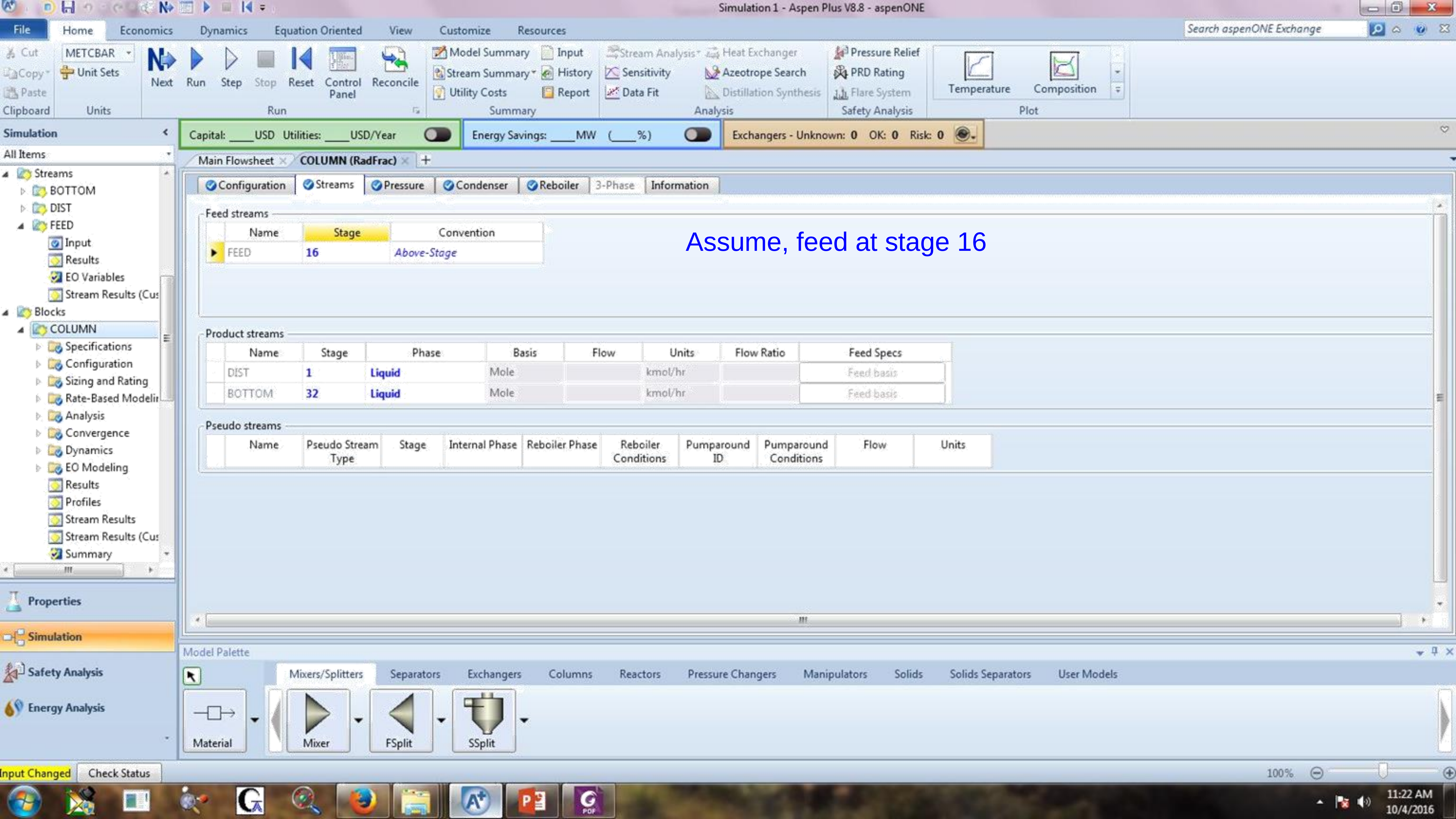
Select
Columns -> RadFrac
and rename the streams.



Feed conditions

Provide initial guess specifications for the column.




Simulation 1 - Aspen Plus V8.8 - aspenONE
File
Home
Economics
Dynamics
Equation Oriented
View
Customize
Resources
Search aspenONE Exchange
Cut
Copy
Paste
Clipboard
METCBAR
Unit Sets
Units
Next
Run
Step
Stop
Reset
Control Panel
Reconcile
Run
Model Summary
Stream Summary
Utility Costs
Input
History
Report
Summary
Stream Analysis
Sensitivity
Data Fit
Heat Exchanger
Azeotrope Search
Distillation Synthesis
Analysis
Pressure Relief
PRD Rating
Flare System
Safety Analysis
Temperature
Composition
Plot
Capital: ___USD Utilities: ___USD/Year
Energy Savings: ___MW (___%)
Exchangers - Unknown: 0 OK: 0 Risk: 0
Simulation
All Items
Streams
BOTTOM
DIST
FEED
Input
Results
EO Variables
Stream Results (Cus
Blocks
COLUMN
Specifications
Configuration
Sizing and Rating
Rate-Based Modelir
Analysis
Convergence
Dynamics
EO Modeling
Results
Profiles
Stream Results
Stream Results (Cus
Summary
Properties
Simulation
Safety Analysis
Energy Analysis
Main Flowsheet
COLUMN (RadFrac)
Configuration
Streams
Pressure
Condenser
Reboiler
3-Phase
Information
Feed streams
Name | Stage | Convention
FEED | 16 | Above-Stage
Assume, feed at stage 16
Product streams
Name | Stage | Phase | Basis | Flow | Units | Flow Ratio | Feed Specs
DIST | 1 | Liquid | Mole | | kmol/hr | | Feed basis
BOTTOM | 32 | Liquid | Mole | | kmol/hr | | Feed basis
Pseudo streams
Name | Pseudo Stream Type | Stage | Internal Phase | Reboiler Phase | Reboiler Conditions | Pumparound ID | Pumparound Conditions | Flow | Units
Model Palette
Mixers/Splitters
Separators
Exchangers
Columns
Reactors
Pressure Changers
Manipulators
Solids
Solids Separators
User Models
Material
Mixer
FSplit
SSplit
Input Changed
Check Status
100%
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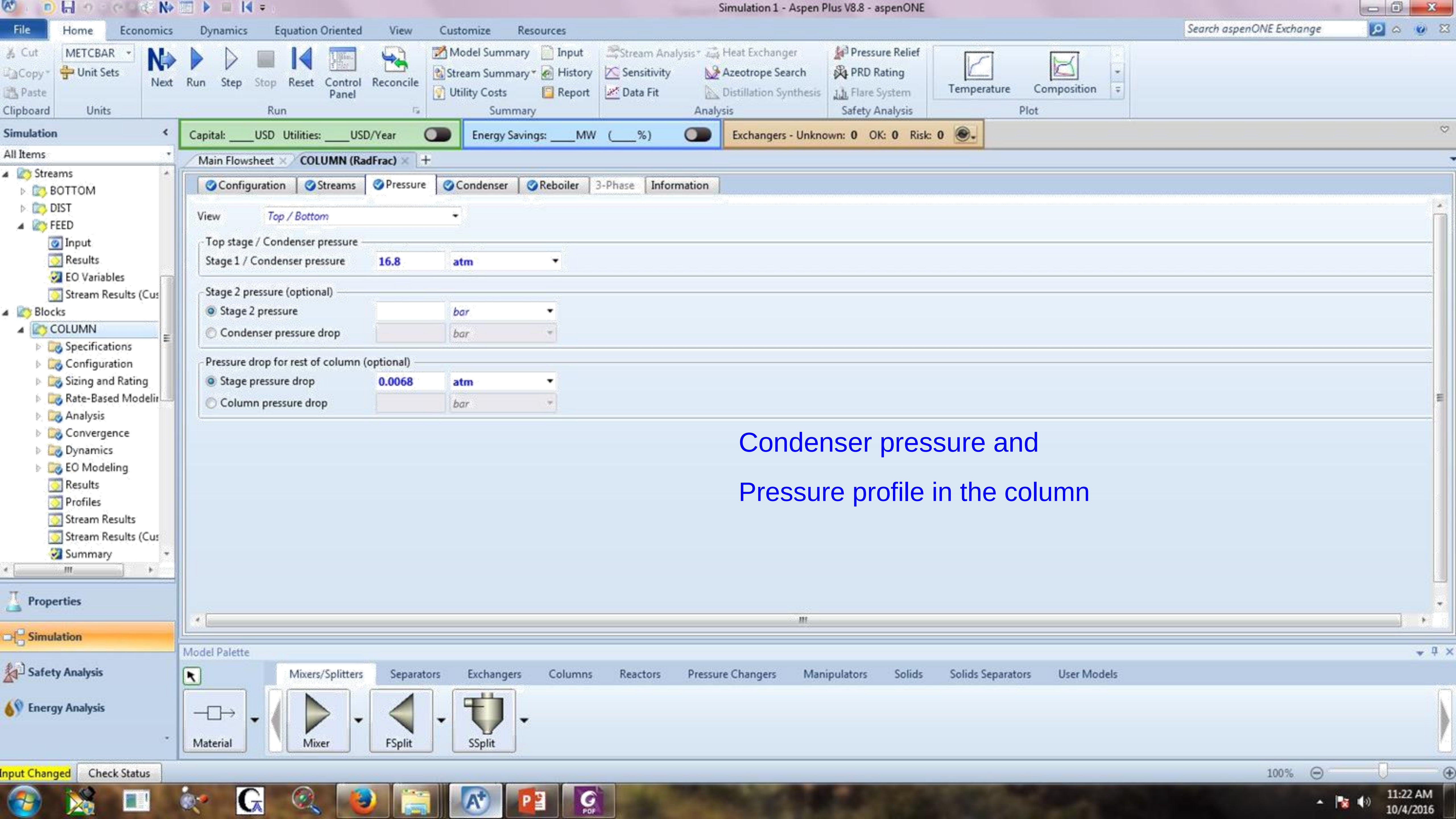


Condenser pressure and

Pressure profile in the column

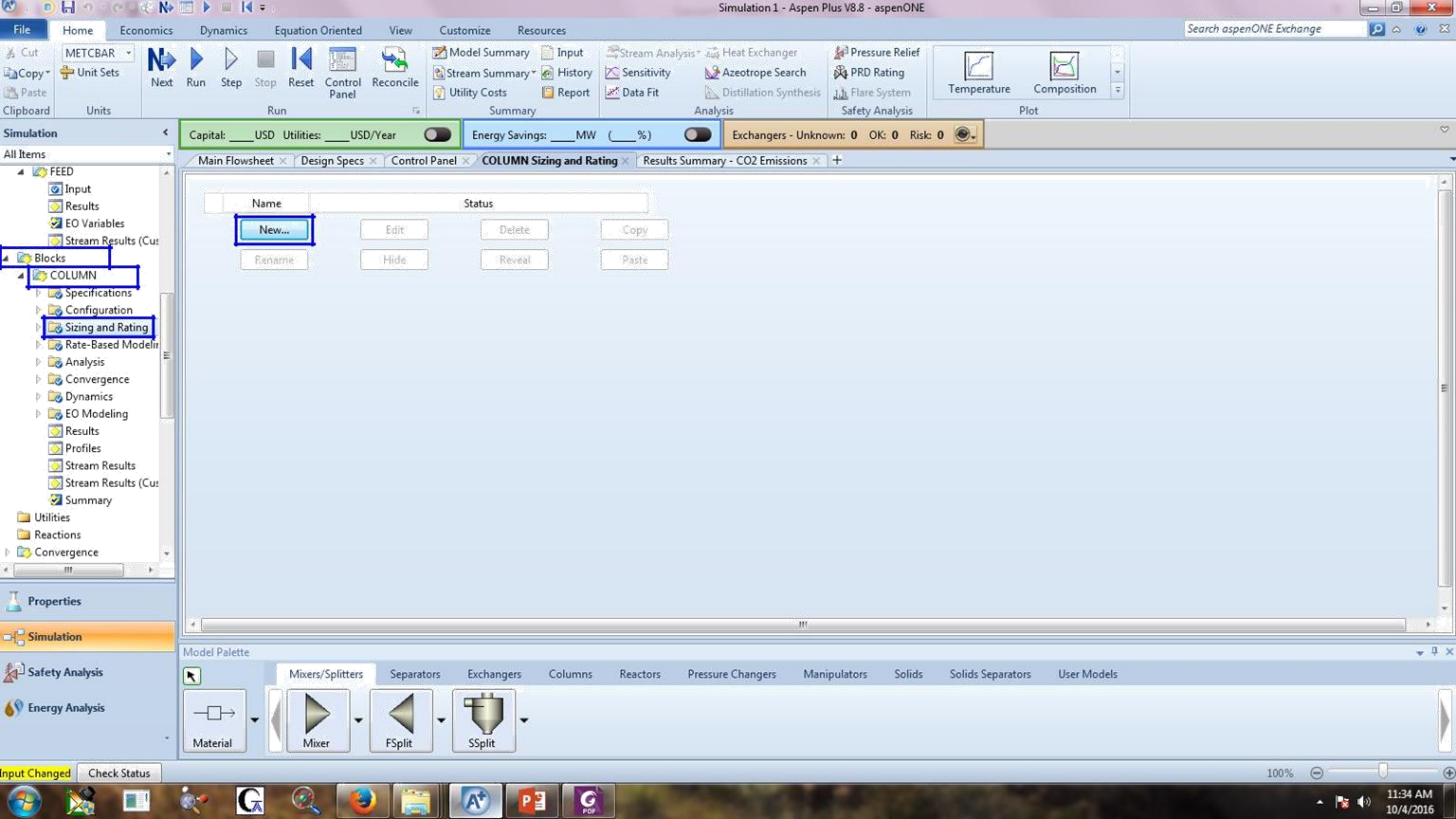
Stream Results

	Units	FEED	DIST	BOTTOM
From			COLUMN	COLUMN
To		COLUMN		
Substream: MIXED				
Phase:		Liquid	Liquid	Liquid
Component Mole Flow				
PROPA-01	KMOL/HR	1440	1244	196.002
ISOBU-01	KMOL/HR	2160	196.002	1964
Component Mole Fraction				
PROPA-01		0.4	0.863887	0.0907418
ISOBU-01		0.6	0.136113	0.909258
Component Mass Flow				
PROPA-01	KG/HR	63499	54856	8643.02
ISOBU-01	KG/HR	125547	11392.3	114154
Component Mass Fraction				
PROPA-01		0.335893	0.828036	0.0703845
ISOBU-01		0.664107	0.171964	0.929616
Mole Flow	KMOL/HR	3600	1440	2160

86 mol% propane in distillate.
90 mol% iso-butane in bottom.

Use design spec to meet the desired specifications.
Two design spec are required.
Hint: Vary distillate rate and RR.

Determination of Column diameter


Simulation 1 - Aspen Plus V8.8 - aspenONE
File
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Dynamics
Equation Oriented
View
Customize
Resources
Search aspenONE Exchange
Cut
Copy
Paste
Clipboard
METCBAR
Unit Sets
Units
Next
Run
Step
Stop
Reset
Control Panel
Reconcile
Model Summary
Stream Summary
Utility Costs
Input
History
Report
Summary
Stream Analysis
Sensitivity
Data Fit
Heat Exchanger
Azeotrope Search
Distillation Synthesis
Analysis
Pressure Relief
PRD Rating
Flare System
Safety Analysis
Temperature
Composition
Plot
Simulation
All Items
Capital: ____USD Utilities: ____USD/Year
Energy Savings: ____MW (____%)
Exchangers - Unknown: 0 OK: 0 Risk: 0
Main Flowsheet
Design Specs
Control Panel
COLUMN Sizing and Rating
Results Summary - CO2 Emissions
FEED
Input
Results
EO Variables
Stream Results (Cus
Blocks
COLUMN
Specifications
Configuration
Sizing and Rating
Rate-Based Modelir
Analysis
Convergence
Dynamics
EO Modeling
Results
Profiles
Stream Results
Stream Results (Cus
Summary
Utilities
Reactions
Convergence
Name
Status
New...
Edit
Delete
Copy
Rename
Hide
Reveal
Paste
Properties
Simulation
Safety Analysis
Energy Analysis
Model Palette
Mixers/Splitters
Separators
Exchangers
Columns
Reactors
Pressure Changers
Manipulators
Solids
Solids Separators
User Models
Material
Mixer
FSplit
SSplit
Input Changed
Check Status
100%
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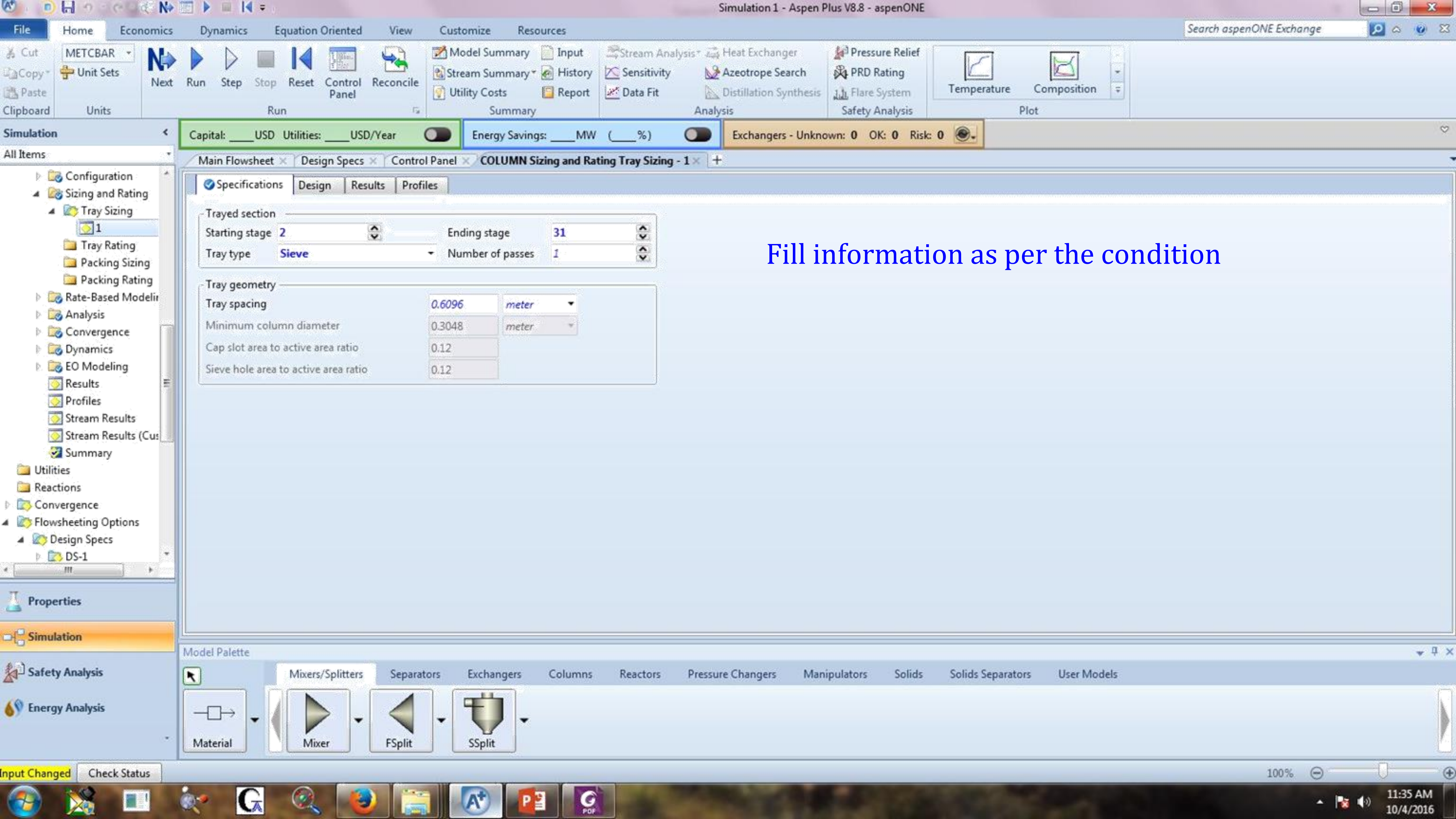
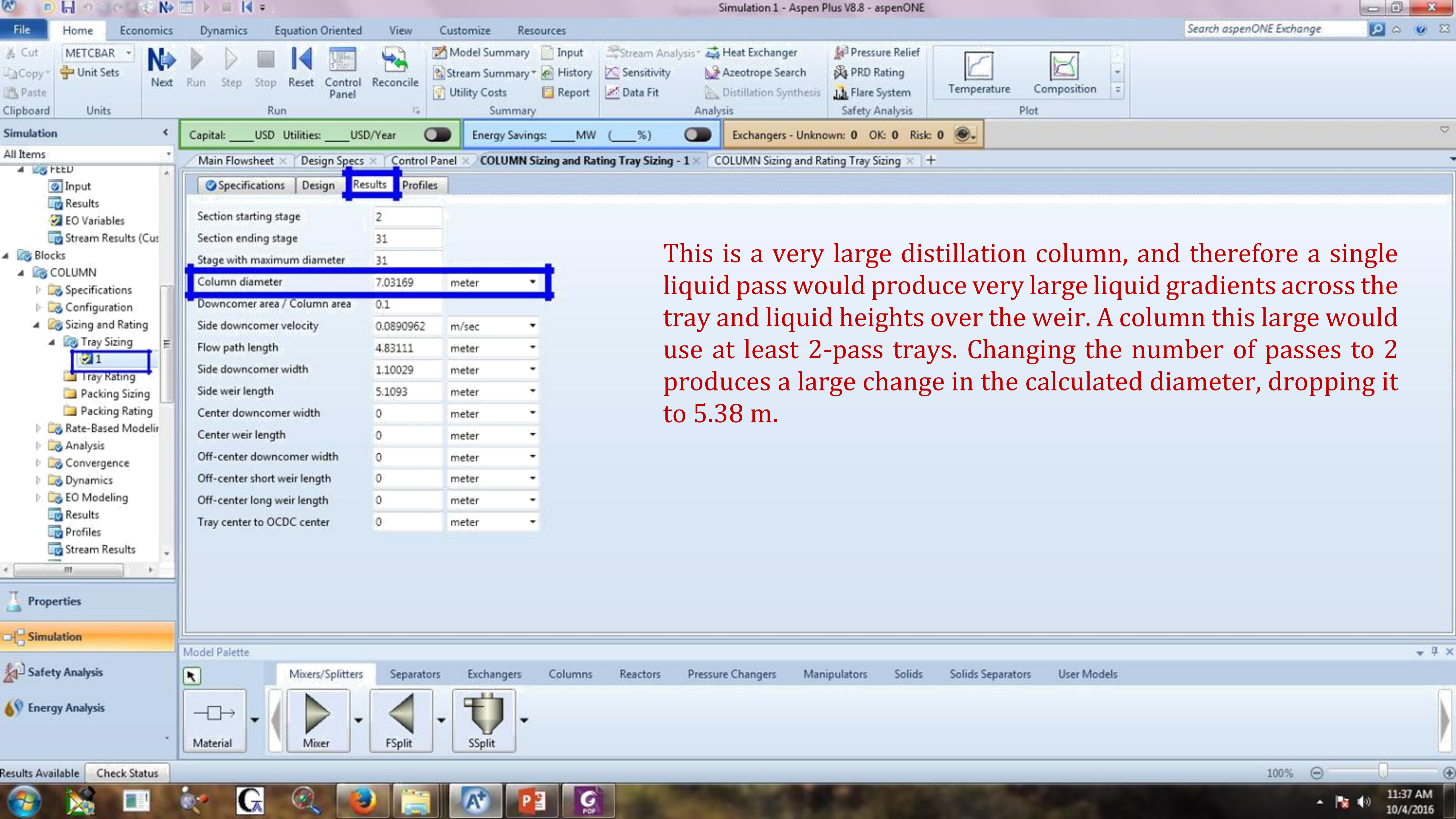
10/4/2016



Fill information as per the condition



This is a very large distillation column, and therefore a single liquid pass would produce very large liquid gradients across the tray and liquid heights over the weir. A column this large would use at least 2-pass trays. Changing the number of passes to 2 produces a large change in the calculated diameter, dropping it to 5.38 m.

Effect of feed stage on Reboiler heat duty

Feed Stage Number	Reboiler Heat Input (MW)	Condenser Heat Removal (MW)	Reflux Ratio
12	28.04	-23.58	3.64
13	27.54	-23.07	3.54
14	27.02	-22.56	3.44
15	**26.98**	**-22.51**	**3.43**
16	27.26	-22.80	3.49

Feed at stage 15 gives minimum Reboiler heat duty. [Feed stage/total no. of stages = 0.46875]

Now, change the number of stages in the column and use TAC calculation sheet to calculate the TAC.
(Maintain feed stage/total no. of stage ratio at 0.46875 while changing the total no. of stages)

TAC Calculation Sheet - Excel

Enter Values in YELLOW cell only.

TAC CALCULATION	1	2	3	4	5	6	
No. of Stages, NT							
Feed Stage, NF							
D(m)							
H(m)	-1.5	-1.5	-1.5	-1.5	-1.5	-1.5	H = 1.2*0.61*(NT-2)
Qc(MW)							
RR							
Qr(MW)							
Ac(m2)	0	0	0	0	0	0	
Ar(m2)	0	0	0	0	0	0	
Shell (10^6 $)	#NUM!	####	#NUM!	#NUM!	####	####	
HX (10^6 $)	0.00	0.00	0.00	0.00	0.00	0.00	
Energy (10^6/year)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	
Capital (10^6 $)	**#NUM!**	**###**	**#NUM!**	**#NUM!**	**###**	**###**	
TAC (10^6 $/year)	**#NUM!**	**###**	**#NUM!**	**#NUM!**	**###**	**###**	
L/D ratio	#DIV/0!	####	#DIV/0!	#####	####	####	

condenser			
	U	0.852	kW/(K m2)
	delta	13.9	K

Reboiler			
	U	0.568	kW/(K m2)
	delta	34.8	K

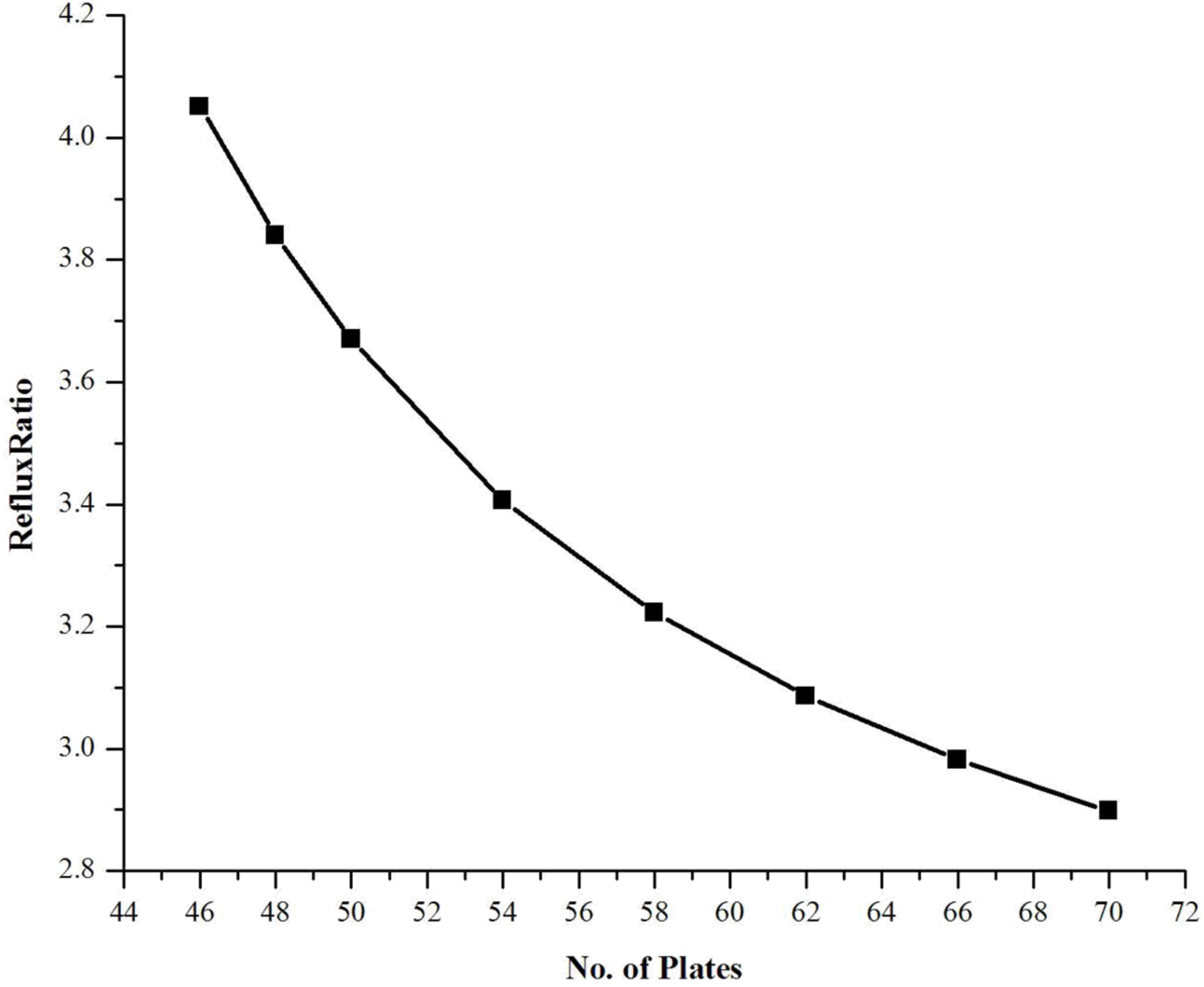
Energy cost 4.7 $/GJ

1	W	3.412142	BTU/hr
0	W	0	BTU/hr
		0	$

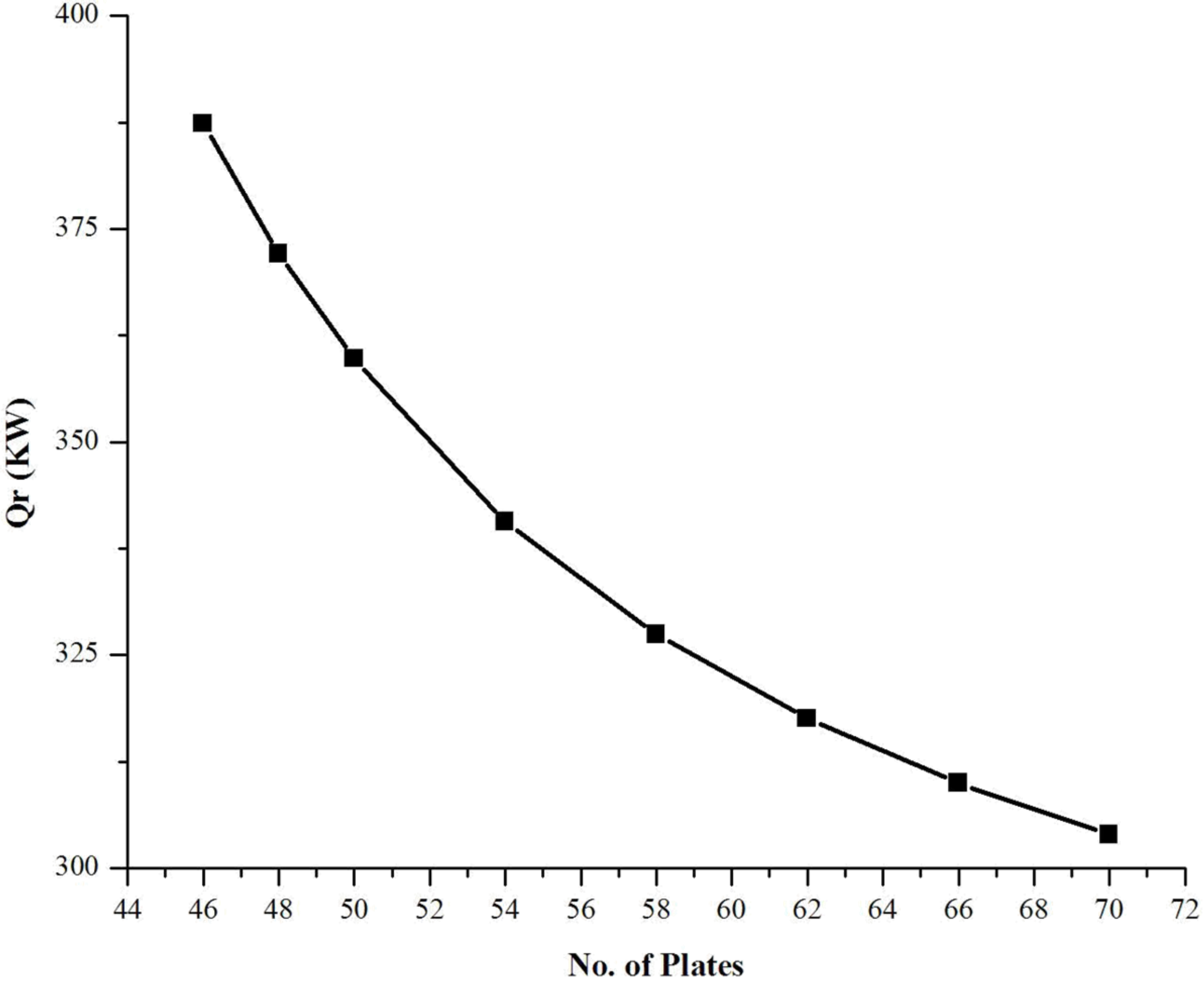
A design heuristic is to provide an additional 20% more height than that required.

TAC calculation sheet.

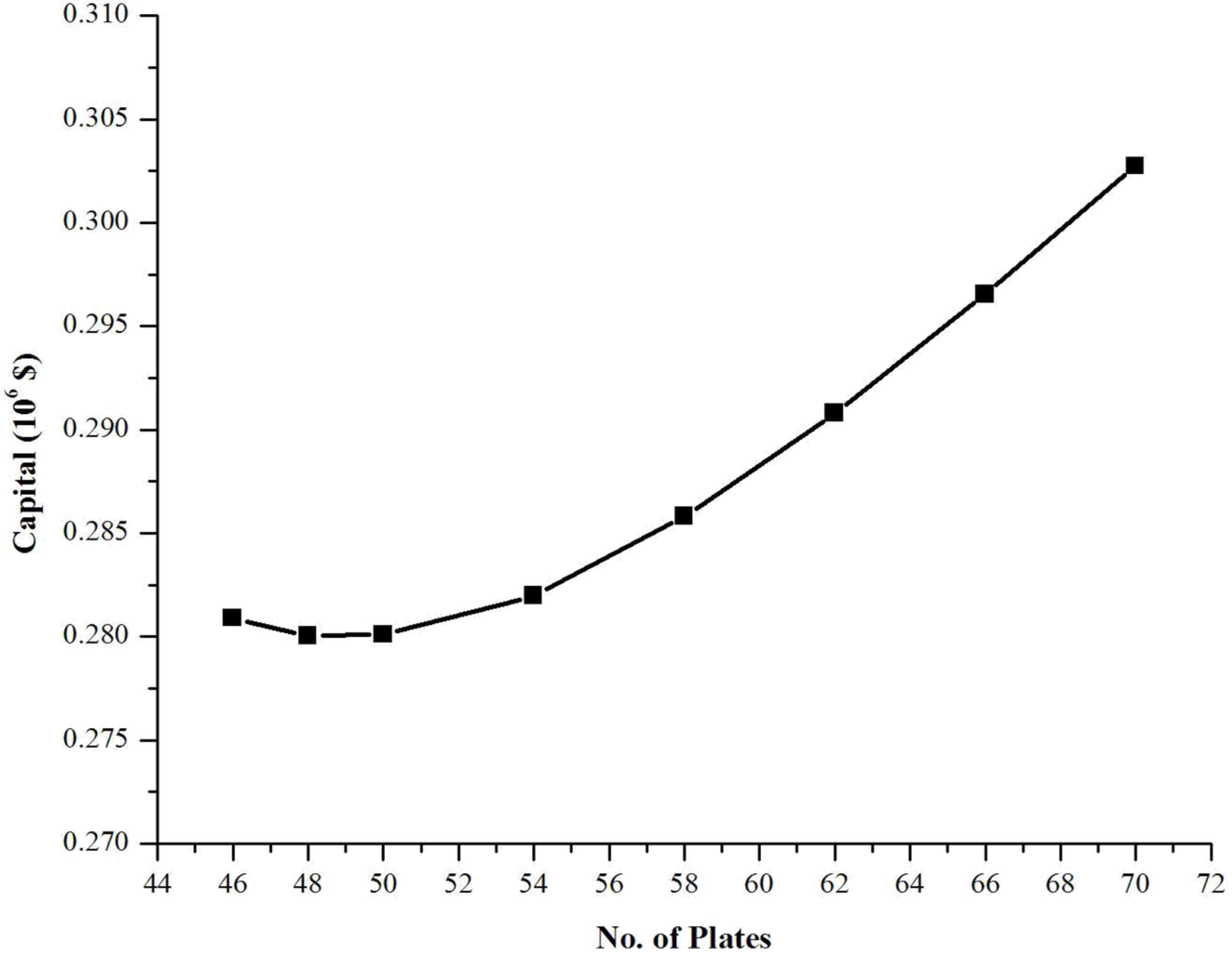
Download the sheet from the CL-402 Home page.



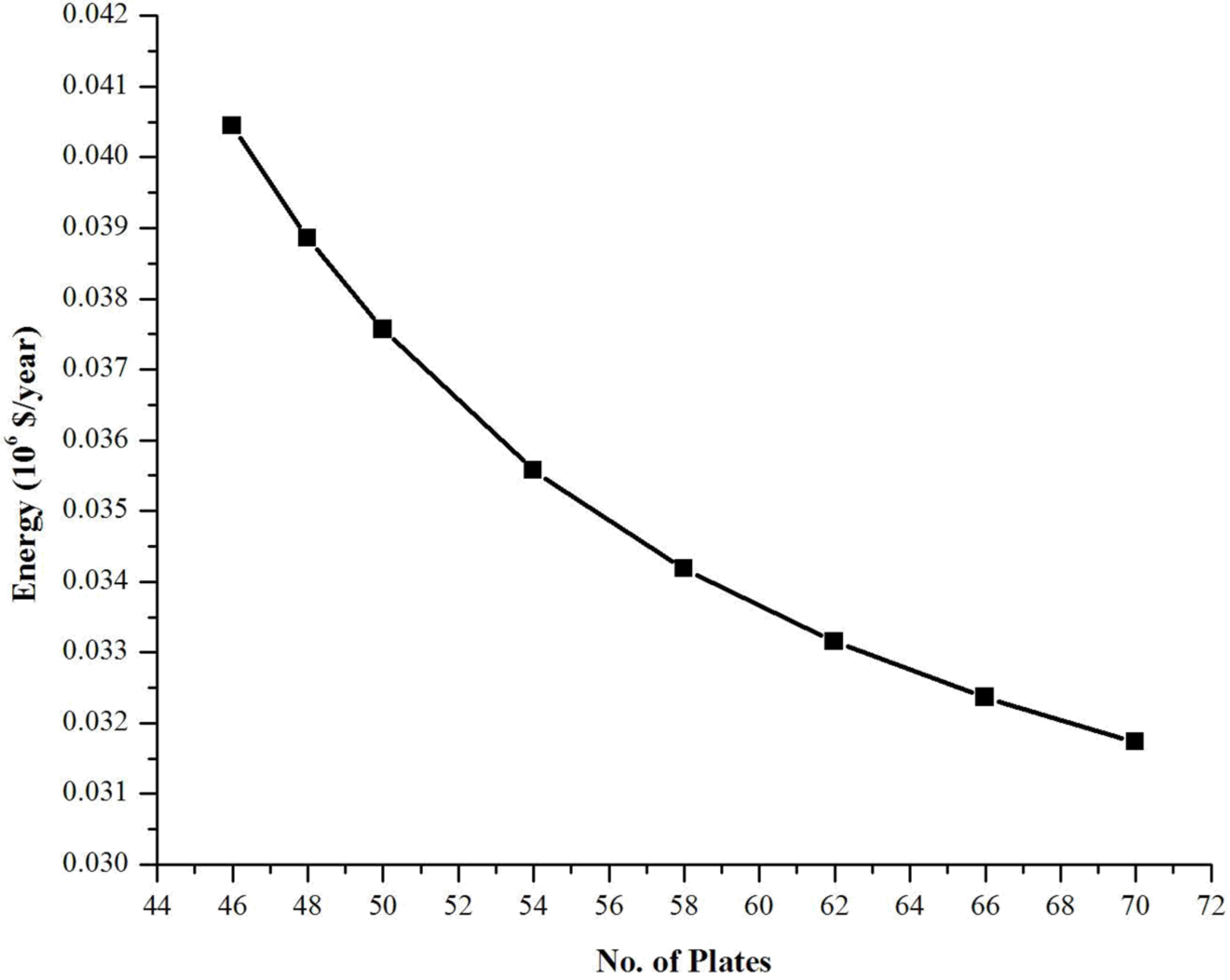
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
RefluxRatio
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
No. of Plates

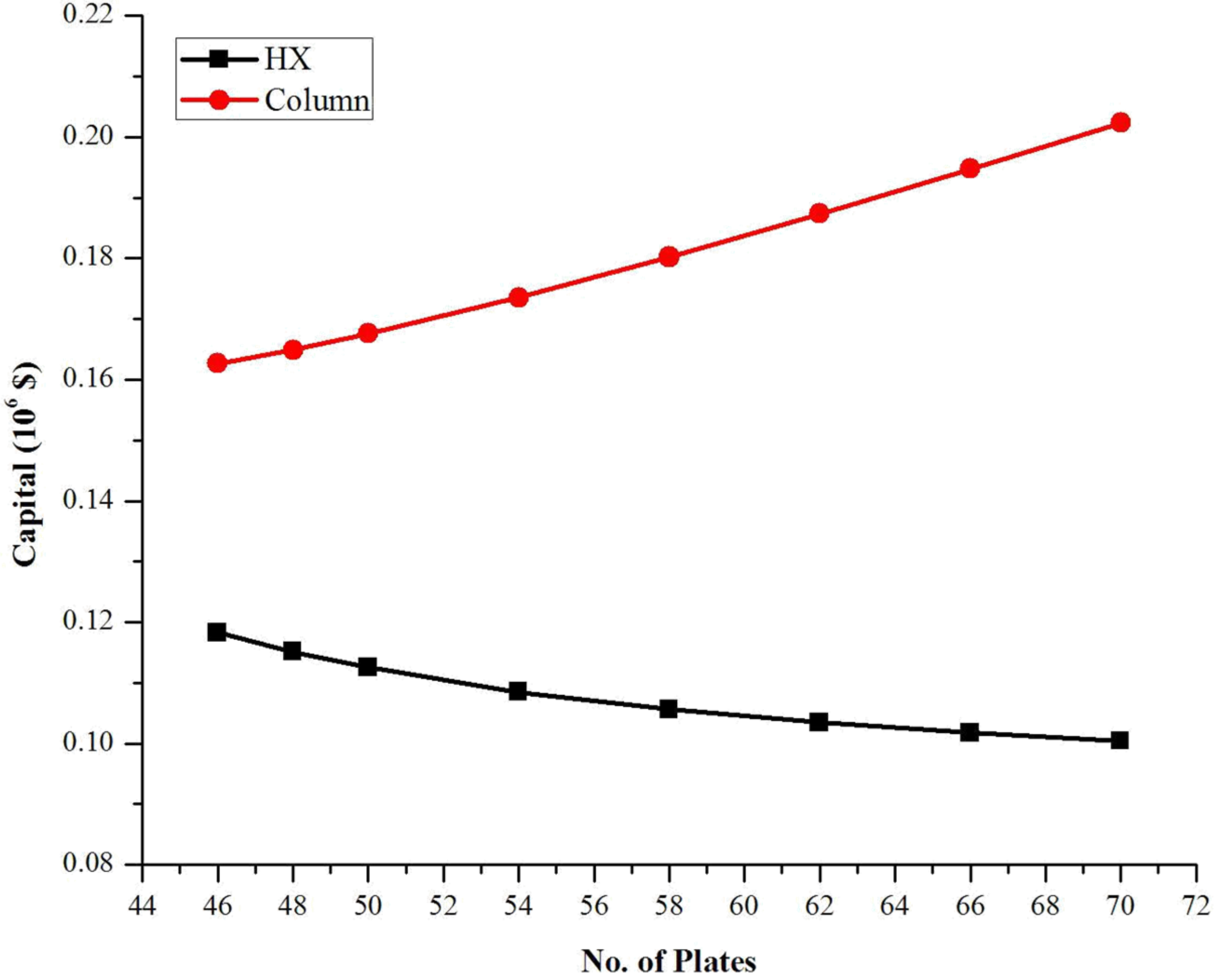


Qr (KW)
400
375
350
325
300
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
No. of Plates

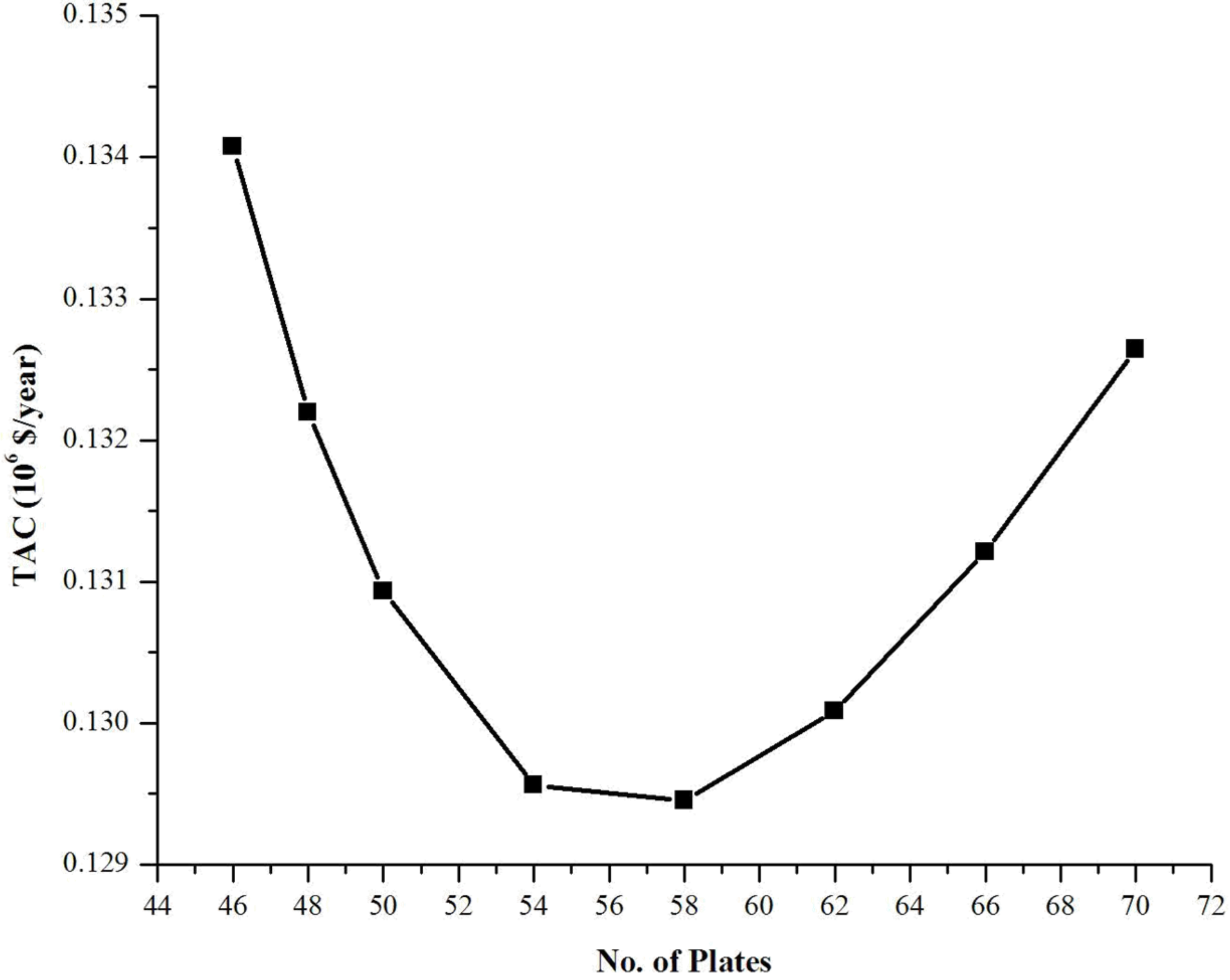


Capital (10^6 \$)
0.310
0.305
0.300
0.295
0.290
0.285
0.280
0.275
0.270
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
No. of Plates


0.042
0.041
0.040
0.039
0.038
0.037
0.036
0.035
0.034
0.033
0.032
0.031
0.030
Energy (10^6 $/year)
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72
No. of Plates



HX
Column
Capital (10^6 $)
No. of Plates
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
44
46
48
50
52
54
56
58
60
62
64
66
68
70
72



TAC (10^6 $/year)
0.135
0.134
0.133
0.132
0.131
0.130
0.129
44 46 48 50 52 54 56 58 60 62 64 66 68 70 72
No. of Plates

THE END