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Delayed Coking : Petro-SIM^{TM} Modeling

Detailed Examples

Agenda

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- **General Modeling Thoughts**
  - Why Do I Need A Coker Model
  - You Must Have A Good Mass Balance
  - What Data Is Generally Bad or Questionable – Why Is This The Case
  - Fit for Purpose – Do I Really Need That Much Detail
  - LP Generation

- **Areas of Discussion**
  - Feed to the Delayed Coker
  - Reactor Model – DC-SIM
  - Transfer Line & The OVHD Line Quench
  - Detailed Fractionator
  - Detailed Gas Plant
  - Simple Gas Plant for LP Generation
  - Furnace Model

Why Do I Need A Coker Model

- **Petro-SIM^{TM}** is the first and only process simulator capable of truly scalable modeling of all facets of processing hydrocarbons from gas-plant modeling including the production and power generation aspects of natural gas, process topsides facilities for oil and gas, through to detailed and rigorous refinery modeling including all key reaction systems. Petro-SIM^{TM} fits itself to the type of modeling you want to do, offering two *themes* that make sure you are presented with sensible choices for available unit operations, properties and functionality.
- **Petro-SIM^{TM} Production** is suited to modeling upstream or production facilities including gas plants, LNG plants and basic oil and gas separation platforms. Petro-SIM^{TM} provides ground-breaking technology to support benchmarking, evaluation and sustained profit improvement. Gas plant operators gain a competitive advantage and enhance profitability by reducing errors, improving decision-making and providing for easy access to asset wide knowledge and expertise.
- **Petro-SIM^{TM} Refining** is suited to modeling refinery and petrochemical processes, bringing a wide range of specialized reaction unit operations, extensive hydrocarbon characterization methods and a comprehensive range of refinery inspection properties to bear to help you build fully rigorous models of your facilities.

Reactor Model : DC-SIM

Start With a Good Mass Balance

- Generally a delayed coker mass balance will be close on the coke yield.
  - This assumes that the feed meter and product meters are correct.
  - A coke yield estimate should be done to check on the mass balance
  - Find a good coke yield correlation – there are several public domain correlations - and can be also used as a check on the balance.
- Normally, the H_2S and NH_3 are not measured and must be estimated.
  - Approximately 25% of the sulfur in the feed will go to H_2S
  - Approximately 15% of the nitrogen in the feed will go to NH_3
- A sulfur balance should be also done to help confirm the mass balance but care must be take to not over state the sulfur balance. A nitrogen balance is much more difficult and may not add to the quality of the mass balance.
- The mass balance flow data should take 3 to 5 drum cycles. For a 2 drum coker the timing of the samples and flow data is more critical – usually the data should be taken a few hours after a drum switch and before a drum warmup.

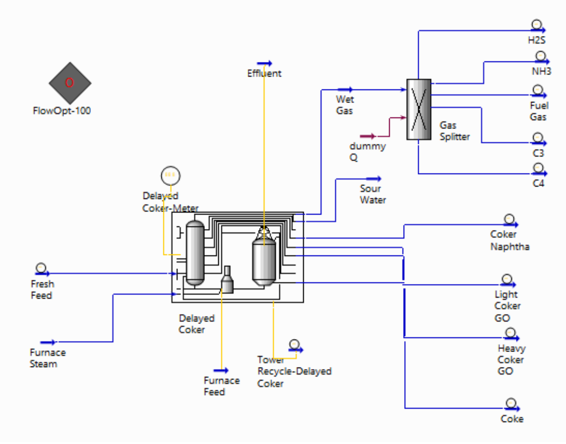
Modeling –Yield Estimates

“Modeling of Processes and Reactors for Upgrading of Heavy Petroleum”

Jorge Ancheyta

Reactor Model - DC-SIM Calibration

- The Model must have a calibration to run
- The calibration does not need to be the exact same operations and feed as the actual operations but the it should be similar
- If the calibration is not good you will get bad results
- You should generate a calibration file 1st and keep it as a separate file you may need to go back and recalibrate if/when you final simulation needs to be adjusted
- The calibration is generally done through the meters associated with each feed/product streams.



Recommendation On Calibration

- First do the calibration on mass only – the sulfur and nitrogen and be add
- You may want to set the feed rate and coke yield
- If your mass balance is good hen there will be few changes in the calibration but it is highly unlikely that the calibration will match you mass balance perfectly

Case 1: Simple Material Balance Example

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Summary Balance Coker Yields	BPD [BFOE]	Vol%	UOP K	API Gravity	Mass		Sulfur		Nitrogen		Carbon		C:H	MW	Mol /Hr	Total Metals ppm
					Lbs/Hr	wt%	Lbs/Hr	wt%	Lbs/Hr	ppm	Lbs/Hr	wt%	wt Ratio			
Coker Feed	60,000	100.0%	11.24	4.00	913,223	100.00%	41,095	4.50%	4,566.1	5,000	774,809	84.84%	8.39	704.8	1,295.7	387.0
Total Feed	60,000	100.0%	11.24	4.00	913,223	100.00%	41,081	4.50%	4,564.6	4,998	774,704	84.83%	8.37	704.8	1,295.7	387.0
Hydrogen Sulfide					10,916	1.20%	10,270	94.13%						34.1	320.3	
NH3					832	0.09%			684.7	82.25%				17.0	48.9	
C5 & Lter Gas Without H2S & NH3	12,478	20.8%			71,851	7.87%					57,301	79.75%	4.10	28.5	2,524.2	
Fuel Gas [C2 & Lter]	8,484	14.1%			39,930	4.37%					30,717	76.93%	3.34	19.0	2,099.2	
LPG [C3s & C4s]	3,994	6.7%			31,921	3.50%					26,584	83.28%	4.98	49.9	640.2	
Light Naphtha [C5 - 300]	11,061	18.4%	11.86	63.28	117,113	12.82%	1,633	1.39%	44.0	384.4	98,284	83.92%	5.73	111.0	1,055.4	0.0
Light Gas Oil [386 - 620]	11,821	19.7%	11.65	34.13	147,192	16.12%	3,606	2.45%	181.7	1,234.2	124,802	84.79%	6.71	210.4	699.7	0.5
Heavy Gas Oil [620 plus]	18,895	31.5%	11.29	16.50	263,306	28.83%	8,973	3.41%	638.6	2,425.5	224,295	85.18%	7.63	353.8	744.2	5.2
Coke [406.9 lbs/BFOE]	[17,797]	29.7%			301,711	33.04%	16,599	5.50%	3,015.6	1.00%	270,021	89.50%	23.03			1,166.2
Total Products	54,256	120.1%			912,922	99.97%	41,081	4.50%	4,564.6	5,000	774,704					387.0
Recycle	5,998	10.0%	11.09	5.18	90,506	9.91%	3,836	4.24%	338.5	3,741	77,114	85.20%	8.37	568.8	159.1	14.4

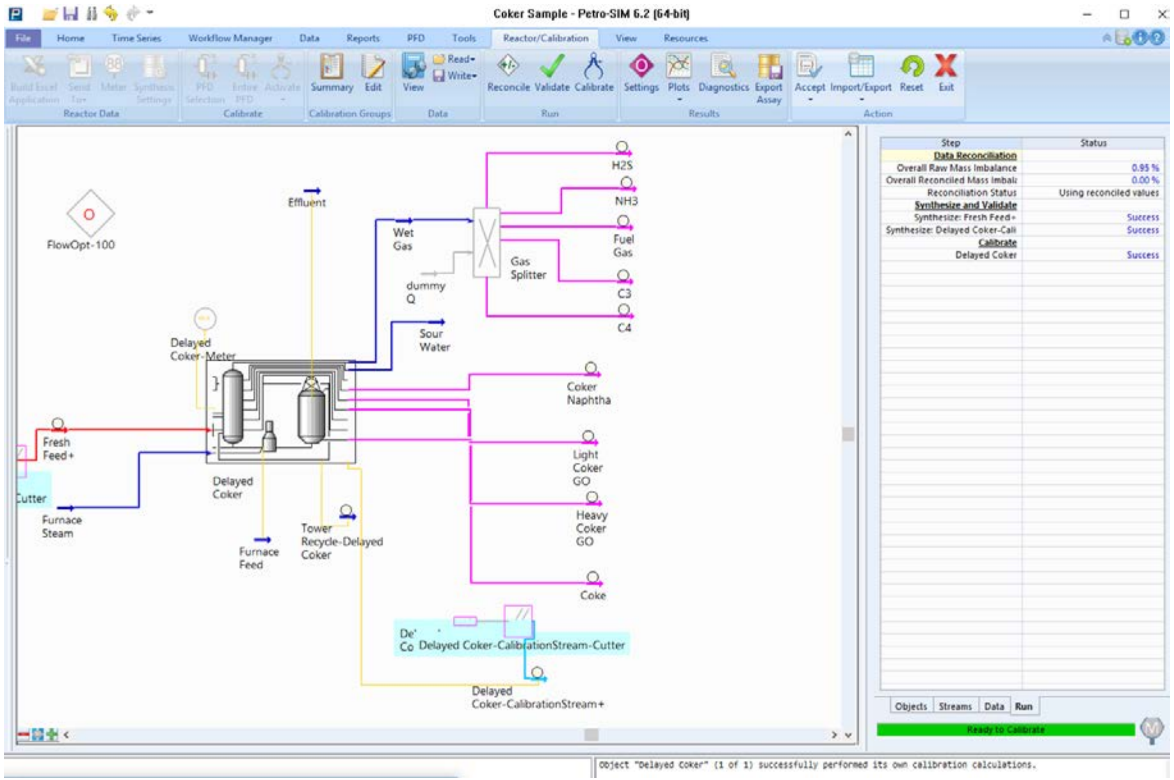
Mass Balance Closure	99.97%
Sulfur Balance Closure	100.00%
Nitrogen Balance Closure	100.00%
Carbon Balance Closure	100.00%
Metals Balance	100.00%

Coke Drum OVHD Press. psig	20	Coke Drum Fill Time, hrs	16	Coke wt% VCM	11.09%
Coke Drum OVHD Temp., F	820.0	Coke Drum Utilization, % of Working Vol	99.4%	Coke HGI	39.06
Recycle Ratio	1.10	C-Factor	0.28	Coke wt% Shot	83.1%

Calibration Error Sum	1.05%
Average Calibration Error	0.21%

This is an example of a detailed material balance, which KBC uses internally to estimate coker yields – not part of Petro-Sim

Case 1: Simple Calibration – Mass Balance Only



Calibration with a mass balance and then a mass, sulfur and nitrogen balance

Case 2 – Multiple Feeds & Types Material Balance

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Summary Balance Coker Yields	BPD [BFOE]	Vol%	UOP K	API Gravity	Mass		Sulfur		Nitrogen		Carbon		C:H	MW	Mol /Hr	Total Metals ppm
					Lbs/Hr	wt%	Lbs/Hr	wt%	Lbs/Hr	ppm	Lbs/Hr	wt%	wt Ratio			
3-Fd Case - VTB	70,000	62.5%	11.25	5.00	1,057,622	61.93%	54,996	5.20%	5,288.1	5,000	890,029	84.15%	8.33	666.0	1,588.1	437.0
3-Fd Case - Slurry	7,000	6.3%	9.95	0.50	109,368	6.40%	1,203	1.10%	282.7	2,585	98,214	89.80%	10.30	274.4	398.6	1,211.7
3-Fd Case - SDA Rock	35,000	31.3%	11.30	2.00	540,694	31.66%	31,360	5.80%	2,225.0	4,115	452,732	83.73%	8.40	855.4	632.1	935.0
Total Feed	112,000	100.0%	11.18	3.76	1,707,684	100.00%	87,560	5.13%	7,795.8	4,565	1,440,408	84.35%	8.43	652.1	2,618.8	644.3
Hydrogen Sulfide					23,526	1.38%	22,134	94.13%						34.1	690.3	
NH3					1,334	0.08%			1,097.4	82.25%				17.0	78.3	
C5 & Lter Gas Without H2S & NH3	24,234	21.6%			141,203	8.27%					112,812	79.89%	4.10	28.5	4,960.6	
Fuel Gas [C2 & Lter]	14,467	12.9%			63,744	3.73%					48,361	75.87%	3.15	17.2	3,700.1	
LPG [C3s & C4s]	9,767	8.7%			77,458	4.54%					64,451	83.21%	4.96	49.1	1,578.6	
Light Naphtha [C5 - 300]	18,542	16.6%	12.14	62.12	197,495	11.57%	3,195	1.62%	50.2	260.7	165,434	83.77%	5.74	108.1	1,826.9	0.0
Light Gas Oil [386 - 650]	24,183	21.6%	11.56	32.03	304,988	17.86%	8,360	2.74%	276.4	906.2	258,441	84.74%	6.82	216.0	1,411.8	0.7
Heavy Gas Oil [650 plus]	34,349	30.7%	11.22	14.45	485,366	28.42%	19,165	3.95%	848.5	1,748.1	412,232	84.93%	7.76	372.3	1,303.6	6.1
Coke [410.5 lbs/BFOE]	[32,374]	28.9%			553,772	32.43%	34,705	6.27%	5,523.2	1.00%	491,489	88.75%	23.45			1,981.1
Total Products	101,307	119.4%			1,707,684	100.00%	87,560	5.13%	7,795.8	4,565	1,440,408					644.3
Recycle	8,961	8.0%	11.06	3.68	136,708	8.01%	6,868	5.02%	386.6	2,828	115,794	84.70%	8.48	607.8	224.9	17.2

Mass Balance Closure	100.00%
Sulfur Balance Closure	100.00%
Nitrogen Balance Closure	100.00%
Carbon Balance Closure	100.00%
Metals Balance	100.00%

Coke Drum OVHD Press. psig	15	Coke Drum Fill Time, hrs	16	Coke wt% VCM	11.24%
Coke Drum OVHD Temp., F	818.0	Coke Drum Utilization, % of Working Vol	95.8%	Coke HGI	37.21
Recycle Ratio	1.08	C-Factor	0.30	Coke wt% Shot	87.0%

Calibration Error Sum	18.48%
Average Calibration Error	3.70%

This is an example of a detailed material balance, which KBC uses internally to estimate coker yields – not part of Petro-Sim

Case 2 – Multiple Feeds & Types Calibration

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Reconcile
Meter Data

Show: Detailed
☐ Show Component Flows

	Mass flow					Nitrogen content					Sulfur content				
	Screened	Typical Error	Error Basis	Reconciled	Rec Error	Screened	Typical Error	Error Basis	Reconciled	Rec Error	Screened	Typical Error	Error Basis	Reconciled	Rec Error
FCC Slurry Oil-Meter	109368 lb/hr	2.00 %	Relative	109326 lb/hr	0.04 %	0.2585 wt %	2.00 %	Relative	0.2585 wt %	0.00 %	1.1000 wt %	2.00 %	Relative	1.1000 wt %	0.00 %
SDA Pitch-Meter	540697 lb/hr	2.00 %	Relative	540605 lb/hr	0.02 %	0.4116 wt %	2.00 %	Relative	0.4116 wt %	0.00 %	5.8000 wt %	2.00 %	Relative	5.8000 wt %	0.00 %
Vac Resid-Meter	1057627 lb/h	2.00 %	Relative	1057663 lb/h	0.00 %	0.5000 wt %	2.00 %	Relative	0.5000 wt %	0.00 %	5.2000 wt %	2.00 %	Relative	5.2000 wt %	0.00 %
Feed Total	1707692 lb/h			1707594 lb/h		7796 lb/hr			7796 lb/hr		87560 lb/hr			87556 lb/hr	
Coke-Meter	553772 lb/hr	2.00 %	Relative	552533 lb/hr	0.22 %	1.0000 wt %	2.00 %	Relative	1.0000 wt %	0.00 %	6.3000 wt %	2.00 %	Relative	6.3000 wt %	0.00 %
Coker_Naphtha-Meter	197495 lb/hr	2.00 %	Relative	197686 lb/hr	0.10 %	0.0260 wt %	2.00 %	Relative	0.0260 wt %	0.00 %	1.6000 wt %	2.00 %	Relative	1.6000 wt %	0.00 %
Fuel_Gas-Meter	63744 lb/hr	2.00 %	Relative	63767 lb/hr	0.04 %	0.0000 wt %	2.00 %	Relative	0.0000 wt %		0.0000 wt %	2.00 %	Relative	0.0000 wt %	
H2S-Meter	23526 lb/hr	5.00 %	Relative	23395 lb/hr	0.56 %	0.0000 wt %	2.00 %	Relative	0.0000 wt %		94.1177 wt %	2.00 %	Relative	94.1177 wt %	0.00 %
Heavy_Coker_GO-Meter	485366 lb/hr	2.00 %	Relative	486038 lb/hr	0.14 %	0.1750 wt %	2.00 %	Relative	0.1750 wt %	0.00 %	3.9500 wt %	2.00 %	Relative	3.9500 wt %	0.00 %
Light_Coker_GO-Meter	304988 lb/hr	2.00 %	Relative	305354 lb/hr	0.12 %	0.0906 wt %	2.00 %	Relative	0.0906 wt %	0.00 %	2.7400 wt %	2.00 %	Relative	2.7400 wt %	0.00 %
LPG-Meter	77458 lb/hr	2.00 %	Relative	77493 lb/hr	0.05 %	0.0000 wt %	2.00 %	Relative	0.0000 wt %		0.0000 wt %	2.00 %	Relative	0.0000 wt %	
NH3-Meter	1334 lb/hr	5.00 %	Relative	1328 lb/hr	0.47 %	82.2436 wt %	2.00 %	Relative	82.2436 wt %	0.00 %	0.0000 wt %	2.00 %	Relative	0.0000 wt %	
Product Total	1707683 lb/h			1707594 lb/h		7812 lb/hr			7796 lb/hr		87718 lb/hr			87556 lb/hr	
Overall Imbalance	9 lb/hr			1 lb/hr		-16 lb/hr			0 lb/hr		-158 lb/hr			0 lb/hr	
Overall Imbalance %	0.00 %			0.00 %		-0.20 %			0.00 %		-0.18 %			0.00 %	

☑ Only Overall Balances
☑ Auto Solve
☑ Auto Accept

Reconcile!
Accept
Reset Values

Warning Level	1.000
Error Level	3.000
Objective	4.574e-002

Data Sources | Configure | Reconcile | Balances | TroubleShooting

Delete
OK
☐ Ignor

Case 2 – Multiple Feeds & Types Calibration

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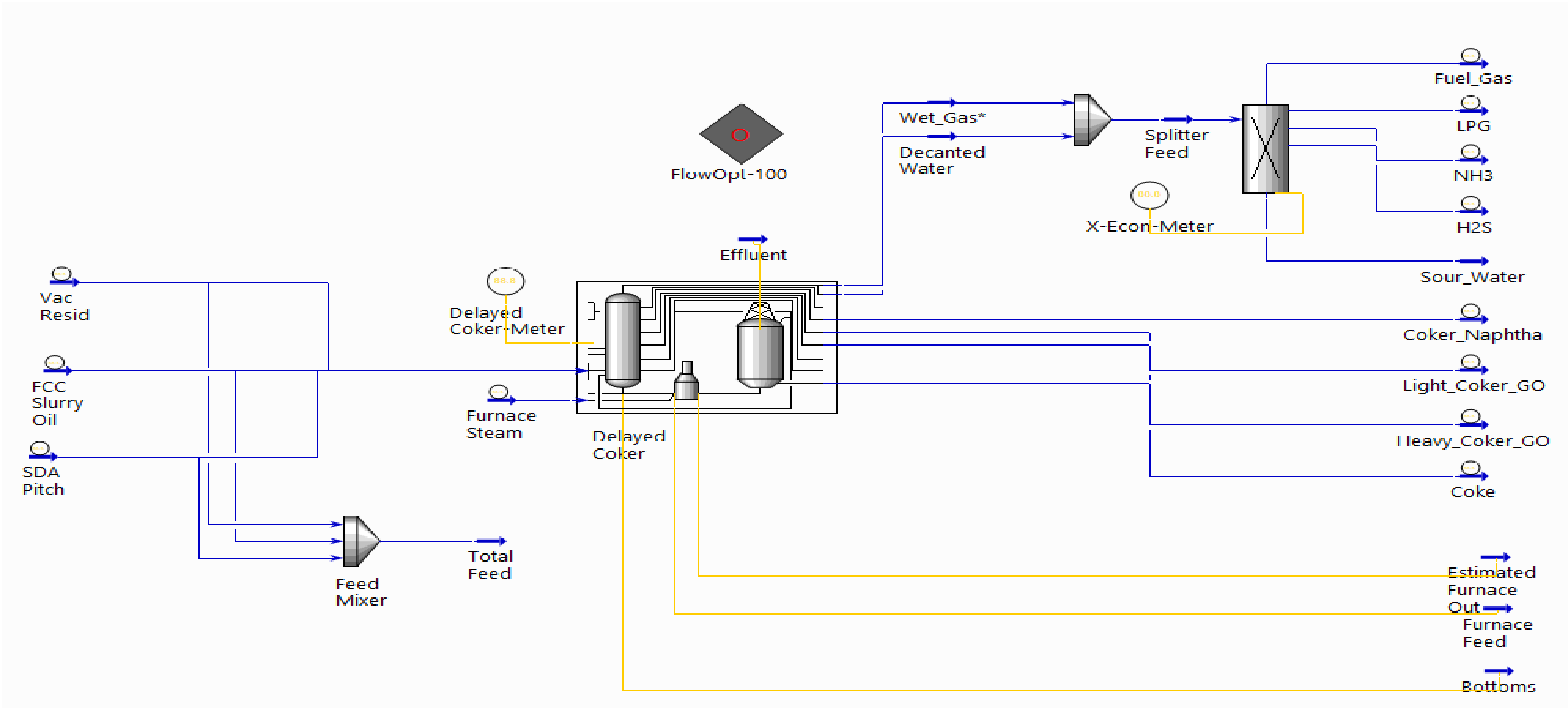

Case 2 – Generate a Material Balance

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Material Balance

Current Cell

Exportable

B1 Variable: Angles in:

	A	B	C	D	E	F	G
1		Vol Flow	API Gravity	Mass Flow	wt% Yield	wt% Sulfur	wt% Nitrogen
2	Vac Resid	70000 barrel/day	4.994	1057663 lb/hr	61.94 %	5.2000 wt %	0.5000 wt %
3	FCC Slurry	6997 barrel/day	0.5000	109326 lb/hr	6.40 %	1.1000 wt %	0.2585 wt %
4	SDA Pitch	34995 barrel/day	2.003	540605 lb/hr	31.66 %	5.8000 wt %	0.4116 wt %
5				1707594 lb/hr	100.00 %		
6							
7	H2S			23394 lb/hr	1.37 %		
8	NH3			1328 lb/hr	0.08 %		
9	Fuel Gas			63766 lb/hr	3.73 %		
10	LPG Product	10169 barrel/day	127.4	81009 lb/hr	4.74 %		
11	Naphtha	18155 barrel/day	62.19	193304 lb/hr	11.32 %	1.5978 wt %	0.0264 wt %
12	LCGO	24300 barrel/day	32.05	306427 lb/hr	17.94 %	2.7396 wt %	0.0905 wt %
13	HCGO	34592 barrel/day	14.70	487983 lb/hr	28.58 %	3.9523 wt %	0.1751 wt %
14	Coke			550382 lb/hr	32.23 %	6.3182 wt %	1.0033 wt %
15				1707594 lb/hr	100.00 %		
16							
17							
18							
19							
20							

Delayed Coker

Results
- Operating Conditions
  - Furnace
  - Drum
  - Quench
  - Fractionator
- Profiles
  - Pressure
  - Temperature
  - Heat
  - Molar Conversion
  - Sulfur
  - Nitrogen
  - Metals
  - Watson K-Factor
  - Molecular Weight
- Yields
  - Weight Percent Basis
  - Weight Basis
  - Volume Percent Basis
  - Volume Basis
  - Fuel Gas & Light Ends
- Coke Properties
- Economic Results
- S vs API Plot
- Diagnostics

Run Time Interval [hours]	0.0000
Opening Inventory [% of Max.]	50.00
Closing Inventory [% of Max.]	50.00
Run Time at Opening Inventory [hours]	<empty>
Run Time at Closing Inventory [hours]	<empty>
Opening Outage [ft]	67.02
Closing Outage [ft]	67.02
Minimum Outage [ft]	30.00
Closing Inventory [ft3]	26171.07
Maximum Coke Volume [ft3]	52342.13
Coke Production Rate [lb/hr]	550390
Weight of HC Vapor Leaving Drum [lb/hr]	1263551
Calculated Drum Fill Time (to Min. Outage) [hours]	15.98
Drum Liquid Holdup [ft3]	1117.52
Notional Depth of Drum Liquid Holdup [ft]	1.581
Drum Vapor Space [ft3]	39899.59
Total Vap Mass Rate per Drum [lb/hr]	432442
Total Vap Vol Rate per Drum [ACFM]	28422.4
Drum Vapor Velocity [ft/s]	0.6701
Drum C Factor	0.3374
Foam Height [ft]	12.03
Foam Height with anti-Foam [ft]	6.016
Remaining Vapor Space Height [ft]	60.52
Foam Over Potential at Closing Inv, %	0.0000
Foam Over Potential at Fill End, %	16.74

Case 2 – Naphtha Component Details

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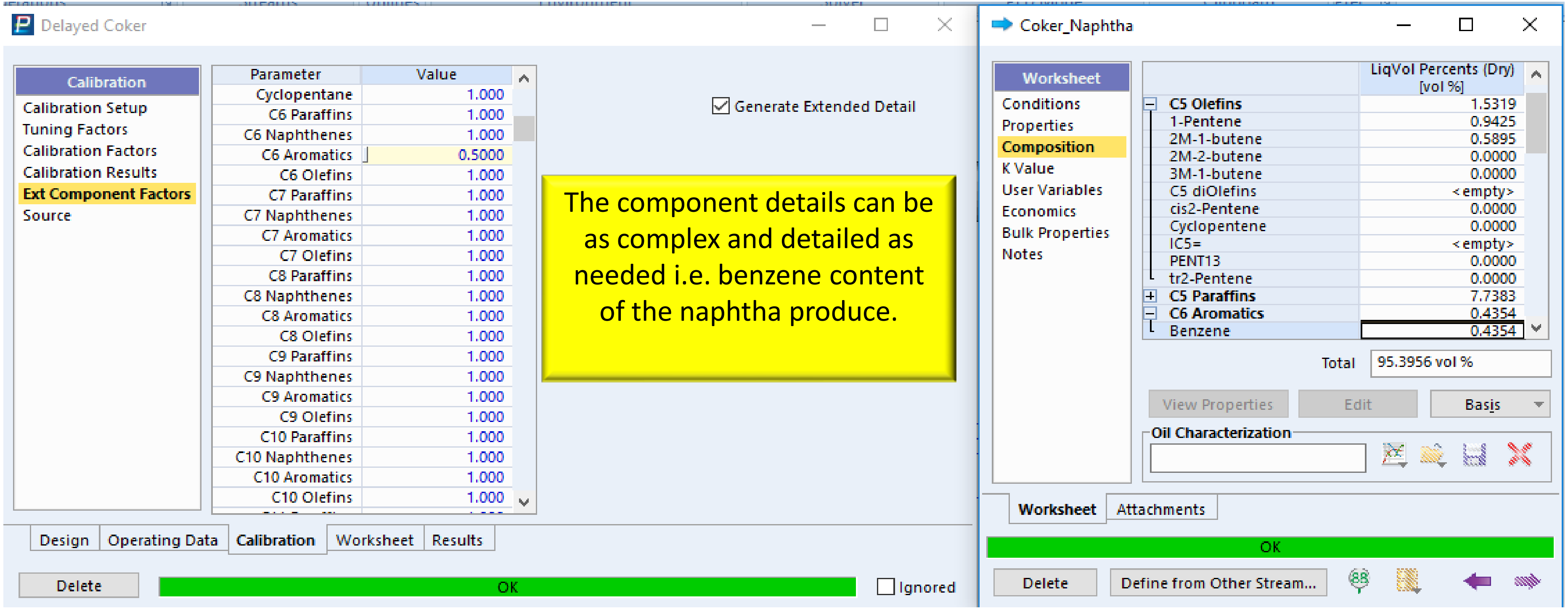
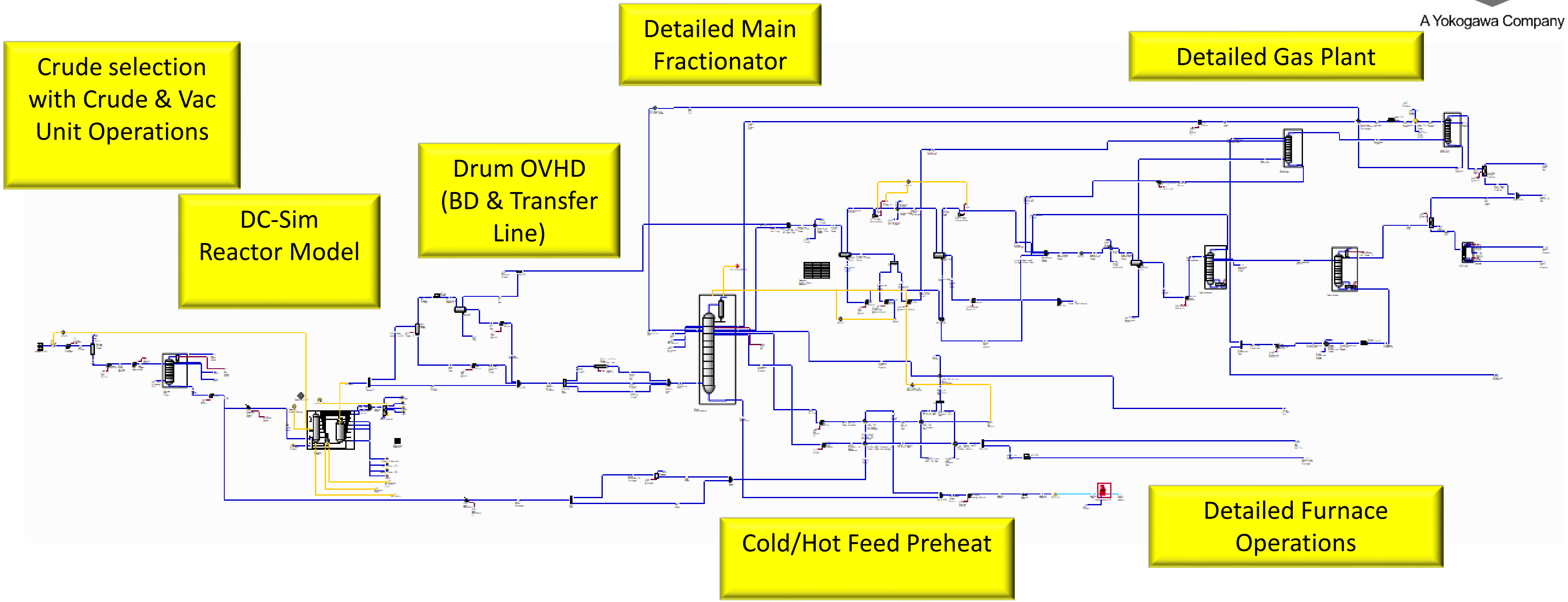


The component details can be as complex and detailed as needed i.e. benzene content of the naphtha produce.

Case 3: Typical Delayed Coker Model



Coker Feed Definition

Feed Definition

- Set By Meter – Used in the calibration
- Set by Plant Data – Easy access
- Set by Crude/Vac Unit Operations – best if the crude slate is defined or will be changed as part of the study. This is also done with a whole refinery model.

Crude Selection & Crude/Vacuum Unit Operations

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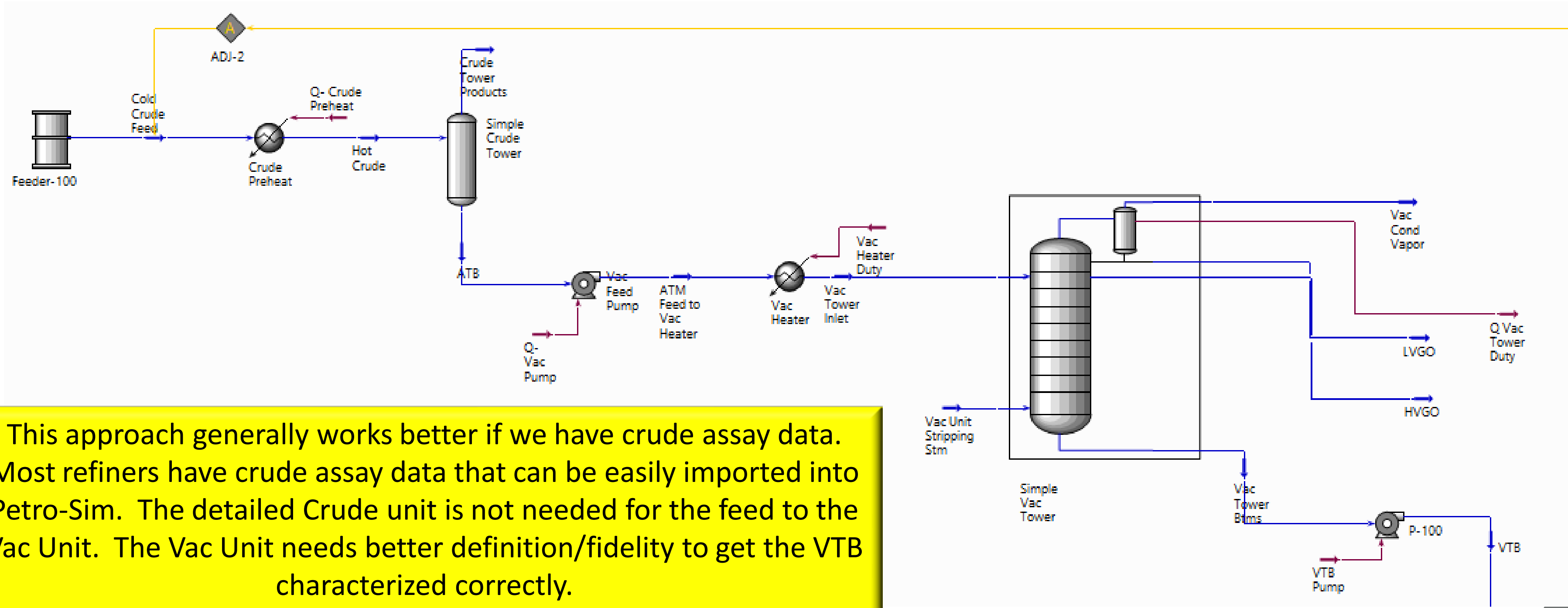

This approach generally works better if we have crude assay data. Most refiners have crude assay data that can be easily imported into Petro-Sim. The detailed Crude unit is not needed for the feed to the Vac Unit. The Vac Unit needs better definition/fidelity to get the VTB characterized correctly.

Crude Selection & Crude Rate – Very Heavy & Light Mix

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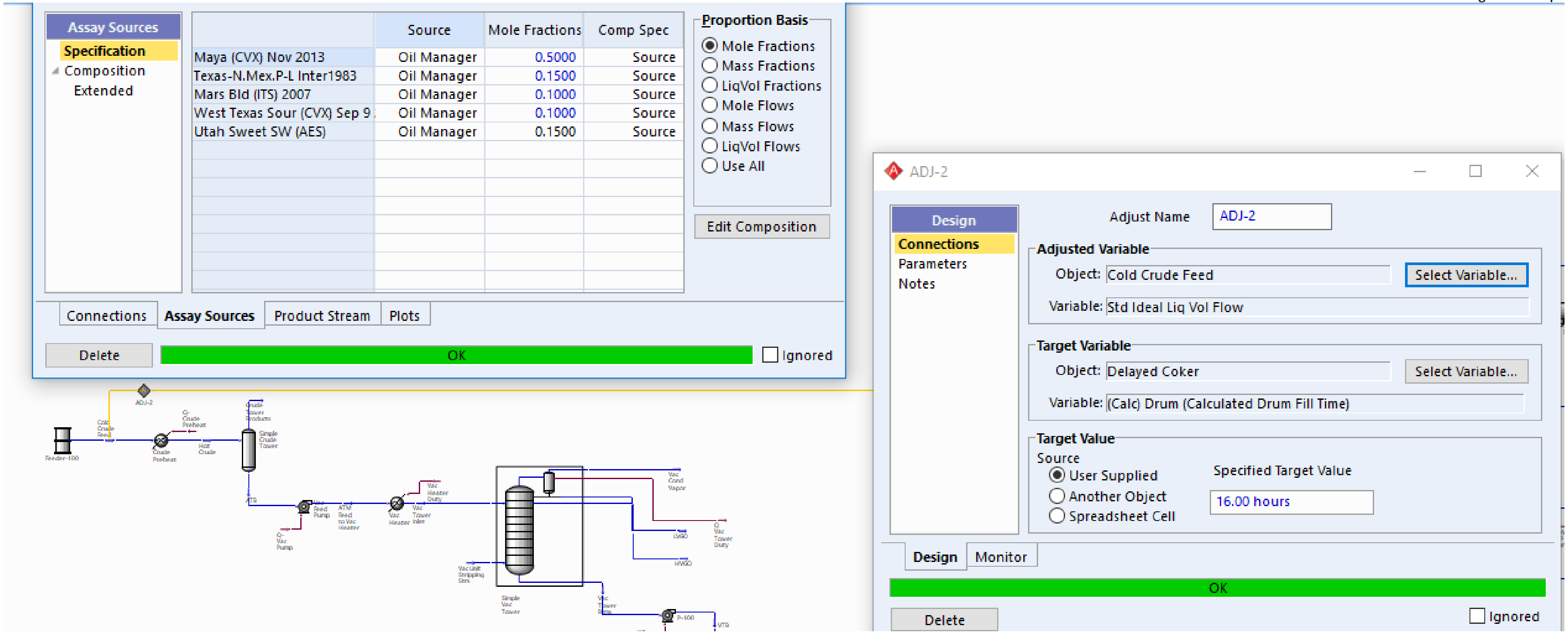

The crude selection, crude rate and Vac cut point can be optimized to any product spec or unit operation required. In this case we adjust the crude rate to get a 16 hour fill cycle.

Coker Feed Results - Vac Unit Cut Point & Crude Types

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VTB

Worksheet
- Conditions
- **Properties**
- Composition
- K Value
- User Variables
- Economics
- Bulk Properties
- Notes
- Time Series
- Time Results

Volume Average Boiling Point [F]	1324
API Gravity (Dry)	1.980
Specific Gravity (Dry)	1.060
Watson K	11.34
Conradson Carbon Content [wt %]	27.9376
Asphaltenes Content [wt %]	25.0829
Sulfur Content [wt %]	5.5228
Nitrogen Content [wt %]	0.6127
Naphthenes by Wt [wt %]	28.3297
Aromatics by Wt [wt %]	65.2622
Refractive Index_67	1.565
Nickel Content [ppmwt]	124.4
Vanadium Content [ppmwt]	628.1
Iron Content [ppmwt]	25.63
Viscosity (Kinematic)_50 [cSt]	4.577e+007
Viscosity (Kinematic)_100 [cSt]	8.188e+004
C To H Ratio [wt %]	8.2927
Mass Lower Heating Value_Methoc	1.655e+004
Distillation ASTM D1160_01 [F]	867.2
Distillation ASTM D1160_05 [F]	988.6
Distillation ASTM D1160_10 [F]	1029
Distillation ASTM D1160_30 [F]	1158
Distillation ASTM D1160_50 [F]	1339
Distillation ASTM D1160_70 [F]	1538

Property Controls

Column: Simple Vac Tower / COL1 Fluid Pkg: Basis-1 / Peng Robinson - LK

Design
- Connections
- **Monitor**
- Specs
- Specs Summary
- Subcooling
- Notes

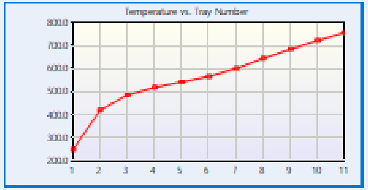
Optional Checks

Input Summary | View Initial Estimates...

Iter	Step	Equilibrium	Heat / Spec
1	1.000	3.799e-015	2.564e-006

Profile

- Temp
- Press
- Flows



Specifications

	Specified Value	Current Value	Wt. Error	Active	Estimate	Current
Reflux Ratio	2.000	2.000	4.108e-006	☑	☑	☑
VTB TBP CutPoint On F	990.0 F	990.0	-1.059e-006	☑	☑	☑
Condenser Temperatur	250.0 F	250.0	7.654e-009	☑	☑	☑
LVGO TBP CutPoint On	670.0 F	802.5	0.2077	☐	☐	☐

Feeder-100

Assay Sources
- **Specification**
- Composition
  - Extended

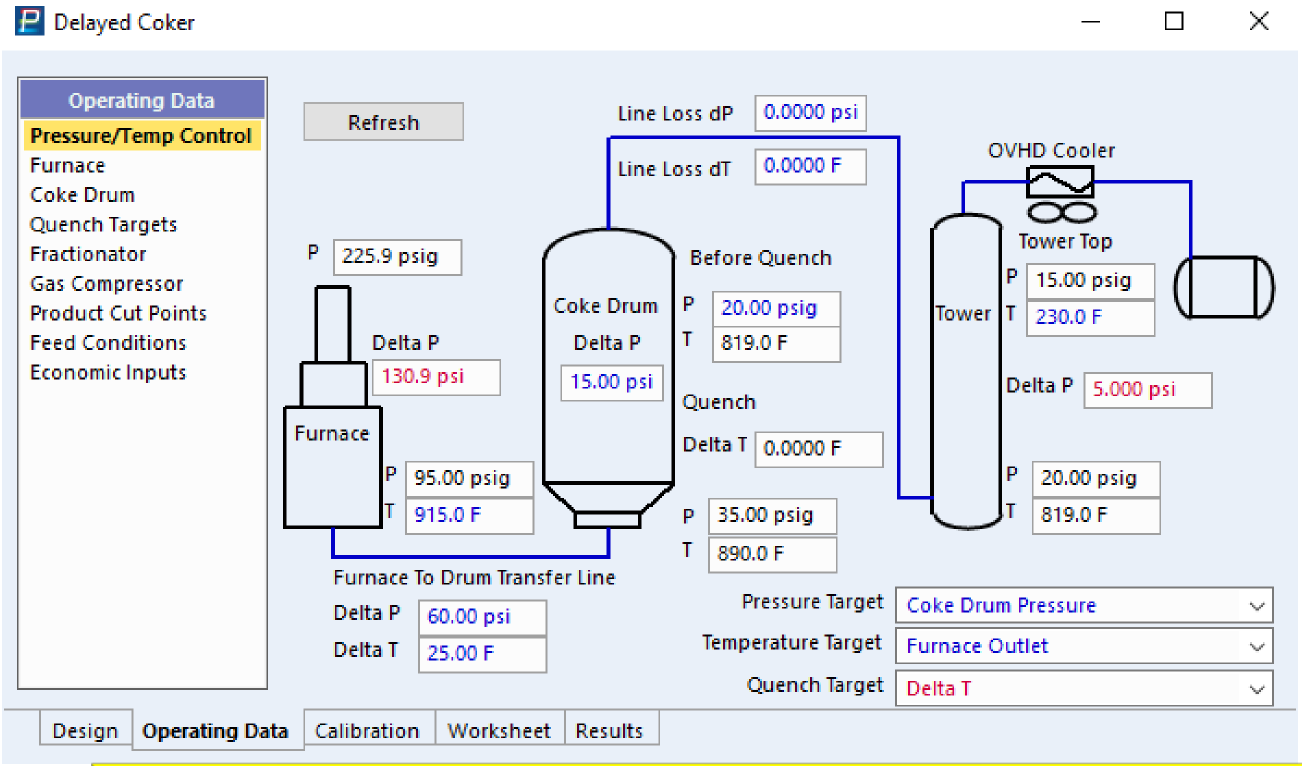
	Source	Mole Fractions	Comp Spec
Maya (CVX) Nov 2013	Oil Manager	0.5000	Source
Texas-N.Mex.P-L Inter1983	Oil Manager	0.1500	Source
Mars Bld (ITS) 2007	Oil Manager	0.1000	Source
West Texas Sour (CVX) Sep 9	Oil Manager	0.1000	Source
Utah Sweet SW (AES)	Oil Manager	0.1500	Source

Proportion Basis
- Mole Fractions
- Mass Fractions
- LiqVol Fractions
- Mole Flows
- Mass Flows
- LiqVol Flows
- Use All

om 0

Outlets Ig

DC-SIM Results

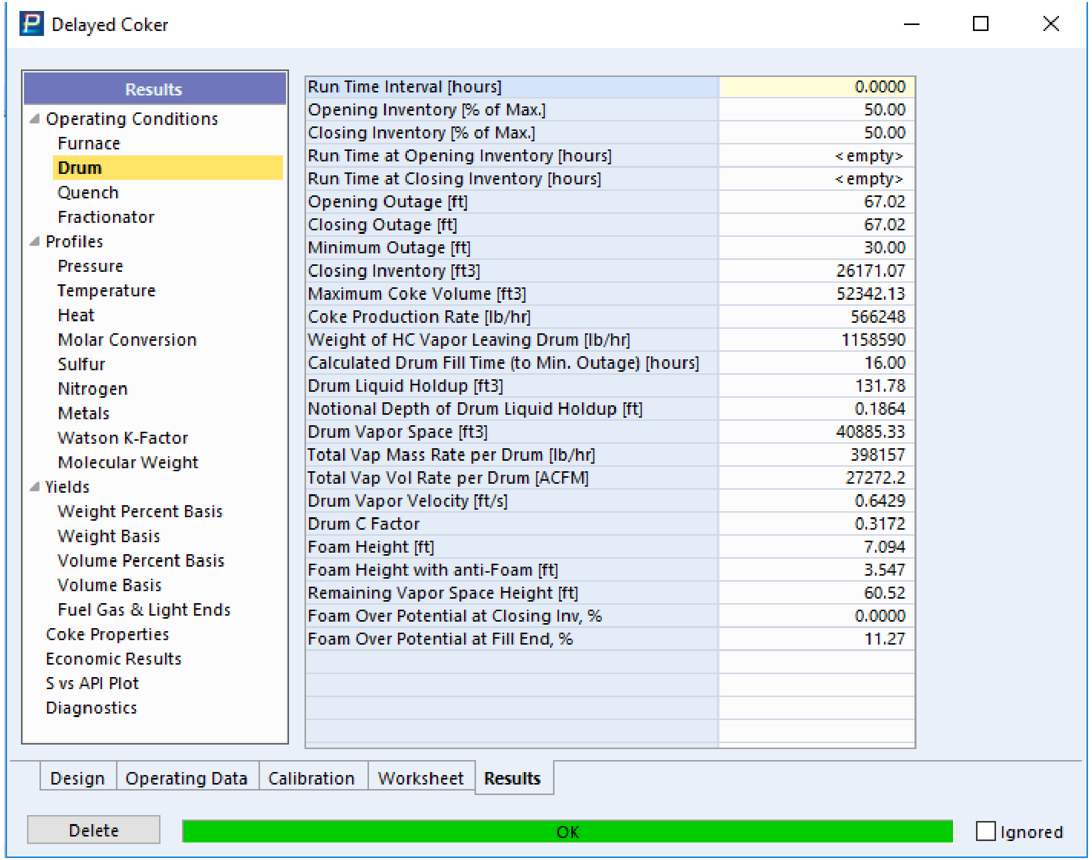


The more paraffinic the coker feed the larger DT between the furnace and drum inlet temperature difference from the furnace outlet to the drum inlet and from the drum inlet to the drum overhead.

The pressure profile is general hydraulics with most heater outlets at about 90 to 100 psig

The temperature and pressure profile should match expected operating conditions. Bad data should not be used and the coke drum overhead temperature is almost always bad.

DC-SIM Results



Run Time Interval [hours]	0.0000
Opening Inventory [% of Max.]	50.00
Closing Inventory [% of Max.]	50.00
Run Time at Opening Inventory [hours]	<empty>
Run Time at Closing Inventory [hours]	<empty>
Opening Outage [ft]	67.02
Closing Outage [ft]	67.02
Minimum Outage [ft]	30.00
Closing Inventory [ft3]	26171.07
Maximum Coke Volume [ft3]	52342.13
Coke Production Rate [lb/hr]	566248
Weight of HC Vapor Leaving Drum [lb/hr]	1158590
Calculated Drum Fill Time (to Min. Outage) [hours]	16.00
Drum Liquid Holdup [ft3]	131.78
Notional Depth of Drum Liquid Holdup [ft]	0.1864
Drum Vapor Space [ft3]	40885.33
Total Vap Mass Rate per Drum [lb/hr]	398157
Total Vap Vol Rate per Drum [ACFM]	27272.2
Drum Vapor Velocity [ft/s]	0.6429
Drum C Factor	0.3172
Foam Height [ft]	7.094
Foam Height with anti-Foam [ft]	3.547
Remaining Vapor Space Height [ft]	60.52
Foam Over Potential at Closing Inv, %	0.0000
Foam Over Potential at Fill End, %	11.27

Petro-SIM™ has an extensive set of output or report result for the reactor that help define the yields, operating parameters and product properties.

Transfer Line & Blowdown

Blow Down

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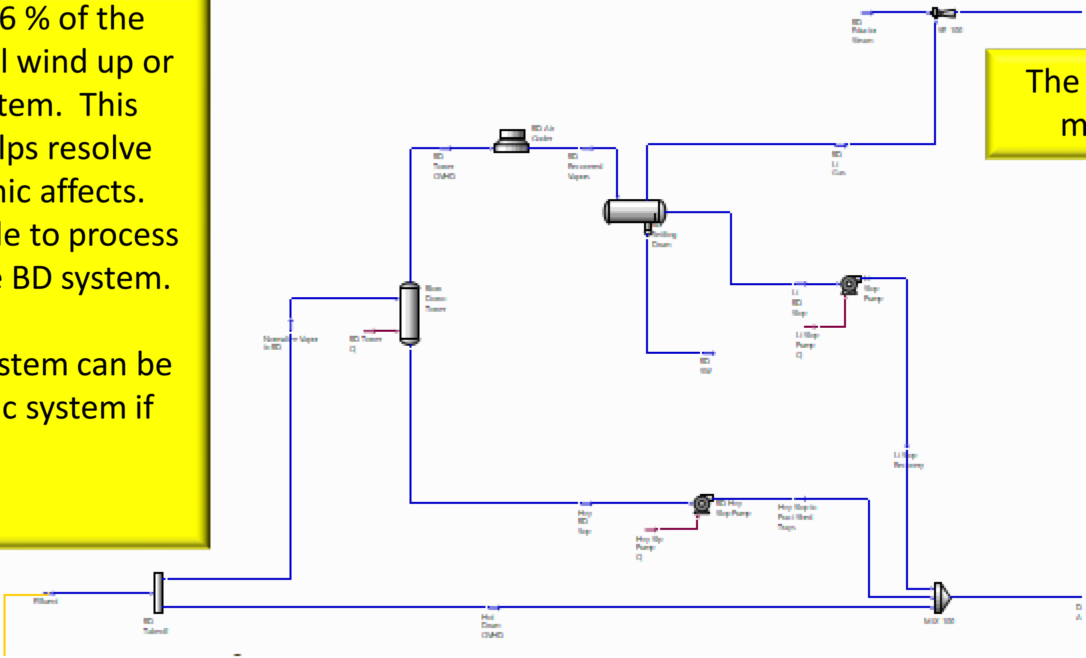
Best practice is to have the coke drum quench done with blowdown slop streams. This allows for a cleaner BD operation and avoiding wet slops going to the tower.

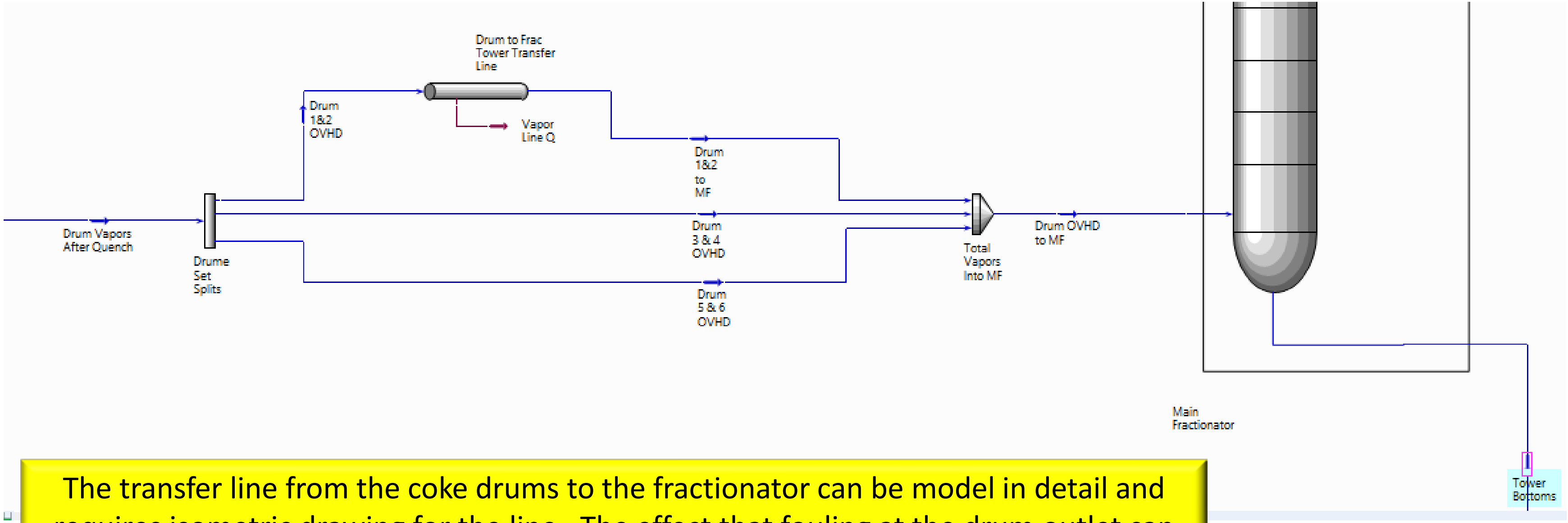
Typically, about 4 to 6 % of the overall coker yields will wind up or report to the BD system. This modeling method helps resolve these process dynamic affects. Some refineries are able to process external slops thru the BD system.

A more complex BD system can be modeled as a dynamic system if required.



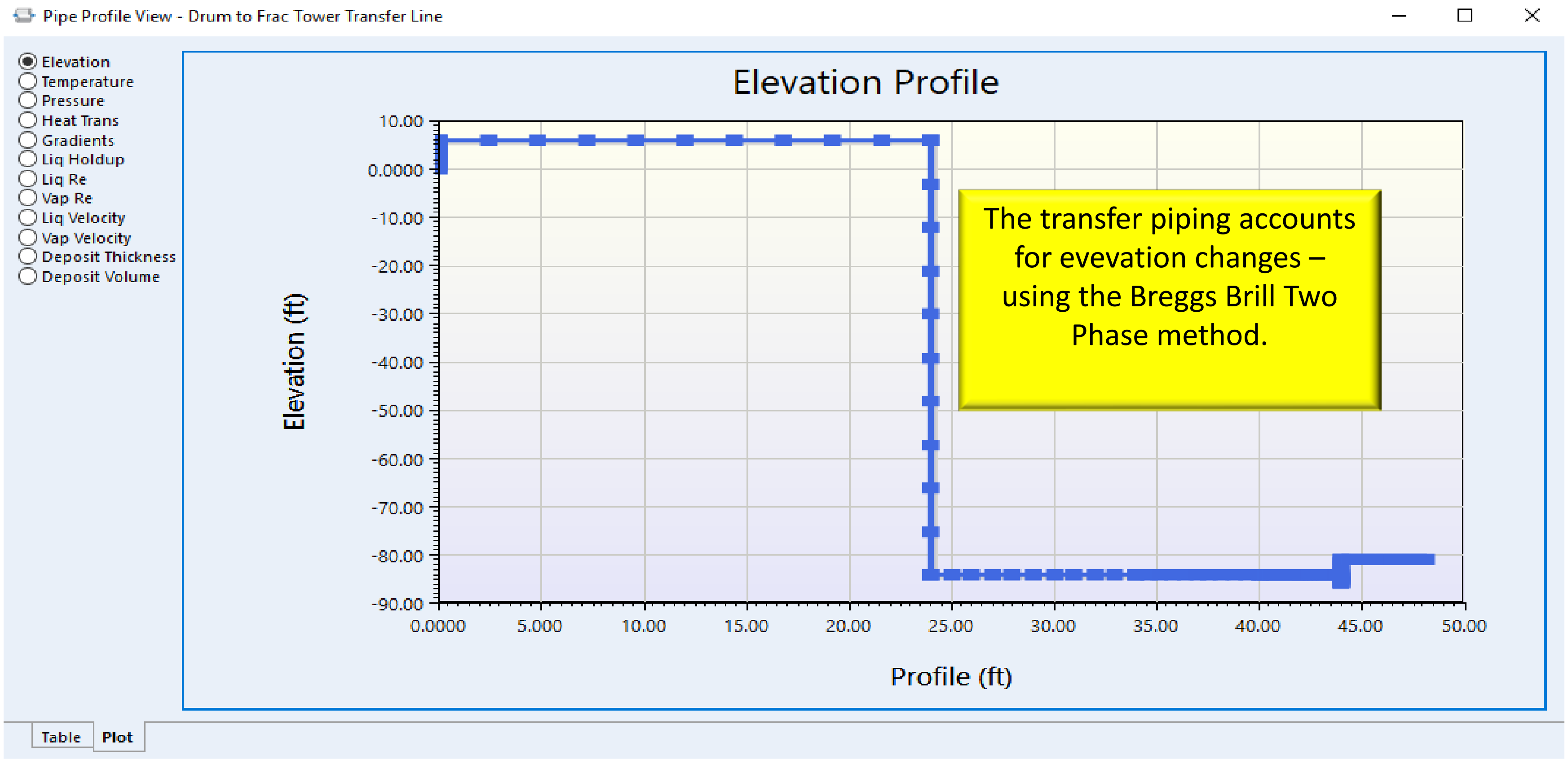
The vapor educator can be modeled here as well.

Transfer Line

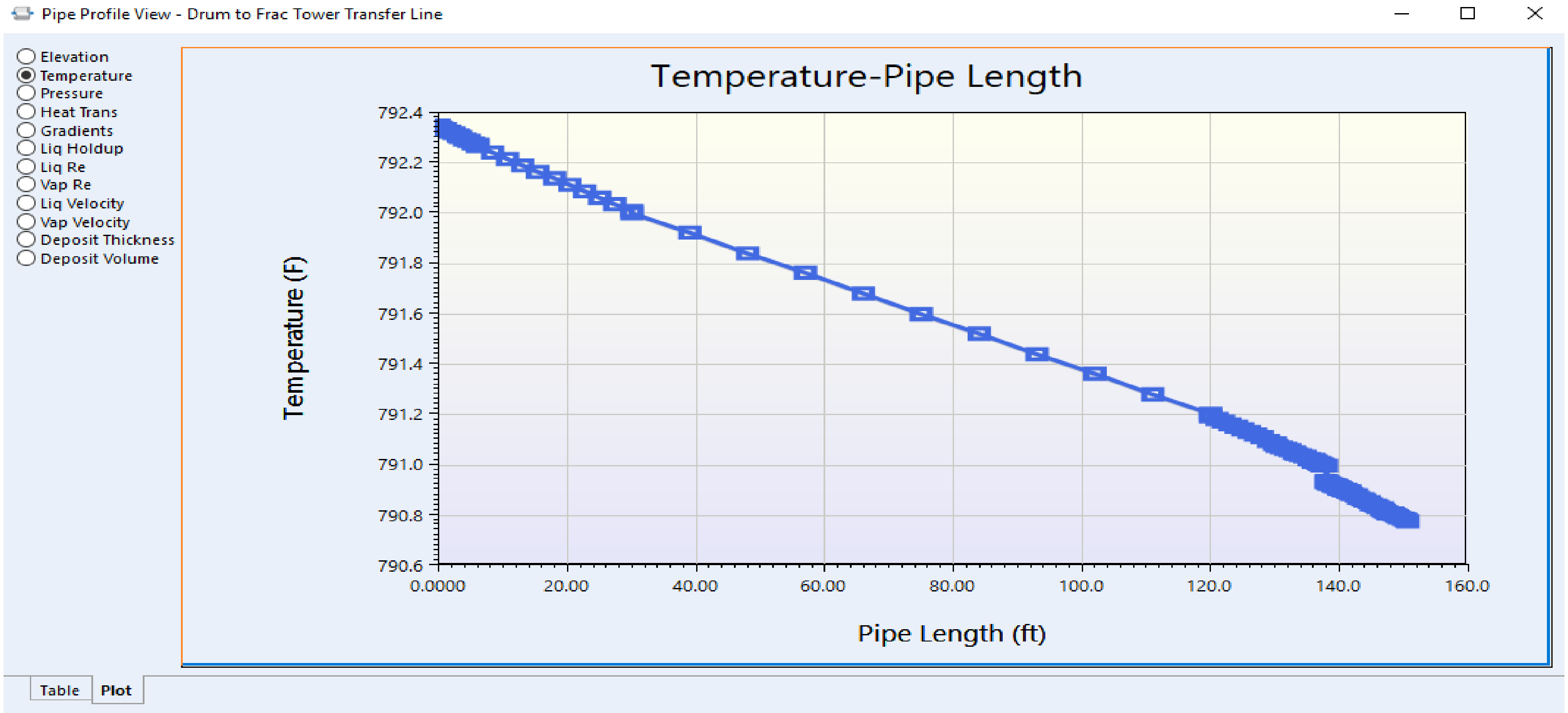


The transfer line from the coke drums to the fractionator can be model in detail and requires isometric drawing for the line. The effect that fouling at the drum outlet can be simulated but a detailed transfer line is not required to see this issue on the coker operations and yield. How line/valves size, overall hydraulic and heat loss effect the operations can be modeled.

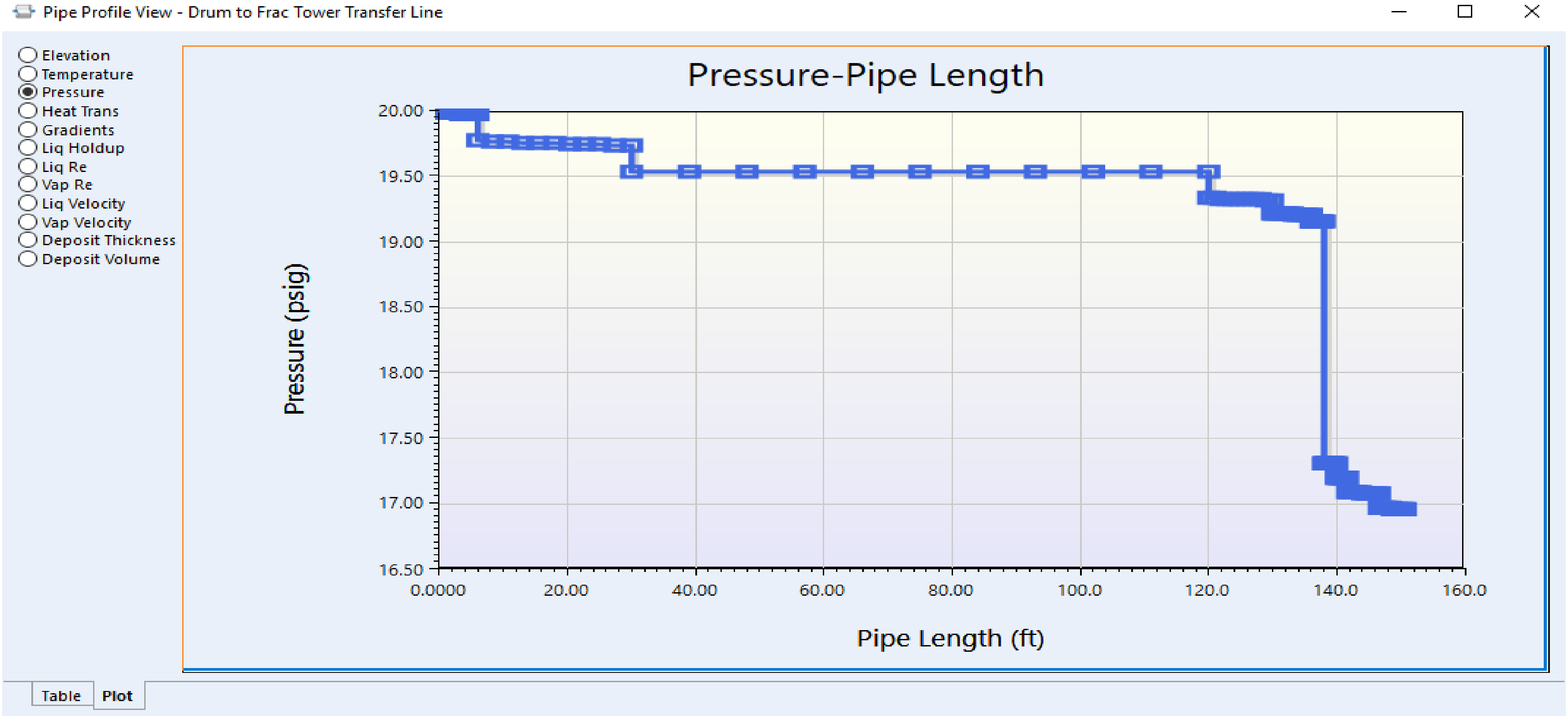
Transfer Line



Transfer Line



Transfer Line



Main Fractionator Model & Heat Removal

Detailed Main Fractionator

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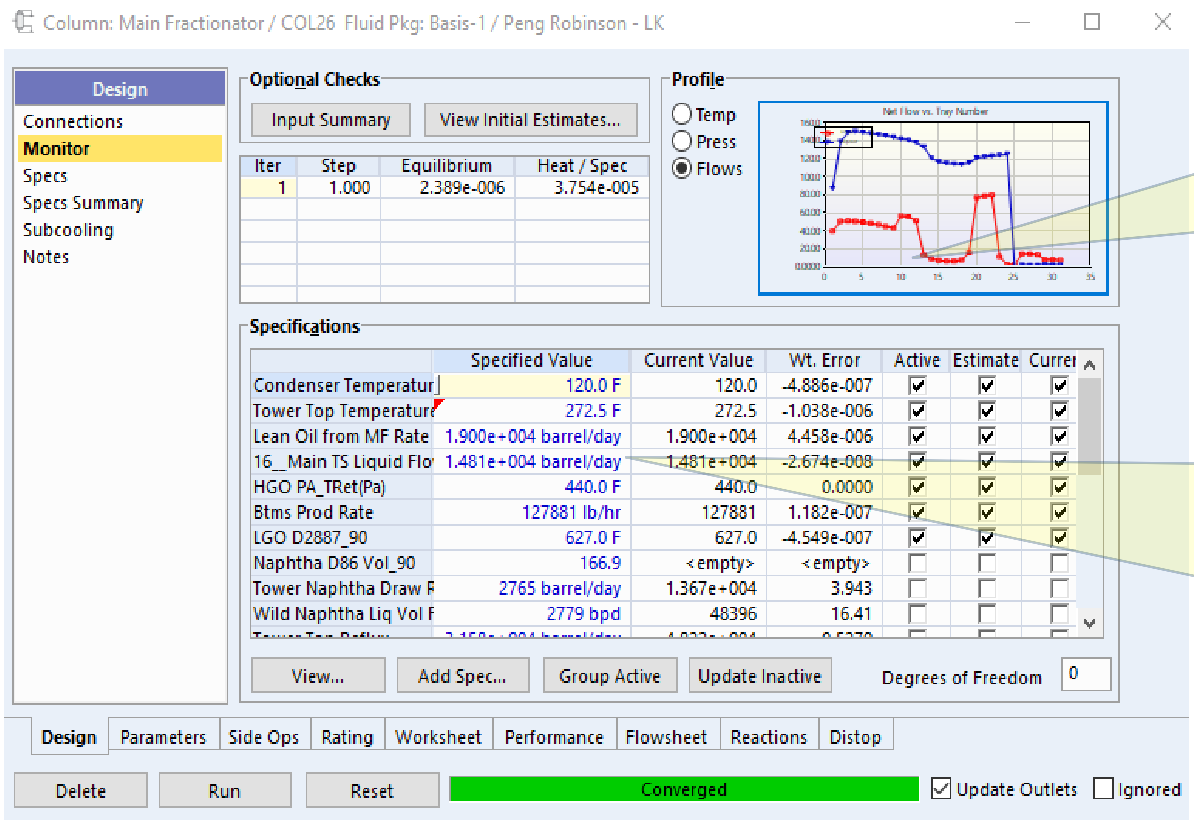

The fractionator trays loads must be watched closely to avoid drying the tray. The tower will not converge if the trays run dry.

To avoid running the trays dry it is common to have a tray loading between the LGO and HGO. This spec will also drive where heat is removed in the tower. A high tray load between the LGO and the HGO will result in more heat removal at the top of the tower but too much heat removal in the tower can have other problems – i.e. flooding, cold OVHD etc…

Detailed Main Fractionator

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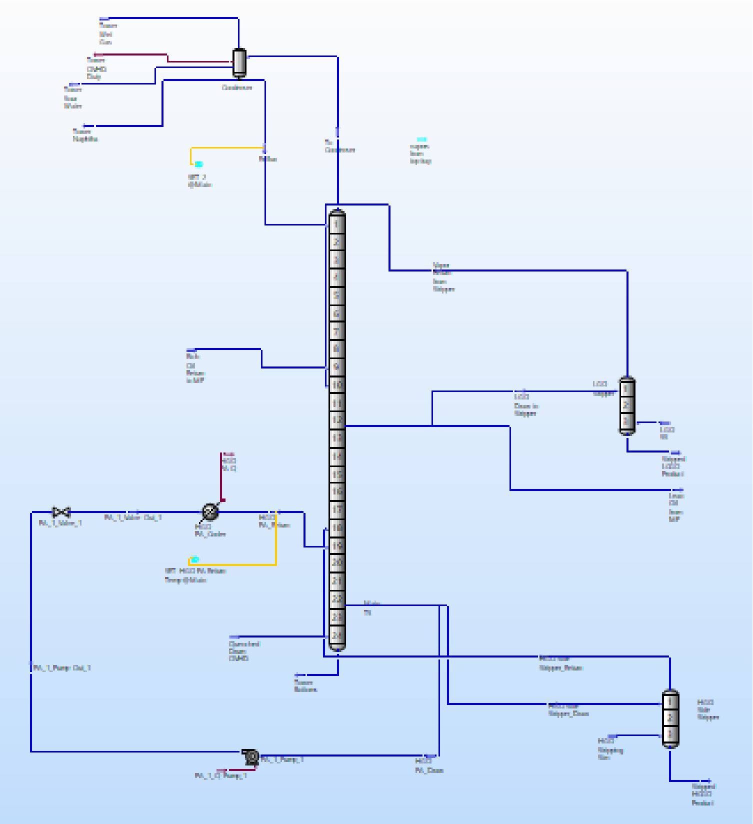

Column Flowsheet

Similar to a sub-flowsheet, the column flowsheet is where you install and define streams and operations contained in a column such as:

•Tray sections
•Condensers
•Reboilers
•Side strippers
•Heat exchangers
•Pumps

Petro-SIM contains ten pre-built column flowsheet templates to help you install a typical type of column and then customize it to your specifications.
The column flowsheet desktop environment closely resembles the flowsheet environment. As well, the Column tab becomes available offering you additional tools and options that you can use to design, modify and converge column flowsheets.

The tower details can be reviewed for each tower in the simulation

Tray Rating / Flooding Estimate

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Quick tray flooding calculation are possible and provide a good estimate or evaluation. A 85% of flood is a normal design practice but the drum steam out conditions need to be factored in this flooding analysis.

Tray Results

	Upper Naphtha Section	Rich Oil to LGO draw	LGO to HGO Trays	HGO PA	Flash Zone
Additional Information					
Internals	Valve	Valve	Valve	Valve	Packed
Section Diameter [ft]	24.00	24.00	24.00	24.00	24.00
Max Flooding [%]	74.66	77.76	59.42	78.21	43.86
X-Sectional Area [ft2]	452.4	452.4	452.4	452.4	452.4
Section Height [ft]	16.00	8.000	12.00	6.000	0.2500
Section DeltaP [psi]	0.9013	0.4497	0.5513	0.3822	4.969e-004
Number of Flow Paths	2	2	1	4	***
Flow Length [in]	118.0	112.0	256.0	59.50	
Flow Width [in]	244.0	246.5	243.3	242.3	
Max DC Backup [%]	42.37	47.13	47.94	45.49	
Max Weir Load [USGPM/ft]	64.71	81.74	125.6	94.42	
Max DP/Tray [psi]	0.1160	0.1225	0.1105	0.1324	
Tray Spacing [in]	24.00	24.00	24.00	24.00	
Total Weir Length [in]	432.7	445.7	131.9	931.6	
Weir Height [in]	2.000	2.000	2.000	2.000	
Active Area [ft2]	399.9	383.5	432.6	400.5	

Gas Plant

Gas Plant Details

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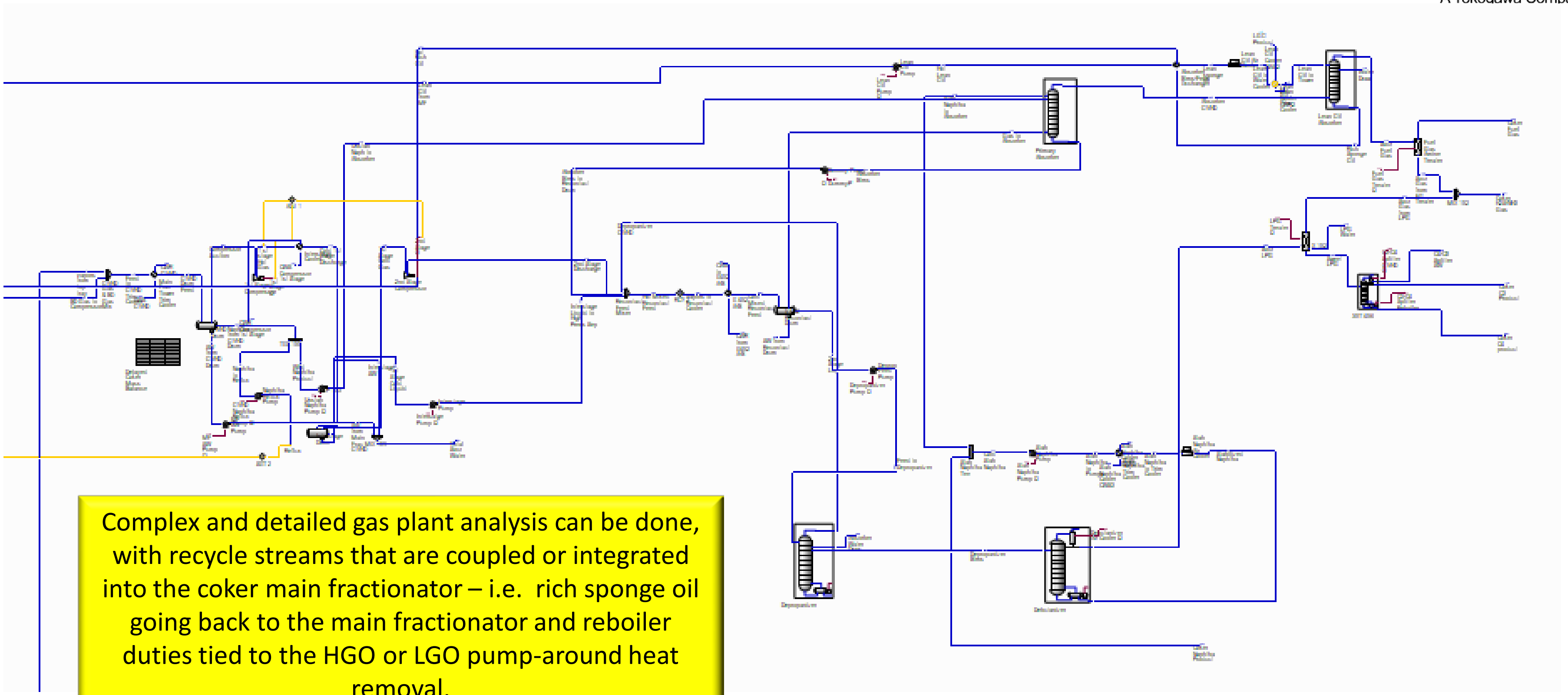

Complex and detailed gas plant analysis can be done, with recycle streams that are coupled or integrated into the coker main fractionator – i.e. rich sponge oil going back to the main fractionator and reboiler duties tied to the HGO or LGO pump-around heat removal.

Feed Preheat

Feed Preheat & Product Cooling

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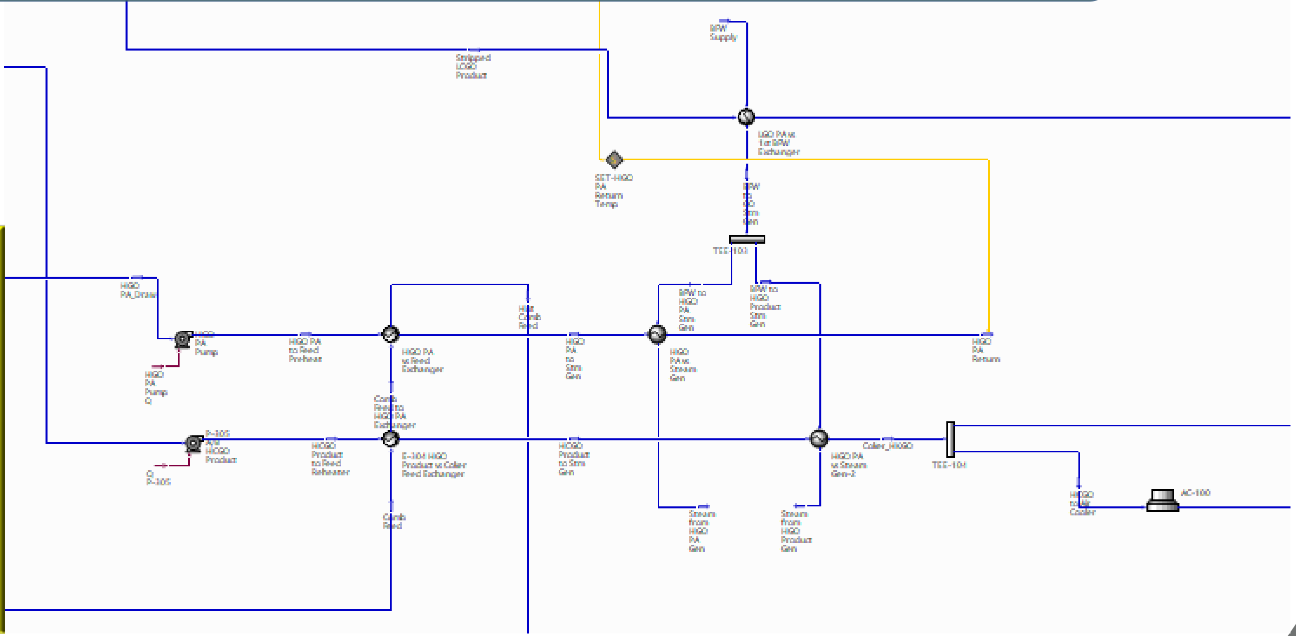
The heat removal requirements for a pump-around can be exported to the main flowsheet to develop and evaluate utility requirements i.e. steam generated in unit.

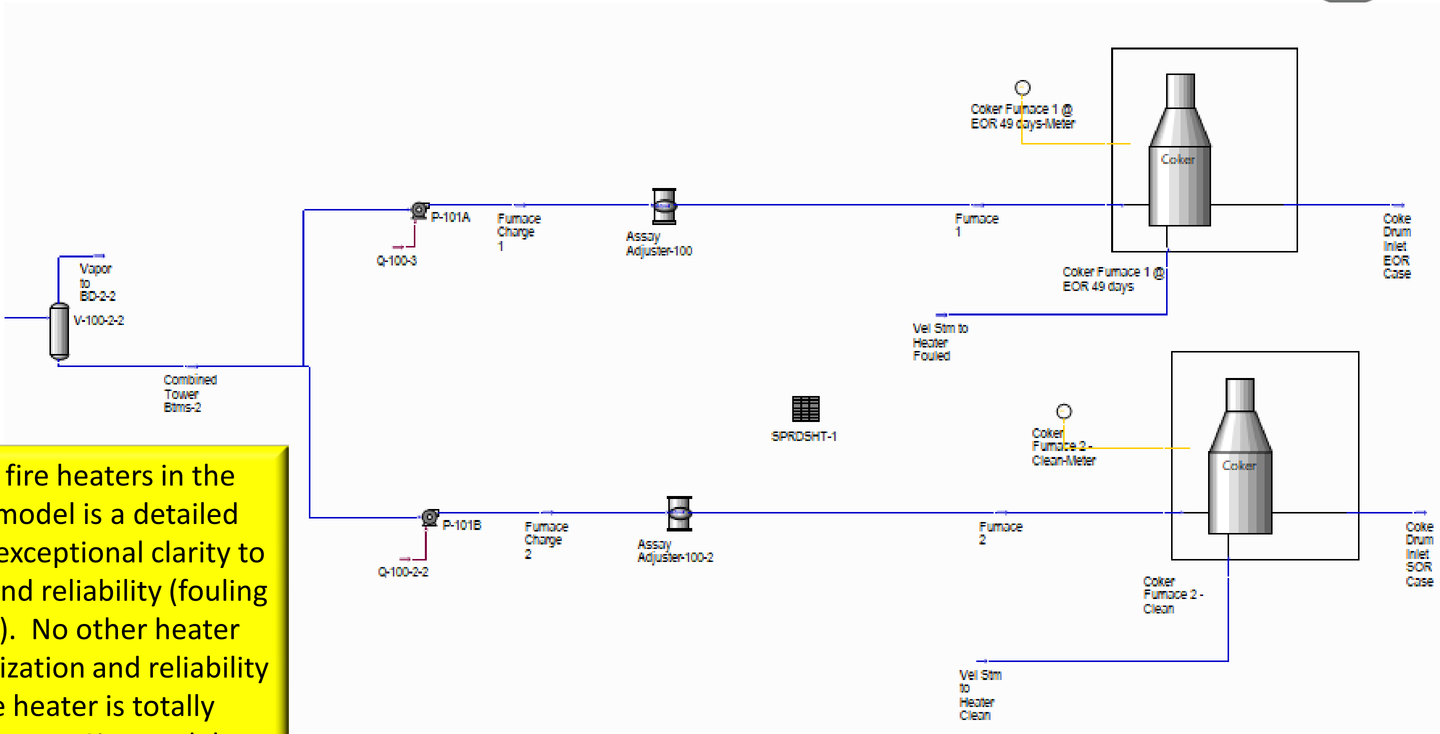
Detailed heat exchanger rating and operations can be evaluated with the addition of the HTRI modeling of the heater.

Again the simulation is built fit for purpose. A simple heater is generally adequate but Petro-Sim provides much more exchanger detailed analysis if required.



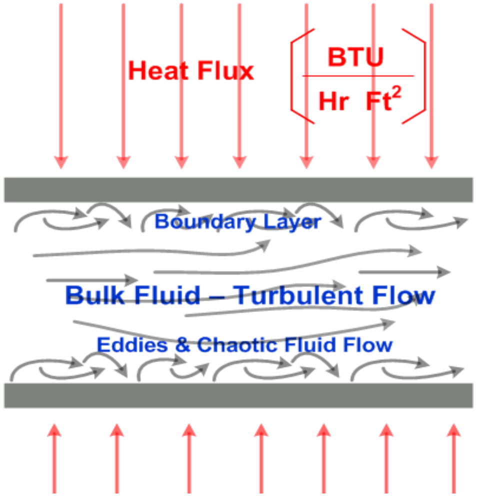
Fired Heater

Furnace Operations



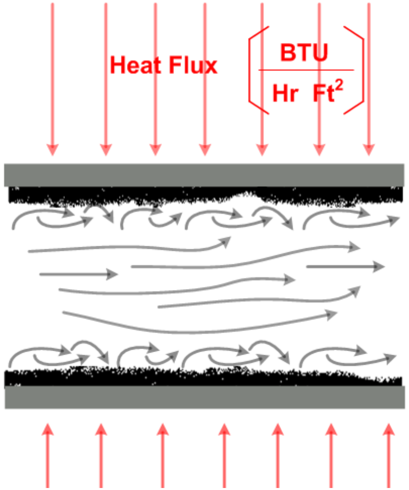
Petro-Sim can simulate the fire heaters in the delayed coker. The heater model is a detailed kinetics model that provides exceptional clarity to the coker heater operations and reliability (fouling as a function of days online). No other heater model can conduct the optimization and reliability analysis. Additionally, the heater is totally integrated into the overall Petro-Sim model.

General Fired Heater Coking



$$\text{Tube Skin Temperature} \propto \text{Heat Flux}$$

Coke formation occurs at the boundary layer where the velocity is low and the temperature is high.



Costs -> Capital vs Operating

$$\text{Absorbed Heat} = \text{Surface Area} \times \text{Heat Flux}$$

The coke thickness acts as insulation to heat transfer causing the tube wall temperature to increase and higher fuel gas firing .

High heat flux and low velocities will increase tube fouling / coking

Radiant Box Heat Flux

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$$Heat\ Flux = 0.4 * 0.173 * \left\{\left[\left(\frac{T_g}{100}\right)^4 - \left(\frac{T_s}{100}\right)^4\right] + 7 * \left[T_g - T_s\right]\right\}$$

$$T_g = the\ bridge\ wall\ temperature$$

The radiant fire box is modeled to further evaluate the performance of the heater and optionally can generate the heat flux delivered to the process.

- The last term is a convective heat transfer adjustment
- This form of the equation gives reasonable bridge wall temperature or fire box temperatures- typically about 1500ºF to 1700ºF

Convection Heat Transfer - Heat Flux

- A convection flux profile has very little radiant heat and the convection heat transfer is a more complex simulation
- The actual flux profile, in the convection section, is not as critical as long as the crossover temperature is known. The convective heat transfer can be adjusted to converge on the known or assumed cross over temperature.
- The crossover temperature shifts slightly as the heater fouls.

Petro-SIMTM Kinetics

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The colloidal instability index and the Na effects on heater fouling have been added to the heater model.

Bulk Phase

$$BRxn_n = \text{Residence Time} * U1 * A1 * e^{\left(-\frac{B1*E1}{T_{bulk}}+C1*K1\right)} + BRxn_{n-1}$$

Wall Film Rxn

$$WRxn_n = \text{Residence Time} * BRxn_n * A2 * e^{\left(-\frac{B2*E2}{T_{film}}+C2*K2\right)}$$

Coking thickness (when MV1 > 0)

$$Cok_n = \text{Initial Thickness} + \left\{\text{Days} * \frac{A3}{\text{Tube inside surface}} * \left[WRxn_n * \left(1 - \frac{\text{Velocity}}{MV1 * \text{MaxVelocity}}\right)\right]\right\}$$

U1 is function of Colloid Instability Index (CII) compared to saved calibration value

The heater model calculates the coke deposited based on the tube boundary wall condition. Time at temperature kinetics determines the coke generated and the shear forces (fluid velocity) determines how much is removed. The difference between coke generated and coke removed (velocity) will determine the coke deposited. The rate of coke deposited changes or is dynamic as the heater fouls and the fouling model take several steps through the heater run to model the overall heater fouling. Typically 7 or more steps are needed to estimate the fouling dynamics.

Colloid Instability Index

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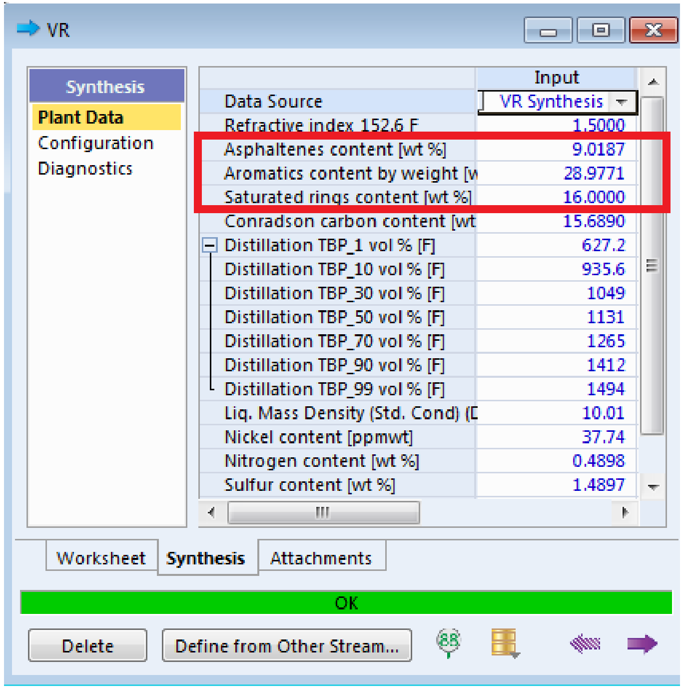
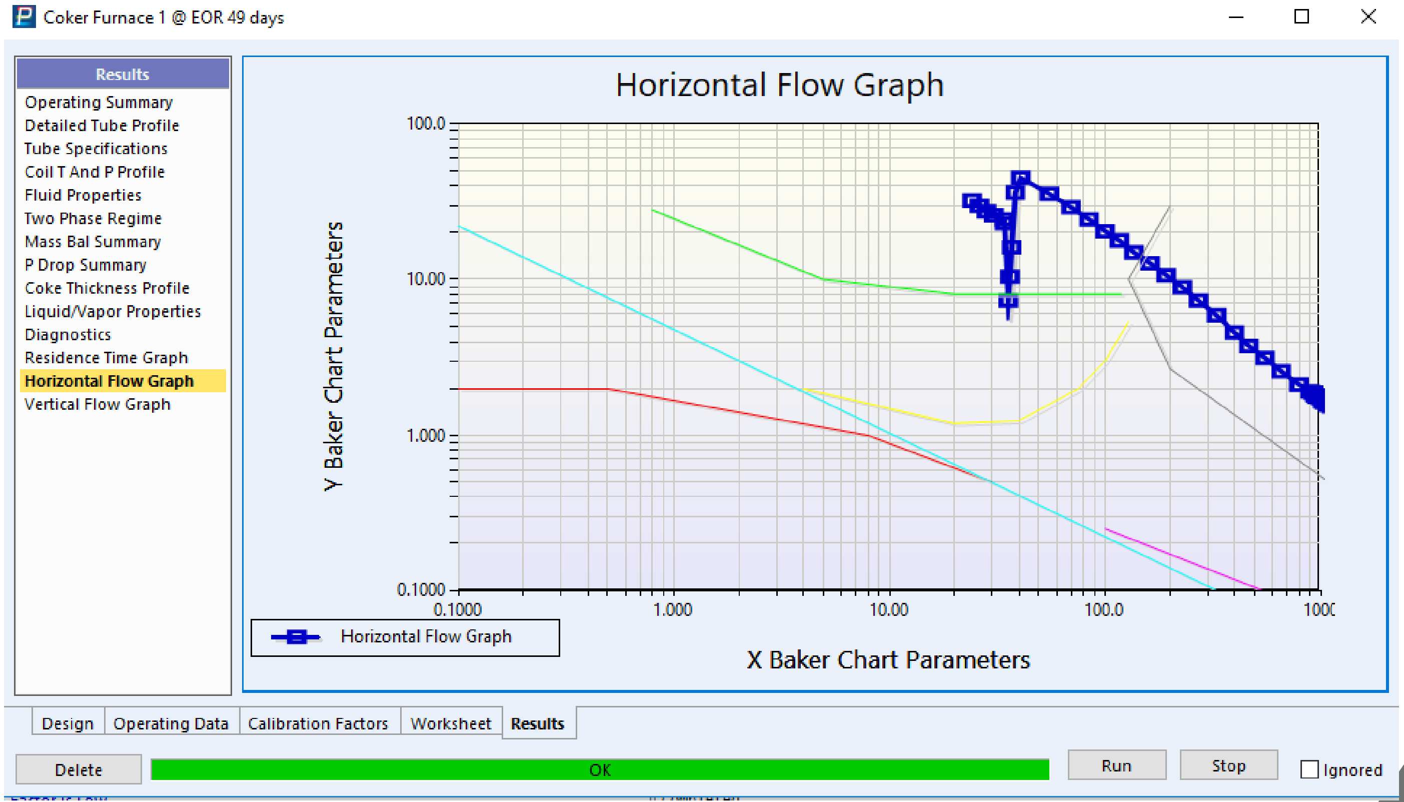
- Colloid Instability Index (CII)
  - $\dfrac{\text{Asphaltenes}+\text{Saturates}}{\text{Aromatics}+\text{Resins}}$
- SARA synthesis from crude assay data is not available yet
- Furnace Feed SARA are specified with stream synthesis
- Some value of sulfur and nitrogen must also be input

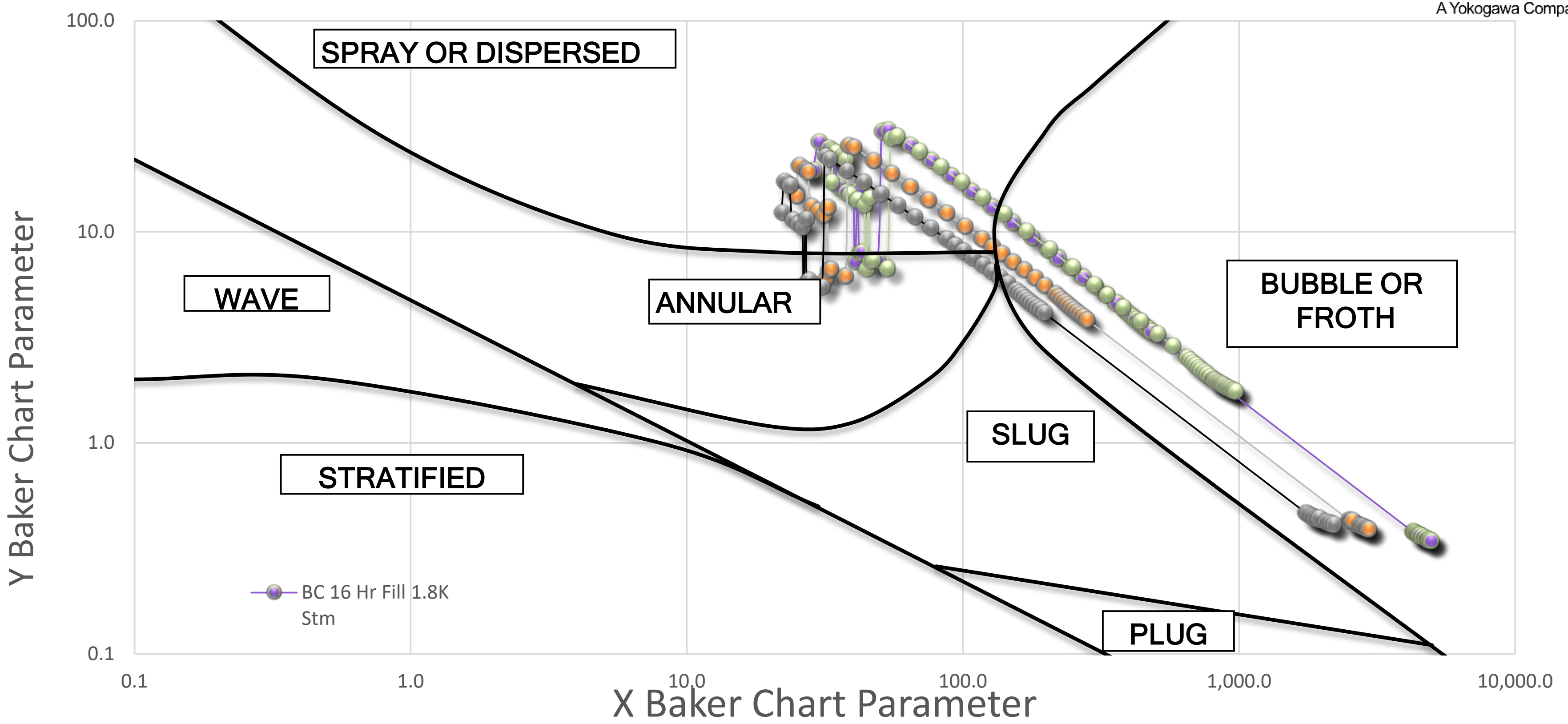


Heater Results

The heater model generates a detailed results section. Additionally the model can export some of the critical result to Excel for detailed fouling case studies.

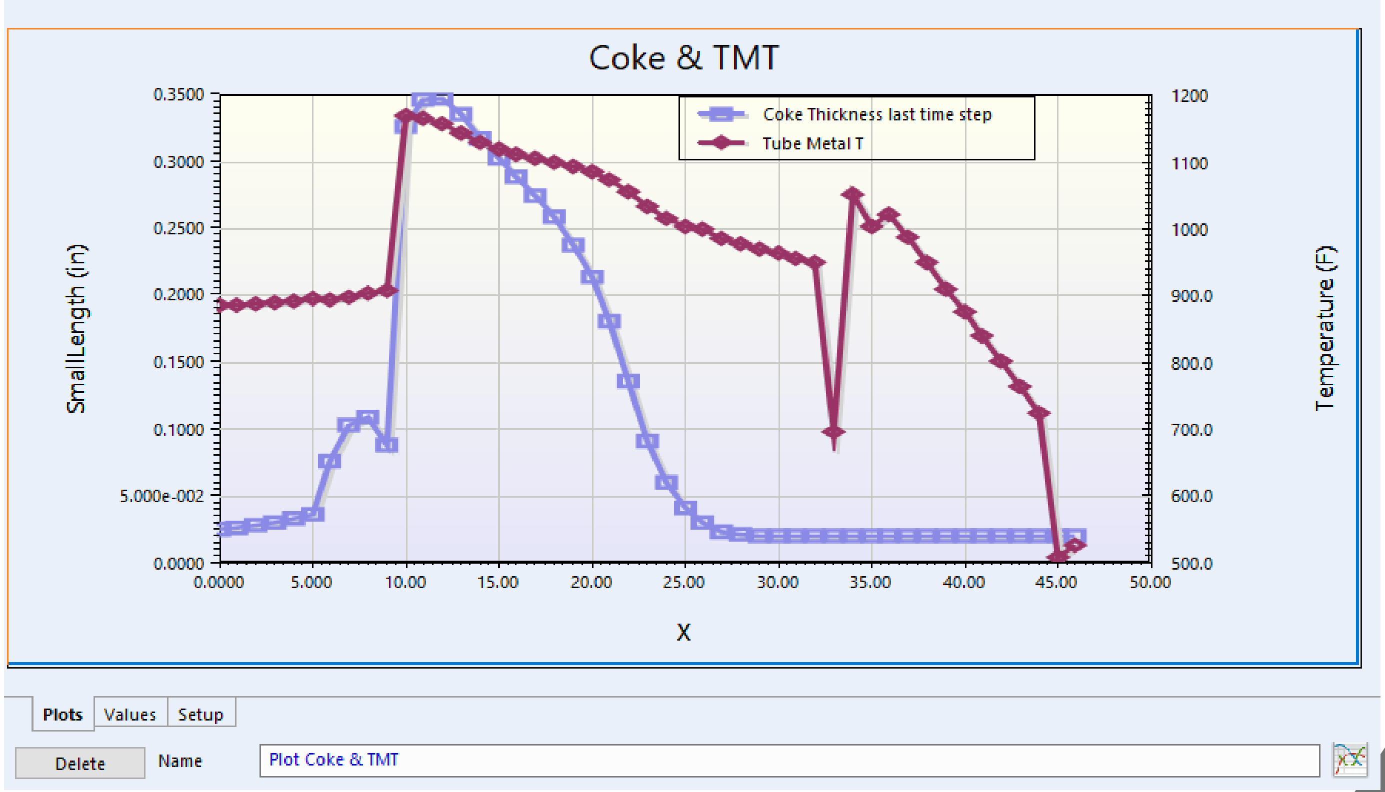


Example: Baker Chart for Reduced Feed and Stm Rates

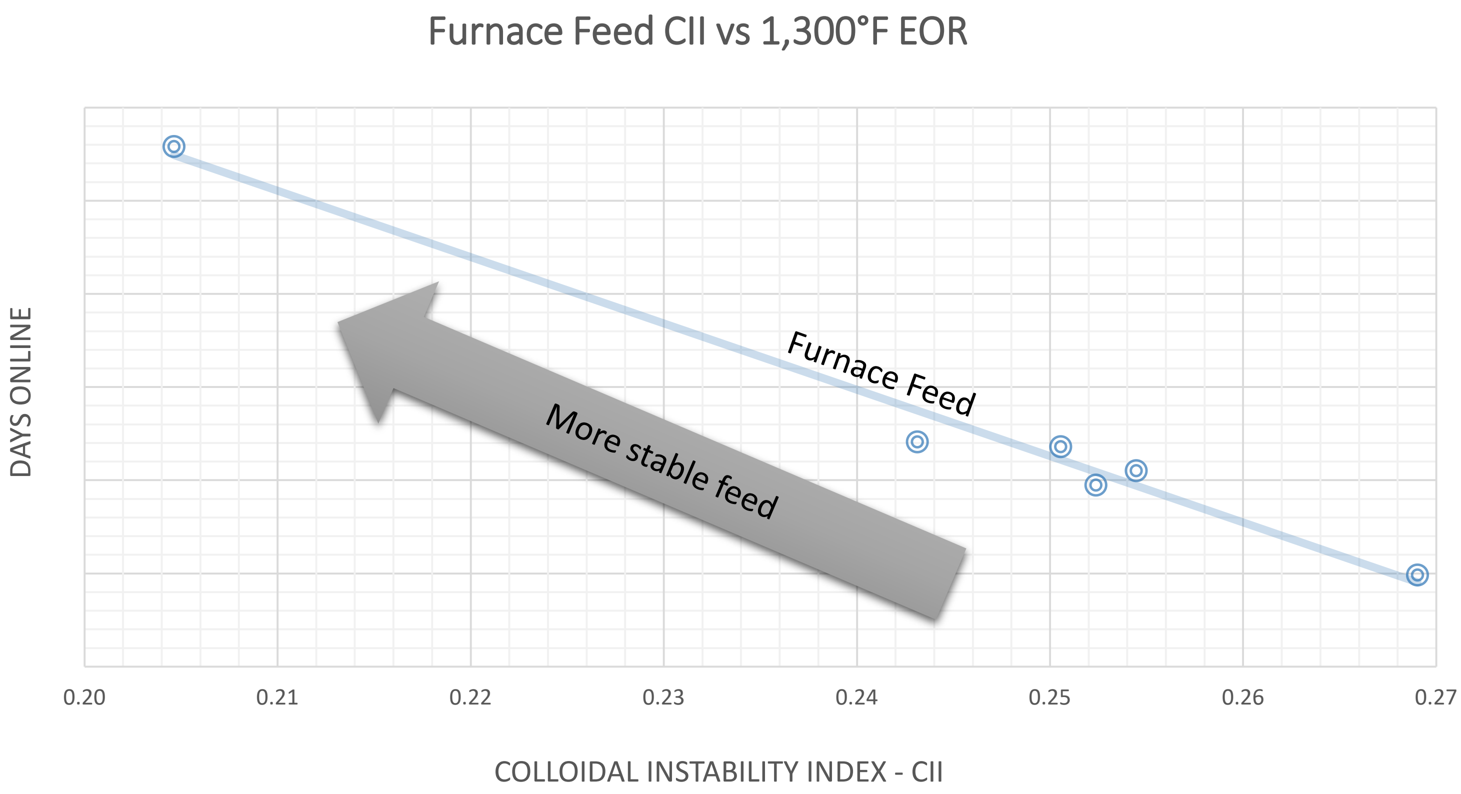


Heater Results

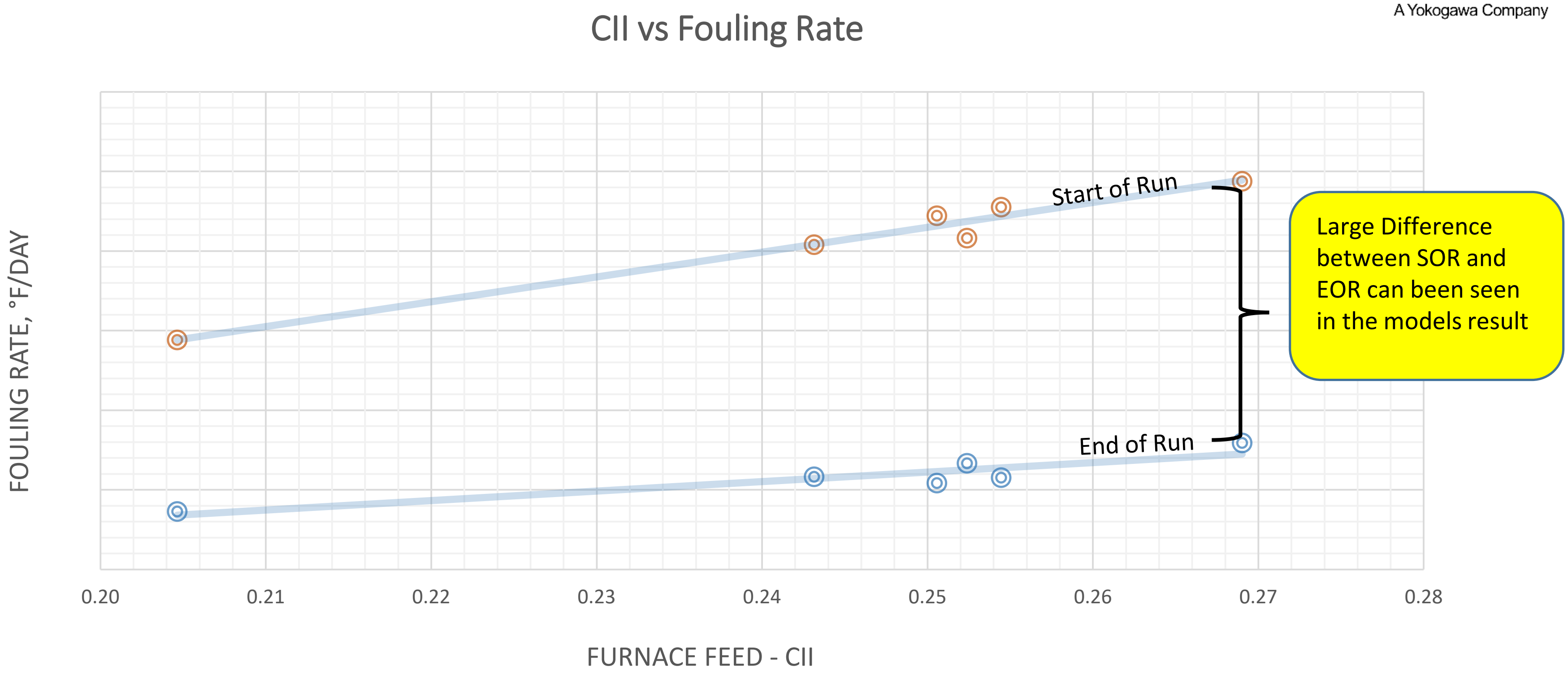
Most of the results generated can be plot but the model can export some of the critical result to Excel for detailed fouling case studies.



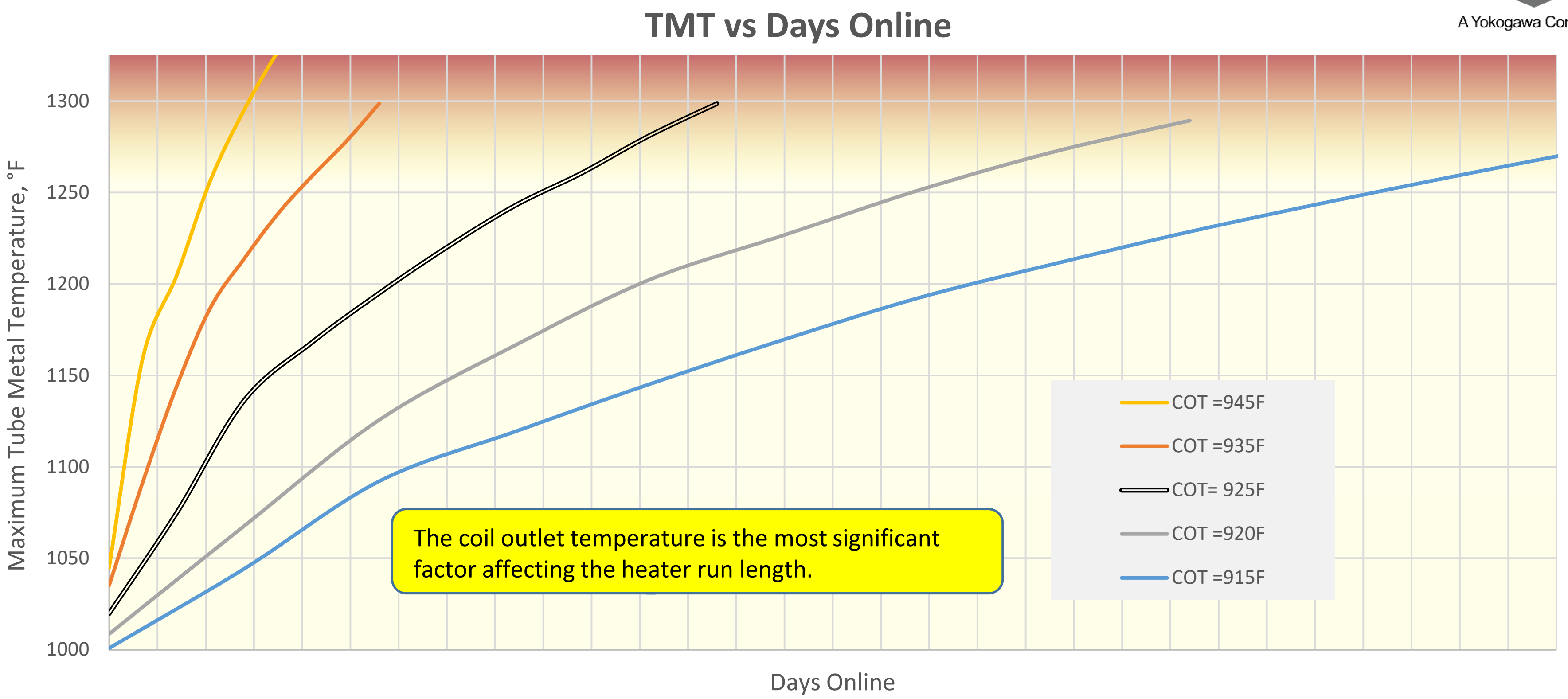
Heater Results– Furnace CII vs Fouling Rate



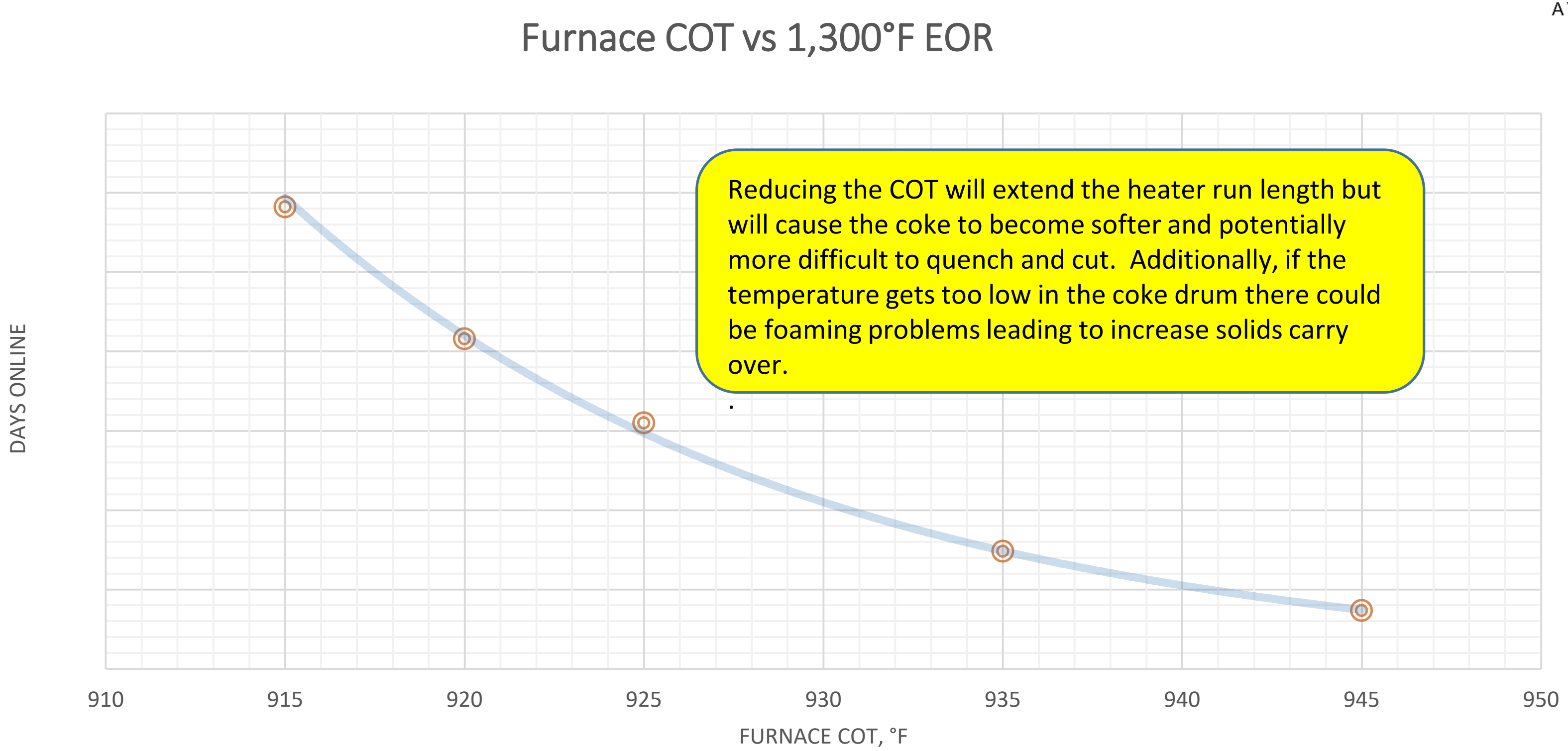
Crude Cases – Furnace CII vs Fouling Rate



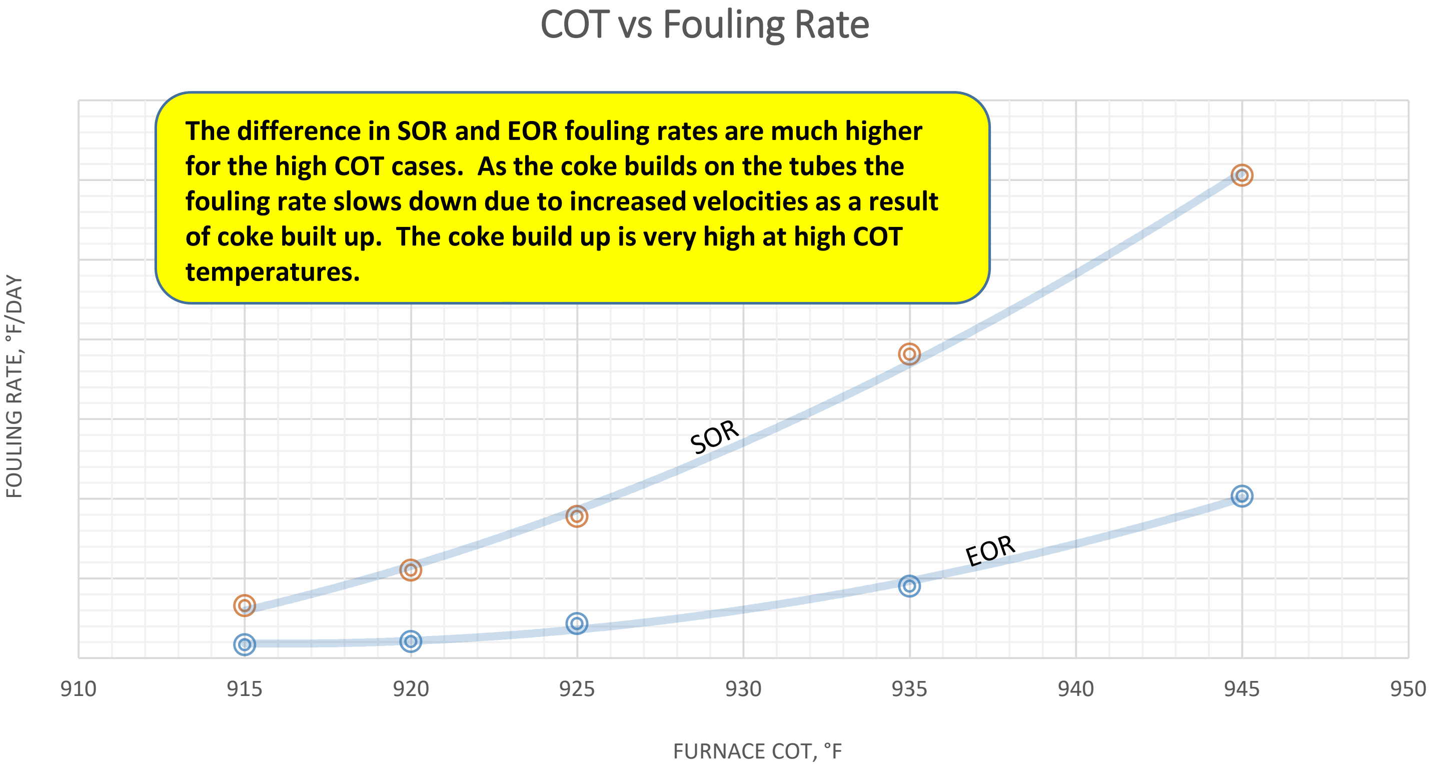
Furnace Outlet Temperature vs Days Online



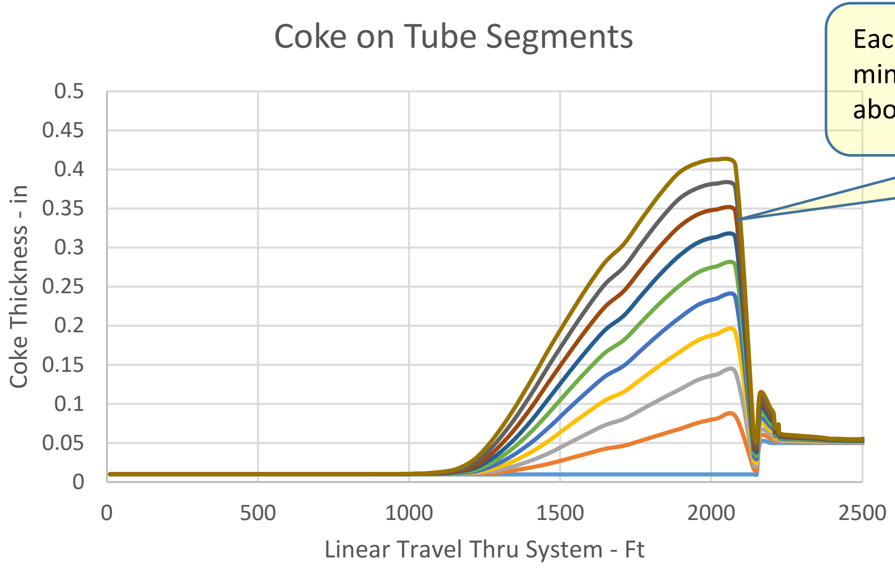
Furnace Outlet Temperature vs Days Online



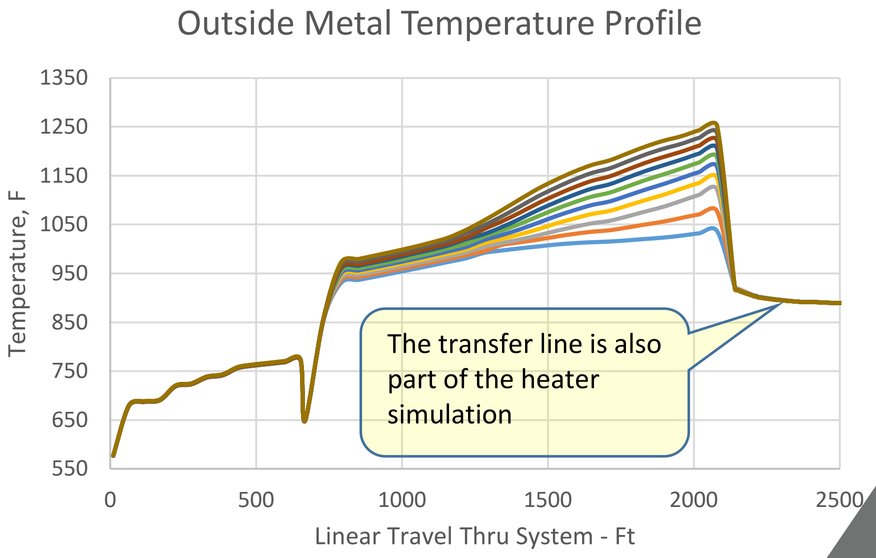
Furnace Outlet Temperature vs Fouling Rate



Typical Heater Simulation Results & Analysis



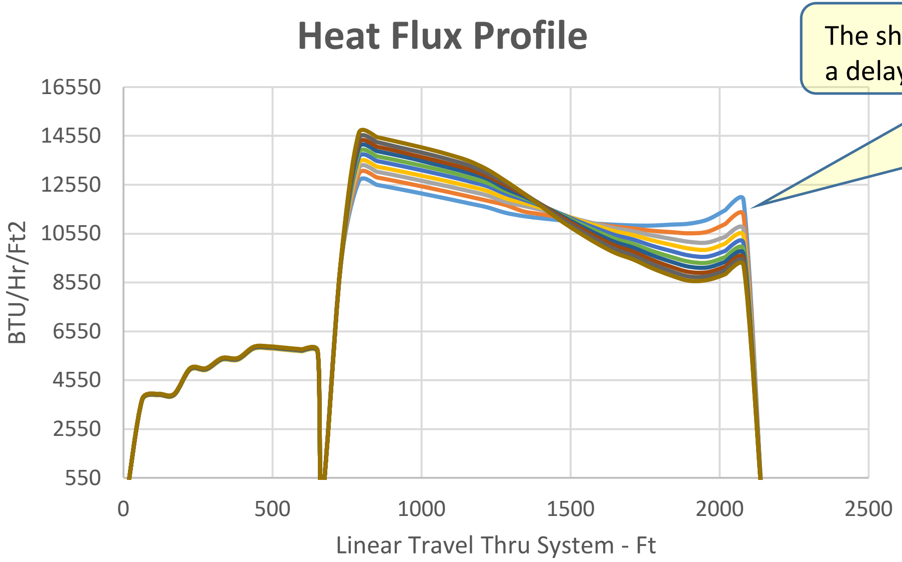
Each line in the plot represents a time step. Generally the model needs a minimum of 7 10 time steps – i.e. a heater that fouls in 49 days needs about 7 steps where each step is 7 days.



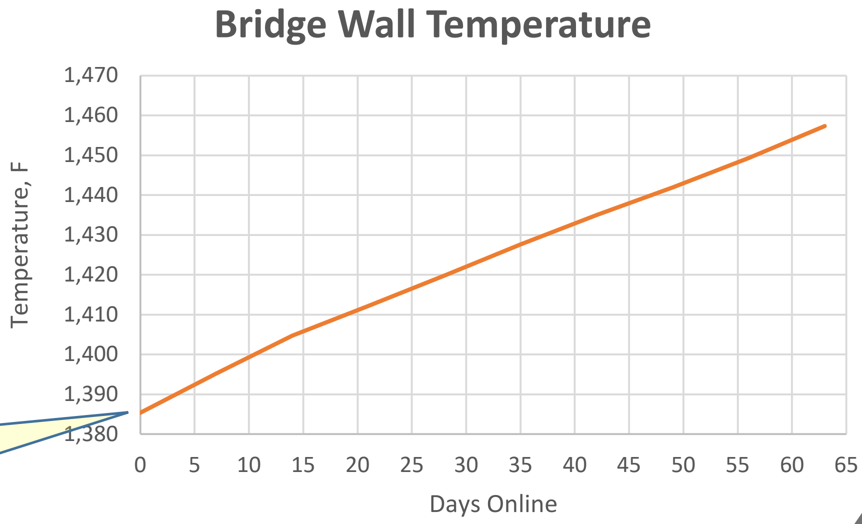
The transfer line is also part of the heater simulation

KBC's furnace model is unique in that it predicts coke deposited on the tubes as a function days online. Additionally, all the properties and results are predicted at each step in the fouling sequence. The time steps can be set individually as can the operating condition and feed for each time step.

Heater Simulation Results & Analysis



The shift in the flux profile is always counterintuitive but is very typical of a delayed coker heater operation.



Bridge wall temperature increases with the heater run – a very typical temperature profile.

Heater Simulation Results & Analysis

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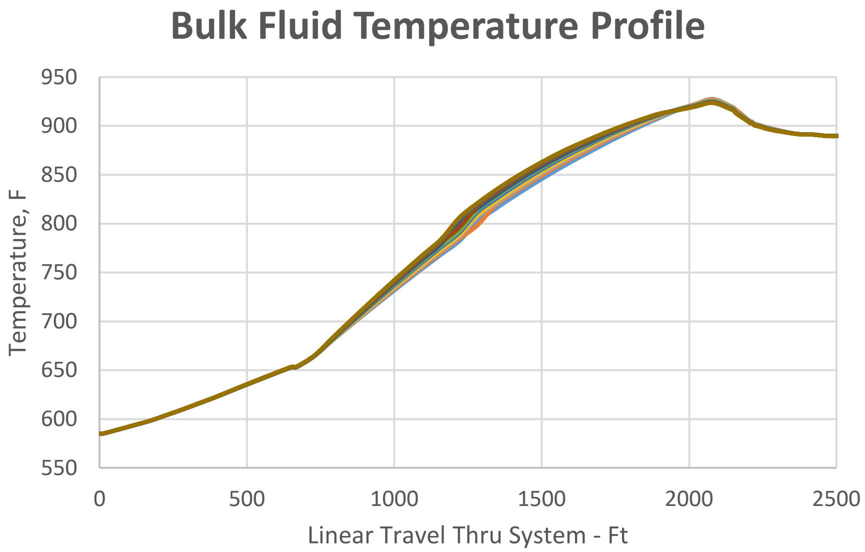
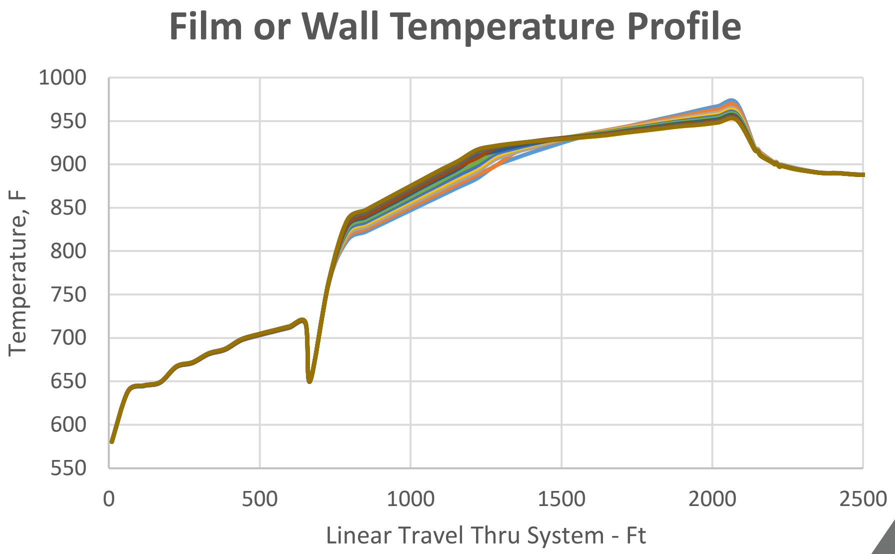
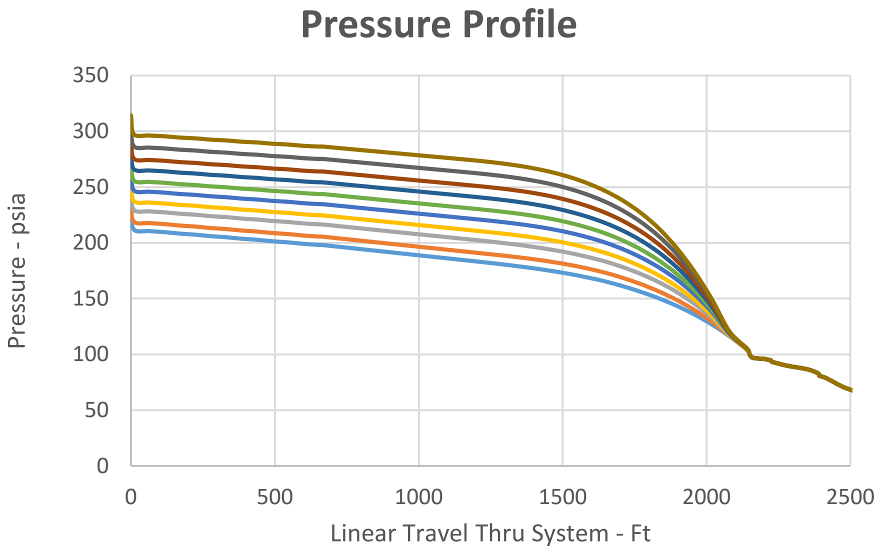
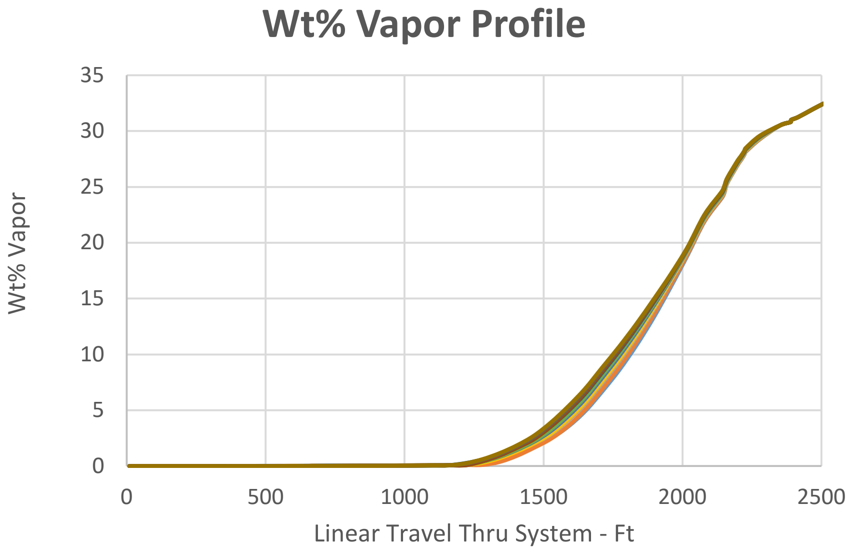




Typical heater output and results

Heater Simulation Results & Analysis





Typical heater output and results Steam can be injected at any point in the heater simulation

Na Content vs Fouling Rate

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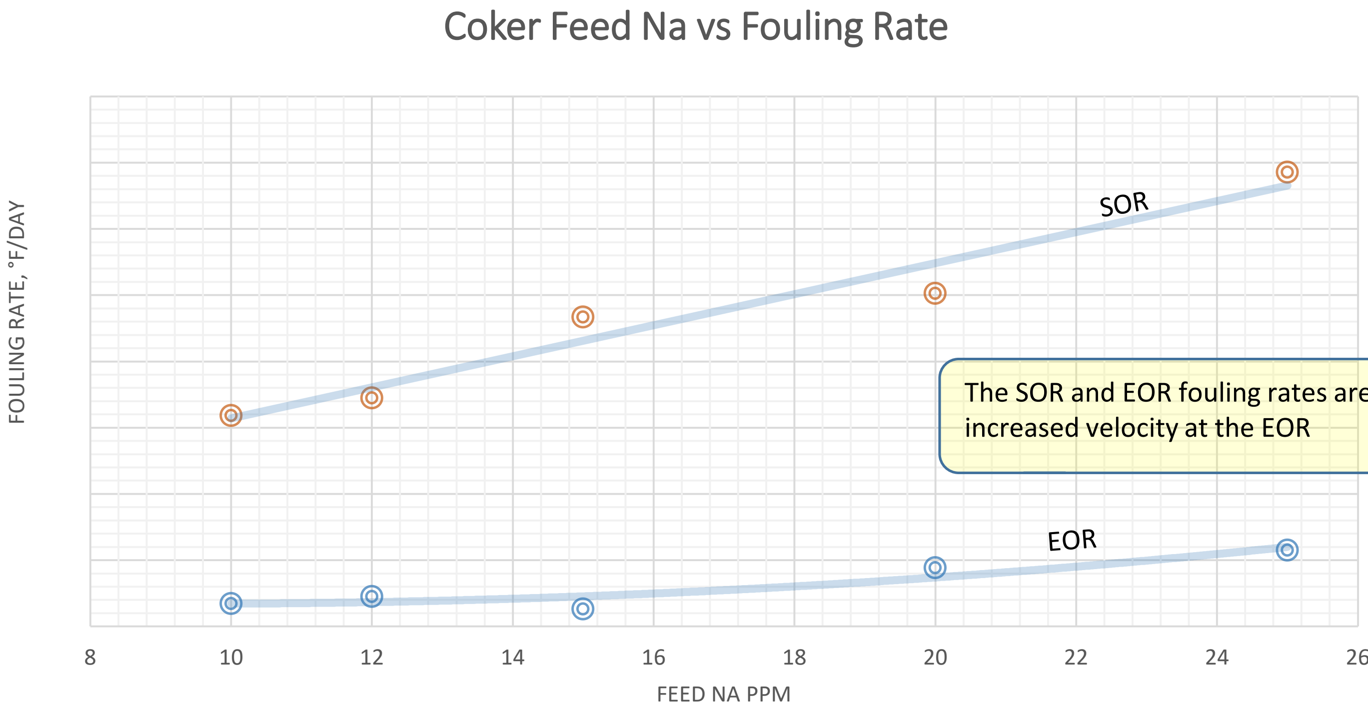
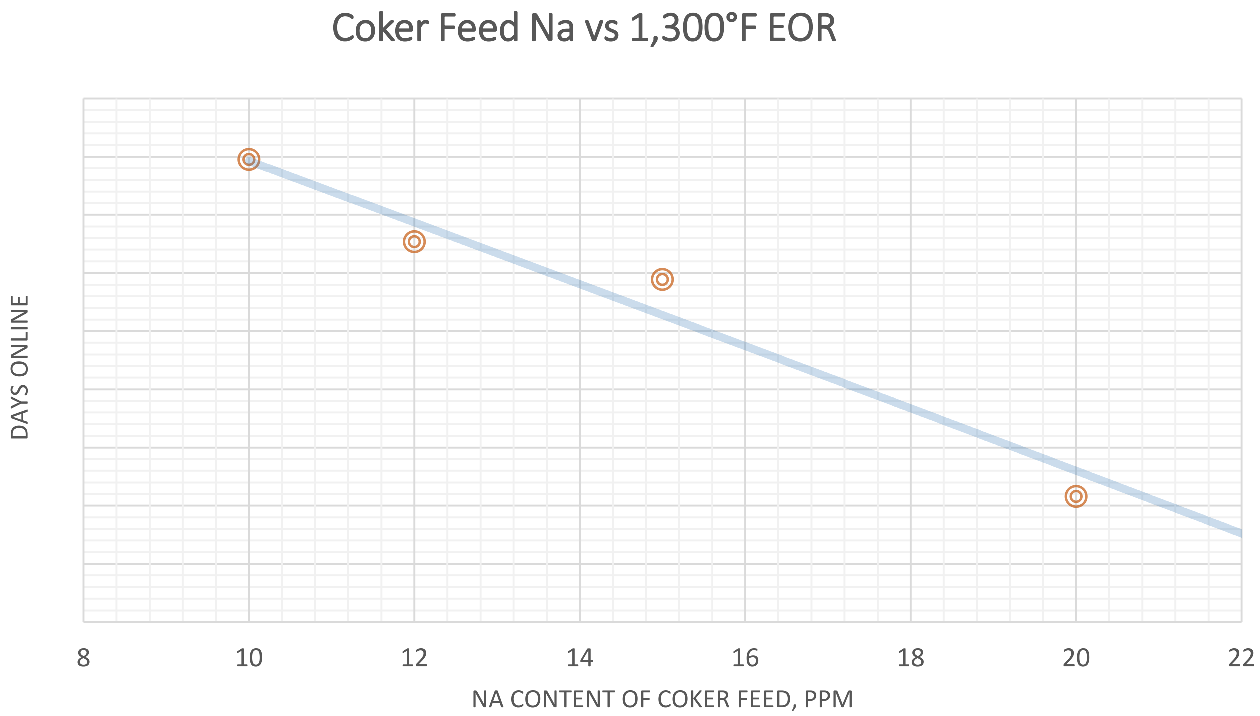


The SOR and EOR fouling rates are different due to the increased velocity at the EOR

Na Content vs Days Online



High Na content results in increase heater fouling.

Generating LP Vectors

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LP Utility

The **LP Utility** creates assay tables and reactor tables for use in programs such as *PIMS*™ and *GRTMPS*™. It also calculates Base Delta Tables and multi-variable linear regression coefficients for the setup you have given it, if necessary.
The LP Utility can generate two basic forms of tables:

Assay
Reactor

Both tables share some common required setup functionality:

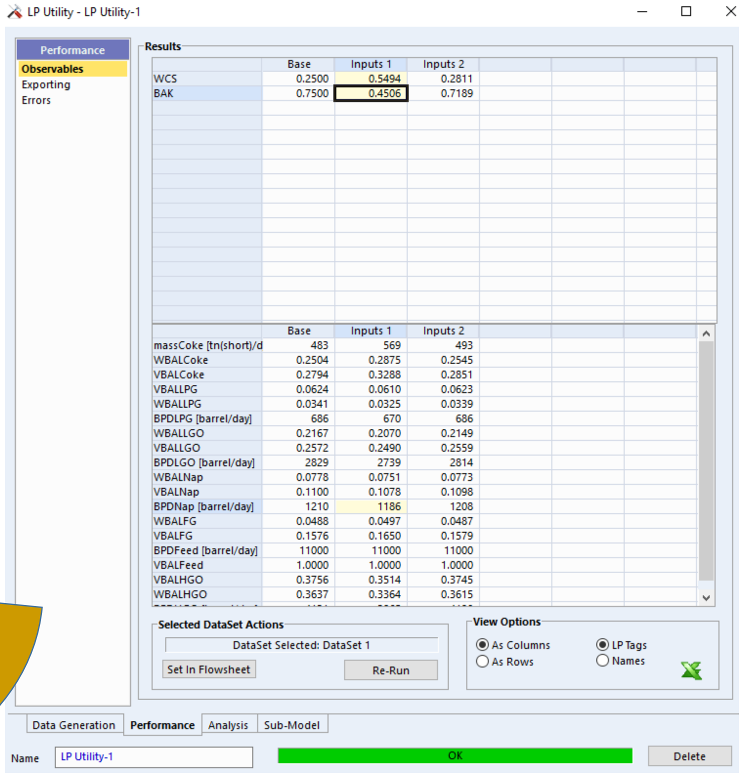
- **On the Observed Variables page, indicate the variables that you are interested in collecting as the data sets are generated.**
- **On LP Tags page, define the tags for streams, objects, and properties that the LP Utility uses to generate the relevant LP Tag in the table it is generating.**
- **Optionally, on the Swing Cuts page, you can choose to model swing cuts in any distillation column in your flowsheet and the LP Utility will calculate the properties of those swing cuts, and the effect that those swing cuts have on any properties being collected downstream of the swing for each data set it runs. The Swing Cuts** page can be used in conjunction with any kind of table generation.

LP Utility – Quick Results

Object	Property	BAS
Unit	Unit	barrel/day
LP Utility-1	Base	
LP Utility-1	Actual	
LP Utility-1	Delta	
LP Utility-1	Row 3	
LP Utility-1	WBALLPG	3.4%
LP Utility-1	WBALNap	7.8%
LP Utility-1	WBALLGO	21.7%
LP Utility-1	WBALCoke	25.0%
LP Utility-1	WBALHGO	36.4%
LP Utility-1	WBALFG	4.9%
LP Utility-1	VBALFeed	100.0%
LP Utility-1	VBALLPG	6.2%
LP Utility-1	VBALNap	11.0%
LP Utility-1	VBALLGO	25.7%
LP Utility-1	VBALCoke	27.9%
LP Utility-1	VBALHGO	37.6%
LP Utility-1	VBALFG	15.8%
LP Utility-1	BPDFeed	11000
LP Utility-1	BPDLPG	686.2170807
LP Utility-1	BPDNap	1210.305147
LP Utility-1	BPDLGO	2828.869464
LP Utility-1	massCoke	483.2423729
LP Utility-1	BPDHGO	4131.290116

Object	Property	Base	Inputs 1	Inputs 2
Unit	Unit			
LP Utility-1	WCS	25%	55%	28%
LP Utility-1	BAK	75%	45%	72%

Object	Property	Base	Inputs 1	Inputs 2	
LP Utility-1	BPDFeed	11,000	11,000	11,000	
LP Utility-1	VBALFeed	100%	100%	100%	
LP Utility-1	WBALFG	5%	5%	5%	
LP Utility-1	VBALFG	16%	16%	16%	
LP Utility-1	VBALLPG	6%	6%	6%	
LP Utility-1	WBALLPG	3%	3%	3%	
LP Utility-1	BPDLPG	686	670	686	
LP Utility-1	WBALNap	8%	8%	8%	
LP Utility-1	VBALNap	11%	11%	11%	
LP Utility-1	BPDNap	1,210	1,186	1,208	
LP Utility-1	WBALLGO	22%	21%	21%	
LP Utility-1	VBALLGO	26%	25%	26%	
LP Utility-1	BPDLGO	2,829	2,739	2,814	
LP Utility-1	VBALHGO	38%	35%	37%	
LP Utility-1	WBALHGO	36%	34%	36%	
LP Utility-1	BPDHGO	4,131	3,865	4,120	
LP Utility-1	massCoke	483.2	568.6	493.0	Ston/Day
LP Utility-1	WBALCoke	25%	29%	25%	
LP Utility-1	VBALCoke	28%	33%	29%	



Result from the LP are easily moved to Excel for review and analysis

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Thank You!

Sim Romero - Principal Consultant
KBC (A Yokogawa Company)
T: +1 281 597 7940 | M: +1 832 494 0441 | F: +1 281 616 0900
W: www.kbc.global | E: SRomero@kbcat.com

Maria Aldescu
Senior Staff Consultant

KBC Advanced Technologies, Inc., 15021 Katy Freeway, Suite 600,
Houston, TX, 77094, United States
T: +1 281 597 7913 | M: +1 713 572 7903 | F: +1 281 616 0900
W: www.kbc.global | E: MAldescu@kbcat.com

Mel Larson
Principal Consultant

KBC Advanced Technologies, Inc., 15021 Katy Freeway, Suite 60
Houston, Texas, 77094, United States
T: +1 281 597 7943 | M: +1 281 831 8202 | F: +1 281 616 0900
W: www.kbc.global | E: MLarson@kbcat.com

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