Delayed Coking : Petro-SIM™ Modeling

Detailed Examples
Agenda

- **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™** 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™ 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™ Production** is suited to modeling upstream or production facilities including gas plants, LNG plants and basic oil and gas separation platforms. Petro-SIM™ 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™ 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 H₂S and NH₃ are not measured and must be estimated.
  - Approximately 25% of the sulfur in the feed will go to H₂S
  - Approximately 15% of the nitrogen in the feed will go to NH₃

- 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 of Processes and Reactors for Upgrading of Heavy Petroleum”

Jorge Ancheyta
Reactors 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 your mass balance perfectly
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

## Summary Balance Coker Yields

<table>
<thead>
<tr>
<th></th>
<th>BPD [BFOE]</th>
<th>Vol%</th>
<th>UOP K</th>
<th>API Gravity</th>
<th>Mass Lbs/Hr</th>
<th>wt%</th>
<th>Sulfur Lbs/Hr</th>
<th>wt%</th>
<th>Nitrogen Lbs/Hr</th>
<th>ppm</th>
<th>Carbon Lbs/Hr</th>
<th>wt%</th>
<th>C:H</th>
<th>MW</th>
<th>Mol /Hr</th>
<th>Total Metals ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Fd Case - VTB</td>
<td>70,000</td>
<td>62.5%</td>
<td>11.25</td>
<td>5.00</td>
<td>1,057,622</td>
<td>61.93%</td>
<td>5,000</td>
<td>5.20%</td>
<td>890,029</td>
<td>84.15%</td>
<td>8,330</td>
<td>8.33</td>
<td>666.0</td>
<td></td>
<td></td>
<td>1,588.1</td>
</tr>
<tr>
<td>3-Fd Case - Slurry</td>
<td>7,000</td>
<td>6.3%</td>
<td>9.95</td>
<td>0.50</td>
<td>109,368</td>
<td>6.40%</td>
<td>1,203</td>
<td>1.10%</td>
<td>282.7</td>
<td>2.585</td>
<td>98,214</td>
<td>89.80%</td>
<td>10.30</td>
<td>274.4</td>
<td></td>
<td>398.6</td>
</tr>
<tr>
<td>3-Fd Case - SDA Rock</td>
<td>35,000</td>
<td>31.3%</td>
<td>11.30</td>
<td>2.00</td>
<td>540,694</td>
<td>31.66%</td>
<td>31,360</td>
<td>5.80%</td>
<td>452,732</td>
<td>83.73%</td>
<td>8.40</td>
<td>855.4</td>
<td>632.1</td>
<td>935.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total Feed</strong></td>
<td>112,000</td>
<td>100.0%</td>
<td>11.18</td>
<td>3.76</td>
<td>1,707,684</td>
<td>100.00%</td>
<td>87,560</td>
<td>5.13%</td>
<td>1,440,408</td>
<td>84.35%</td>
<td>8.43</td>
<td>652.1</td>
<td>2,618.8</td>
<td>644.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

## Hydrogen Sulfide

<table>
<thead>
<tr>
<th></th>
<th>Lbs/Hr</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>C5 &amp; Lter Gas Without H2S &amp; NH3</td>
<td>23,526</td>
<td>94.13%</td>
</tr>
<tr>
<td>NH3</td>
<td>1,334</td>
<td>0.08%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>112,812</td>
<td>79.89%</td>
</tr>
</tbody>
</table>

## NH3

<table>
<thead>
<tr>
<th></th>
<th>Lbs/Hr</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel Gas [C2 &amp; Lter]</td>
<td>63,744</td>
<td>3.73%</td>
</tr>
<tr>
<td>LPG [C3s &amp; C4s]</td>
<td>77,458</td>
<td>4.54%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>64,451</td>
<td>83.21%</td>
</tr>
</tbody>
</table>

## Light Naphtha [C5 - 300]

<table>
<thead>
<tr>
<th></th>
<th>Lbs/Hr</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Gas Oil [386 - 650]</td>
<td>304,988</td>
<td>17.86%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>34,536</td>
<td>84.70%</td>
</tr>
</tbody>
</table>

## Heavy Gas Oil [650 plus]

<table>
<thead>
<tr>
<th></th>
<th>Lbs/Hr</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke [410.5 lbs/BFOE]</td>
<td>553,772</td>
<td>32.43%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>51,615</td>
<td>84.70%</td>
</tr>
</tbody>
</table>

## Total Products

<table>
<thead>
<tr>
<th></th>
<th>Lbs/Hr</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Products</td>
<td>1,707,684</td>
<td>100.00%</td>
</tr>
<tr>
<td>87,560</td>
<td>5.13%</td>
<td></td>
</tr>
<tr>
<td>7,795.8</td>
<td>4.565</td>
<td></td>
</tr>
<tr>
<td>1,440,408</td>
<td>84.35%</td>
<td></td>
</tr>
</tbody>
</table>

## Recycle

<table>
<thead>
<tr>
<th></th>
<th>Lbs/Hr</th>
<th>ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Recycle</td>
<td>101307</td>
<td>119.4%</td>
</tr>
<tr>
<td>136,708</td>
<td>8.01%</td>
<td></td>
</tr>
<tr>
<td>6,668</td>
<td>0.02%</td>
<td></td>
</tr>
<tr>
<td>386.6</td>
<td>5.02%</td>
<td></td>
</tr>
<tr>
<td>2,828</td>
<td>84.70%</td>
<td></td>
</tr>
<tr>
<td>115,794</td>
<td>8.48%</td>
<td></td>
</tr>
<tr>
<td>607.8</td>
<td>8.48%</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>224.9</td>
<td>17.0%</td>
</tr>
</tbody>
</table>

## Calibration Error Sum

- **Average Calibration Error**: 3.70%
- **Average Calibration Error**: 18.48%

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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

#### Mass Flow

<table>
<thead>
<tr>
<th>Mass Flow</th>
<th>Screened</th>
<th>Typical Error</th>
<th>Error Basis</th>
<th>Reconciled</th>
<th>Rec Error</th>
<th>Screened</th>
<th>Typical Error</th>
<th>Error Basis</th>
<th>Reconciled</th>
<th>Rec Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCC Slurry Oil-Meter</td>
<td>109368 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>109326 lb/hr</td>
<td>0.04 %</td>
<td>0.2585 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>0.2585 wt %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>SDA Pitch-Meter</td>
<td>540697 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>540685 lb/hr</td>
<td>0.02 %</td>
<td>0.4116 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>0.4116 wt %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>Vac Resid-Meter</td>
<td>1057627 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>1057665 lb/hr</td>
<td>0.00 %</td>
<td>0.5000 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>0.5000 wt %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>Feed Total</td>
<td>1707692 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>1707594 lb/hr</td>
<td>0.00 %</td>
<td>7796 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>7796 lb/hr</td>
<td>0.00 %</td>
</tr>
<tr>
<td>Coke-Meter</td>
<td>5527712 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>552533 lb/hr</td>
<td>0.22 %</td>
<td>1.0000 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>1.0000 wt %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>Coker_Naphtha Meter</td>
<td>197495 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>197686 lb/hr</td>
<td>0.10 %</td>
<td>0.2600 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>0.2600 wt %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>Fuel_Gas-Meter</td>
<td>63744 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>63761 lb/hr</td>
<td>0.04 %</td>
<td>0.0000 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>0.0000 wt %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>H2S Meter</td>
<td>23526 lb/hr</td>
<td>5.00 %</td>
<td>Relative</td>
<td>23395 lb/hr</td>
<td>0.56 %</td>
<td>0.0000 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>0.0000 wt %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>Heavy_Coker_GO-Meter</td>
<td>455366 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>456030 lb/hr</td>
<td>0.14 %</td>
<td>0.1750 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>0.1750 wt %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>Light_Coker_GO-Meter</td>
<td>304988 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>305344 lb/hr</td>
<td>0.12 %</td>
<td>0.0996 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>0.0996 wt %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>LPG-Meter</td>
<td>77458 lb/hr</td>
<td>2.00 %</td>
<td>Relative</td>
<td>77493 lb/hr</td>
<td>0.05 %</td>
<td>0.0000 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>0.0000 wt %</td>
<td>0.00 %</td>
</tr>
<tr>
<td>NGL-Meter</td>
<td>1334 lb/hr</td>
<td>5.00 %</td>
<td>Relative</td>
<td>1338 lb/hr</td>
<td>0.47 %</td>
<td>82.2436 wt %</td>
<td>2.00 %</td>
<td>Relative</td>
<td>82.2436 wt %</td>
<td>0.00 %</td>
</tr>
</tbody>
</table>

#### Nitrogen Content

<table>
<thead>
<tr>
<th>Nitrogen Content</th>
<th>Screened</th>
<th>Typical Error</th>
<th>Error Basis</th>
<th>Reconciled</th>
<th>Rec Error</th>
<th>Screened</th>
<th>Typical Error</th>
<th>Error Basis</th>
<th>Reconciled</th>
<th>Rec Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall Imbalance</td>
<td>0.00 %</td>
<td>0.00 %</td>
<td>-0.02 %</td>
<td>0.00 %</td>
<td>0.00 %</td>
<td>0.00 %</td>
<td>0.00 %</td>
<td>0.00 %</td>
<td>0.00 %</td>
<td>0.00 %</td>
</tr>
</tbody>
</table>
Case 2 – Multiple Feeds & Types Calibration
# Case 2 – Generate a Material Balance

## Material Balance

### Current Cell

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td>Vol Flow</td>
<td>API Gravity</td>
<td>Mass Flow</td>
<td>wt% Yield</td>
<td>wt% Sulfur</td>
<td>wt% Nitrogen</td>
</tr>
<tr>
<td>2</td>
<td>Vac Resid</td>
<td>70000 barrel/day</td>
<td>4.994</td>
<td>1057663 lb/hr</td>
<td>61.94%</td>
<td>5.2000 wt %</td>
<td>0.5000 wt %</td>
</tr>
<tr>
<td>3</td>
<td>FCC Slurry</td>
<td>6997 barrel/day</td>
<td>0.5000</td>
<td>109326 lb/hr</td>
<td>6.40%</td>
<td>1.1000 wt %</td>
<td>0.2585 wt %</td>
</tr>
<tr>
<td>4</td>
<td>SDA Pitch</td>
<td>34995 barrel/day</td>
<td>2.003</td>
<td>54065 lb/hr</td>
<td>31.66%</td>
<td>5.8000 wt %</td>
<td>0.4115 wt %</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td>1707594 lb/hr</td>
<td>100.00%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>H2S</td>
<td>23394 lb/hr</td>
<td>1.37%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>NH3</td>
<td>1328 lb/hr</td>
<td>0.08%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Fuel Gas</td>
<td>6376 lb/hr</td>
<td>3.73%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>LPG Product</td>
<td>10169 barrel/day</td>
<td>127.4</td>
<td>81009 lb/hr</td>
<td>4.74%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Naphtha</td>
<td>18155 barrel/day</td>
<td>62.19</td>
<td>193304 lb/hr</td>
<td>11.32%</td>
<td>1.5978 wt %</td>
<td>0.0264 wt %</td>
</tr>
<tr>
<td>11</td>
<td>LCGO</td>
<td>24000 barrel/day</td>
<td>32.05</td>
<td>306427 lb/hr</td>
<td>17.94%</td>
<td>2.7966 wt %</td>
<td>0.0905 wt %</td>
</tr>
<tr>
<td>12</td>
<td>HCGO</td>
<td>34992 barrel/day</td>
<td>14.70</td>
<td>467983 lb/hr</td>
<td>28.58%</td>
<td>3.9523 wt %</td>
<td>0.1751 wt %</td>
</tr>
<tr>
<td>13</td>
<td>Coke</td>
<td>550382 lb/hr</td>
<td>32.23%</td>
<td>6.5182 wt %</td>
<td>1.0033 wt %</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td>1707594 lb/hr</td>
<td>100.00%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### 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>
- **Closing Outage [Hr]**: 67.02
- **Closing Outage [%]**: 67.02

### Operating Conditions

- **Drum**
  - **Pressure**: 26171.07
  - **Temperature**: 52342.15
  - **Heat**: 550390
  - **Molar Conversion**: 126333
  - **Sulfur**: 15.90
  - **Nitrogen**: 11173.32
  - **Drum Liquid Holdup [%]**: 1.581
  - **Drum Vapor Space [%]**: 39699.59
  - **Total Vap Mass Rate per Drum [lb/hr]**: 452492
  - **Total Vap Vol Rate per Drum [ACFM]**: 28423.4
  - **Drum Vapor Velocity [lb/s]**: 0.0701
  - **Drum C Factor**: 0.2524
  - **Foam Height [In]**: 12.03
  - **Foam Height with anti-Foam [In]**: 6.016
  - **Remaining Vapor Space Height [In]**: 60.52
  - **Foam Over Potential at Closing In, %**: 0.0000
  - **Foam Over Potential at Full End, %**: 16.74

### Economic Results

- **S vs API Plot**
- **Diagnostics**
Case 2 – Naphtha Component Details

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

Crude selection with Crude & Vac Unit Operations

DC-Sim Reactor Model

Drum OVHD (BD & Transfer Line)

Detailed Main Fractionator

Cold/Hot Feed Preheat

Detailed Gas Plant

Detailed Furnace Operations
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.
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.
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

Worksheet Properties

- Volume Average Boiling Point [°F]: 1324
- API Gravity (Dry): 1.506
- Specific Gravity (Dry): 1.060
- Watson K: 11.34
- Condensation Carbon Content (wt %): 27.9376
- Asphaltene Content (wt %): 25.0829
- Sulfur Content (wt %): 5.5228
- Nitrogen Content (wt %): 6.6127
- Naphthenes by Wt (wt %): 26.3297
- Aromatics by Wt (wt %): 65.2622
- Refractive Index: 1.565
- Nickel Content [ppmw]: 124.4
- Vanadium Content [ppmw]: 628.1
- Iron Content [ppmw]: 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 Method: 1.655e+004

Distillation ASTM D1160_01 (°F): 867.2
Distillation ASTM D1160_02 (°F): 898.6
Distillation ASTM D1160_10 (°F): 1029
Distillation ASTM D1160_30 (°F): 1135
Distillation ASTM D1160_50 (°F): 1335
Distillation ASTM D1160_70 (°F): 1535

Size: 639x340 pixels
Type: Image
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.

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.
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
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.
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.
The transfer piping accounts for elevation changes – using the Breggs Brill Two Phase method.
Temperature-Pipe Length

Temperature (°F) vs Pipe Length (ft)

- Elevation
- Temperature
- Pressure
- Heat Transfer
- Gradients
- Liquid Holdup
- Liquid Reboil Rate
- Vapour Reboil Rate
- Liquid Velocity
- Vapour Velocity
- Deposit Thickness
- Deposit Volume

Table | Plot
Transfer Line

Pipe Profile View - Drum to Frac Tower Transfer Line

Pressure-Pipe Length

Pressure (psig)

Pipe Length (ft)
Main Fractionator Model & Heat Removal
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...
**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.
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.
Gas Plant
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 reboller duties tied to the HGO or LGO pump-around heat removal.
Feed Preheat
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
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.
The coke thickness acts as insulation to heat transfer causing the tube wall temperature to increase and higher fuel gas firing.

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

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

Costs -> Capital vs Operating

Absorbed Heat = Surface Area × Heat Flux

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

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

\[T_g = \text{the bridge wall temperature}\]

- 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.

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.
Petro-SIMTM Kinetics

Bulk Phase

\[ BR_{xn_n} = \text{Residence Time} \times U1 \times A1 \times e^{\left( \frac{B1 + E1}{T_{\text{bulk}}} + C1 \times K1 \right)} + BR_{xn_{n-1}} \]

Wall Film Rxn

\[ WR_{xn_n} = \text{Residence Time} \times BR_{xn_n} \times A2 \times e^{\left( \frac{B2 + E2}{T_{\text{film}}} + C2 \times K2 \right)} \]

Coking thickness (when \( MV1 > 0 \))

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

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

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

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

- Colloid Instability Index (CII)
  - Asphaltenes+Saturates
  - Aromatics+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
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

Proprietary Information

BC 16 Hr Fill 1.8K
Stm

Spray or Dispersed
Wave
Annular
Stratified
Plug
Bubble or Froth
Slug
Most of the results generated can be plotted, but the model can export some of the critical results to Excel for detailed fouling case studies.
Heater Results – Furnace CII vs Fouling Rate

Furnace Feed CII vs 1,300°F EOR

More stable feed
Crude Cases – Furnace CII vs Fouling Rate

Large Difference between SOR and EOR can be seen in the models result.
The coil outlet temperature is the most significant factor affecting the heater run length.
Reducing the COT will extend the heater run length but will cause the coke to become softer and potentially more difficult to quench and cut. Additionally, if the temperature gets too low in the coke drum there could be foaming problems leading to increase solids carry over.
The difference in SOR and EOR fouling rates are much higher for the high COT cases. As the coke builds on the tubes the fouling rate slows down due to increased velocities as a result of coke built up. The coke build up is very high at high COT temperatures.
Typical Heater Simulation Results & Analysis

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.

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.
Heater Simulation Results & Analysis

**Heat Flux Profile**

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

**Bridge Wall Temperature**

Bridge wall temperature increases with the heater run – a very typical temperature profile.
Heater Simulation Results & Analysis

Bulk Fluid Temperature Profile

Film or Wall Temperature Profile

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

The SOR and EOR fouling rates are different due to the increased velocity at the EOR.
Na Content vs Days Online

Coker Feed Na vs 1,300°F EOR

High Na content results in increase heater fouling.
Generating LP Vectors
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 the 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

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

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<th>BAS</th>
<th>Object</th>
<th>Property</th>
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Proprietary Information

6/11/2018
Thank You!

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