Pilot Results For A Revolutionary Cross-Flow, Fluid Bed Upgrading Process

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The Challenge

- How to meet future energy demands in the face of:
  - Diminishing conventional oil resources
  - Escalating capital costs
  - Unstable oil prices
  - Environmental uncertainties
  - Political uncertainties
  - Challenging capital markets
Role of Technology

- Use technology to:
  - Improve economics
    - Reduce capital
    - Better use of resource
  - Improve environmental footprint
    - Facilitate integration with environmental technologies
    - Better use of resource
The Growing Emphasis on Primary Upgrading

- Primary upgrading converts pitch into distillable liquids
- Primary upgrading benchmark is a century old
- Significant performance gap relative to “ideal coking”
Comparing Primary Upgrading Technology is Simple…

- The technology metrics are:
  - Liquid yield
  - Liquid quality
  - Capacity / Capital

- The winner achieves benefits in some categories, but compromises in none
...but Finding the Winning Concept is Difficult

- Current picture of upgrading science

- How to meet opposing constraints in liquid and vapour phases with a single technology?
IYQ Upgrading Leverages Current Understanding

- Thin films limit liquid severity
- Decoupling of vapour and liquid phase residence times allow constraints of vapour phase to be met without compromising capacity
- Reactor characteristics enable reduction in operating temperature which benefits both yield and quality
Temperature Dictates Fate of Hydrogen

- Final distribution of hydrogen among coking products is significantly affected by reaction temperature
- Positively affects qualities

<table>
<thead>
<tr>
<th>Reaction Temperature</th>
<th>Liquid Products</th>
<th>Gas</th>
<th>Coke</th>
</tr>
</thead>
<tbody>
<tr>
<td>450°C</td>
<td>83%</td>
<td>8%</td>
<td>9%</td>
</tr>
<tr>
<td>470°C</td>
<td>82%</td>
<td>9%</td>
<td>9%</td>
</tr>
<tr>
<td>500°C</td>
<td>79%</td>
<td>13%</td>
<td>8%</td>
</tr>
<tr>
<td>530°C</td>
<td>74%</td>
<td>18%</td>
<td>8%</td>
</tr>
</tbody>
</table>
Demonstration of IYQ Upgrading at 1 bbl/d

- Solids and vapour phase residence times scaled to match commercial design
- Two main trains - reactor train and accumulator train
- Nitrogen used as fluidization gas – preheated to reactor temperature before introduction
- Full coke circulation
Assessing Yield Benefit

- For a given technology, coke production has been shown to be relatively insensitive to temperature.

- Therefore, to assess relative impact of temperature, focus on split between gas and liquid production.
Assessing Yield Benefit (cont’d)

- For once through yields, performance measured based on product produced per quantity of feed consumed

![Diagram showing yield distribution for Liquid, Pitch, Gas, and Coke]
Pilot Results

- Unit operated until steady state conditions achieved
- Liquid samples collected continuously over the steady state period
- Gas composition assessed every 15 minutes using online refinery gas analysis system
- Following each run, the data was compiled and checked for data consistency by assessing total mass closure, and individual elemental balances – typical mass closures > 96%
Gas Yields Show Benefits

- Sulfur release indicates excellent data consistency

![Graph showing gas yields vs bed temperature]
Coke and Gasoil Yields Consistent with Expectations

- Coke yields relatively insensitive to temperature
- Bulk of yield benefit lies in gasoil
Assessing Quality Benefit

- Primary factor driving quality is hydrogen content
- Hydrogen content of gas is much higher than liquids
- Olefinic character of gas related to severity of treatment
Quality metrics support I^YQ Upgrading Claims

- Indications that overcracking dramatically reduced
Hydrogen Losses to Gas Phase Reduced

- Conservative?
Recycle to Extinction

- Model in good agreement with experimental data

<table>
<thead>
<tr>
<th>Product</th>
<th>Yield (Mass %)</th>
<th>Model</th>
<th>Pilot Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Liquids</td>
<td>76.1</td>
<td>75.2</td>
<td></td>
</tr>
<tr>
<td>Pitch</td>
<td>14.2</td>
<td>14.2</td>
<td></td>
</tr>
<tr>
<td>Coke</td>
<td>6.5</td>
<td>6.3</td>
<td></td>
</tr>
<tr>
<td>Gas</td>
<td>3.0</td>
<td>3.01</td>
<td></td>
</tr>
<tr>
<td>H2S</td>
<td>1.2</td>
<td>1.4</td>
<td></td>
</tr>
</tbody>
</table>
Advantage Leveraged Upon Recycle

- Link between once through and recycle to extinction well established

<table>
<thead>
<tr>
<th>Product</th>
<th>Mass Yields (%)</th>
<th>Volume Yields (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I^YQ Upgrading</td>
<td>Fluid Coking</td>
</tr>
<tr>
<td>Liquids</td>
<td>66.4</td>
<td>60.8</td>
</tr>
<tr>
<td>HGO</td>
<td>41.6</td>
<td>36.5</td>
</tr>
<tr>
<td>LGO</td>
<td>13.2</td>
<td>11.6</td>
</tr>
<tr>
<td>Naphtha</td>
<td>11.6</td>
<td>12.7</td>
</tr>
<tr>
<td>Coke</td>
<td>25.7</td>
<td>28.3</td>
</tr>
<tr>
<td>Gas</td>
<td>7.9</td>
<td>10.9</td>
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<tr>
<td>Liquids</td>
<td>76.7</td>
<td>70.0</td>
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<tr>
<td>HGO</td>
<td>45.0</td>
<td>38.9</td>
</tr>
<tr>
<td>LGO</td>
<td>15.6</td>
<td>13.5</td>
</tr>
<tr>
<td>Naphtha</td>
<td>16.1</td>
<td>17.6</td>
</tr>
</tbody>
</table>
Challenges with Pilot Testing

- Width of fluidized bed using conventional scaling methodologies is essentially impossible to feed – bed width had to be increased to accommodate feed introduction, resulting in an increase in non-condensable gases and challenges in product collection
  - Indirect heat transfer equipment required to facilitate mass balance closure
- Product collection system adopted for the pilot proved very difficult to commission – hydrocarbons had a propensity to form fog in the heat exchangers making the liquids impossible to separate from the non-condensable fluidization gas
  - Resolved through systematic troubleshooting and innovative low-cost modifications to the condensing equipment
Challenges with Pilot Testing

- Electrical immersion heaters used for preheating fluidized coke were initially not able to achieve heat transfer design requirements -- issue was found to be related to the fluid dynamics of the system coupled with the chemical environment.
  - Redesign of heaters combined with a change in the process operating conditions resolved this problem.

- Two phase atomizing nozzles did not perform as designed -- largely related to the lack of understanding of nozzle performance at reactor conditions.
  - In-house development program was able to develop baseline correlation between gas pressure and reactor/feed conditions, resulting in proper nozzle selection.
Summary

- Piloting at 1 bpd scale was undertaken to provide support to yield and quality claims of new primary upgrading technology, IYQ Upgrading
- Results from pilot supported claim of 9% liquid yield advantage on a whole bitumen basis relative to delayed coking
- Pilot work also supported claims of increased hydrogen retention