Bottom of Barrel Processing

Chapters 5, 6, & 8
Need For Heavy Ends Processing

**Worldwide** crude slate has become heavier

- Concentration of sulfur & other contaminants has been increasing
- Sulfur specifications becoming more stringent
  - Environmental protection
- Demand for No. 6 Fuel Oil declining
  - Environmental protection
- Cost of light crude relative to heavy crude is increasing
- Trends in the United States have become more complicated due to the flood of light, sweet, tight oil from shale in the United States

![Graph showing US refinery crude feedstock quality](image)

Gunaseelan & Buehler
“Changing US crude imports are driving refinery upgrades”
*Oil & Gas Journal*, Aug. 10, 2009
Processing Options

Physical separations
- Vacuum distillation
  - Volatility
- Solvent Deasphalting
  - Solubility

Lube Oil Processing
- Requires specialized feedstocks

Chemical reactions (in order of increasing severity)
- Visbreaking
- Catalytic cracking
- Coking
  - Delayed coking
  - Fluidized bed coking
- Hydrocracking
U.S. Refinery Implementation

EIA, Jan. 1, 2017 database, published June 2017
http://www.eia.gov/petroleum/refinerycapacity/

Updated: July 5, 2017
Copyright © 2017 John Jechura (jjechura@mines.edu)
Solvent Deasphalting

Purpose
- Remove asphalts from lube plant feeds
- Increase gas oil yield from crude
- Make commercial asphalts from asphaltic crude unit bottoms

Characteristics
- Physical recovery using light hydrocarbon solvent (C3, C4, C5)
  - Dissolve saturated components
  - Leave behind/precipitate asphaltenes
  - Resins split between phases

Products
- Deasphalted Oil (DAO)
- Resins
- Bottoms/pitch – asphaltenes

Residue Upgrading Technology Options for Cost Effective Solutions, Steve Beeston, ARTC 2014, Singapore, March 5, 2014
Typical SDA Process

Foster Wheeler SDA process
Characteristics of Products

DAO resembles gas oil but is of drastically different boiling point range.
Characteristics of Products

First 50% DAO molecules are suitable to hydrocrack
50-70+% DAO molecules are challenging to hydrocrack

DAO Yield

Residue Upgrading Technology Options for Cost Effective Solutions,
Steve Beeston, ARTC 2014, Singapore, March 5, 2014
Integration of SDA into Refinery

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>With SDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atm Resid Feed</td>
<td>bpsd</td>
<td>50,000</td>
</tr>
<tr>
<td>°API</td>
<td>15.1</td>
<td>15.1</td>
</tr>
<tr>
<td>wt% S</td>
<td>4.02</td>
<td>4.02</td>
</tr>
<tr>
<td>ppmw metals</td>
<td>69</td>
<td>69</td>
</tr>
<tr>
<td>Vac Resid</td>
<td>bpsd</td>
<td>20,000</td>
</tr>
<tr>
<td>°API</td>
<td>5.6</td>
<td>5.6</td>
</tr>
<tr>
<td>wt% S</td>
<td>5.55</td>
<td>5.55</td>
</tr>
<tr>
<td>ppmw metals</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>SDA Bottoms</td>
<td>bpsd</td>
<td>5,400</td>
</tr>
<tr>
<td>°API</td>
<td>-12.6</td>
<td>-12.6</td>
</tr>
<tr>
<td>wt% S</td>
<td>7.15</td>
<td>7.15</td>
</tr>
<tr>
<td>ppmw metals</td>
<td>475</td>
<td>475</td>
</tr>
<tr>
<td>SDA DAO</td>
<td>bpsd</td>
<td>14,600</td>
</tr>
<tr>
<td>°API</td>
<td>11.4</td>
<td>11.4</td>
</tr>
<tr>
<td>wt% S</td>
<td>4.84</td>
<td>4.84</td>
</tr>
<tr>
<td>ppmw metals</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>Gas Oil</td>
<td>bpsd</td>
<td>30,000</td>
</tr>
<tr>
<td>°API</td>
<td>22.3</td>
<td>22.3</td>
</tr>
<tr>
<td>wt% S</td>
<td>3.04</td>
<td>3.04</td>
</tr>
<tr>
<td>ppmw metals</td>
<td>7</td>
<td>7</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Base</th>
<th>With SDA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed to FCC</td>
<td>bpsd</td>
<td>27,340</td>
</tr>
<tr>
<td>°API</td>
<td>24.0</td>
<td>24.0</td>
</tr>
<tr>
<td>HDS Fuel Gas</td>
<td>Mscfd</td>
<td>4,200</td>
</tr>
<tr>
<td>°API</td>
<td>24.0</td>
<td>24.0</td>
</tr>
<tr>
<td>FCC Fuel Gas</td>
<td>Mscfd</td>
<td>4,430</td>
</tr>
<tr>
<td>°API</td>
<td>25.5</td>
<td>25.5</td>
</tr>
<tr>
<td>Total Fuel Gas</td>
<td>Mscfd</td>
<td>8,630</td>
</tr>
<tr>
<td>°API</td>
<td>54.5</td>
<td>54.5</td>
</tr>
<tr>
<td>HDS C3/C4</td>
<td>bpsd</td>
<td>190</td>
</tr>
<tr>
<td>°API</td>
<td>9.0</td>
<td>9.0</td>
</tr>
<tr>
<td>Total C3/C4</td>
<td>bpsd</td>
<td>5,220</td>
</tr>
<tr>
<td>°API</td>
<td>25.5</td>
<td>25.5</td>
</tr>
<tr>
<td>HDS Naphtha</td>
<td>bpsd</td>
<td>15,420</td>
</tr>
<tr>
<td>°API</td>
<td>22.9</td>
<td>22.9</td>
</tr>
<tr>
<td>Total Naphtha</td>
<td>bpsd</td>
<td>15,680</td>
</tr>
<tr>
<td>°API</td>
<td>23.3</td>
<td>23.3</td>
</tr>
<tr>
<td>FCC Cycle Oil</td>
<td>bpsd</td>
<td>7,108</td>
</tr>
<tr>
<td>°API</td>
<td>25.5</td>
<td>25.5</td>
</tr>
<tr>
<td>FCC Slurry</td>
<td>bpsd</td>
<td>1,367</td>
</tr>
<tr>
<td>°API</td>
<td>0.9</td>
<td>0.9</td>
</tr>
<tr>
<td>HDS Distillate</td>
<td>bpsd</td>
<td>2,750</td>
</tr>
<tr>
<td>°API</td>
<td>32.5</td>
<td>32.5</td>
</tr>
</tbody>
</table>

*Handbook of Petroleum Refining Processes*
Robert Meyers
Visbreaking

Purpose
- Cut viscosity in ½ of feed (specs for heavy fuel oil)
- Reduces "cutter stock"
- Reduces heavy fuel oil amount

Characteristics
- Relatively mild thermal cracking operation
- Flexible on feedstock quality
- Typically high resin crude oils
- Low capital cost for process

Products
- ~20% feed cracked to light ends, naphtha, gas oil & distillate
- Products contain a lot of olefins
  - Olefinic C3s & C4s often recovered
  - Naphtha & distillate often hydrotreated because of olefins & sulfur
- Gas oil high in aromatics — more appropriate for hydrocracking than cat cracking
- Large volumes of heavy fuel oil with high sulfur content
- Bottoms (visbreaker tar) sent directly to heavy fuel oil
Typical Coil Visbreaker

http://www.fwc.com/industries/pdf/Residue_upgrading_English_10th_Sept.pdf?DIRNAME=%23dirName%23
Catalytic Cracking

Purpose
- Make gasoline & distillates (diesel/heating oil)
- Try to minimize heavy fuel oil

Characteristics
- Medium severity cracking process
- Gas oils are typical feedstocks
- Not normally used on whole atmospheric or vacuum resid
  - PNAs tend to condense, leading to coking
  - Catalysts sensitive to poisoning by sulfur & metals present in PNAs

Products
- Light gases
  - Olefins
- Light & Heavy Naphtha
- Light & Heavy Cycle Oils
- Slurry

Figure: [http://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_2.html](http://www.osha.gov/dts/osta/otm/otm_iv/otm_iv_2.html)
Hydrocracking

Purpose

- Minimize heavy fuel oil

Characteristics

- Severe cracking process
  - Combines cracking & hydrogenation
- Coking better for resids
- High pressures & large amounts of hydrogen required

Products

- Produces high yields of liquids
  - Hydrogen suppresses coke formation
  - Liquids low in sulfur & olefins

Figure: Haldo Topsøe process flow
2011 Refining Processes Handbook
Hydrocarbon Processing, 2011

Coking

Purpose

- Create light gases & distillates
- “Carbon rejection”

Characteristics

- Severe thermal cracking process
- Can process a wide variety of feedstocks – high High metals (nickel and vanadium), sulfur, resins & asphaltenes
- Side chains broken off from thermally stable PNA cores
  - PNAs contain majority of the heteroatoms (sulfur, nitrogen, metals)

Products

- Light gases, distillates (naphthas & gas oils) for catalytic upgrading
  - High in sulfur & olefins
- Coke
  - High in sulfur & metals
Summary
Summary

Reason for “Bottom of the Barrel” processing

- Attempt to get more liquid fuels from the portion of the crude oil that is heavier (of higher boiling point) than the diesel range

Processes

- Physical separations
  - Vacuum Column
  - Solvent Deasphalting (SDA)

- Chemical conversions
  - Visbreaking
  - Coking
  - Fluidized Catalytic Cracking (FCC)
  - Hydrocracking
Supplemental Slides
## SDA Technology Providers

<table>
<thead>
<tr>
<th>Provider</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foster Wheeler</td>
<td>Light hydrocarbon solvent with DAO/solvent separation at supercritical conditions</td>
</tr>
<tr>
<td>KBR</td>
<td></td>
</tr>
</tbody>
</table>

**Provider Features**

Foster Wheeler

KBR ROSE©

Hydrocarbon Processing’s *2008 Refining Processes Handbook*
## Visbreaking Technology Providers

<table>
<thead>
<tr>
<th>Provider</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foster Wheeler</td>
<td>Visbreaker heater &amp; downstream coil</td>
</tr>
<tr>
<td>Shell Global Solutions</td>
<td></td>
</tr>
</tbody>
</table>

---

**Foster Wheeler**

**Shell Global Solutions**

*Hydrocarbon Processing’s 2008 Refining Processes Handbook*

Updated: July 5, 2017  
Copyright © 2017 John Jechura (jjechura@mines.edu)