In The Name Of God
Upgrading Process of Heavy Oil

CORPORATIVE PLANING DIRECTORATE
(Consumption Affairs)
Spring 1387
Heavy Oil Upgrading Process

Contents

1. Introduction: Key for Heavy Oil Upgrading Process Selection
2. Features of Heavy Oil Upgrading Processes
3. Feasibility Study for Typical Model Case
4. Process Configuration in Domestic Refinery
5. Summary
What is the Heavy Oil?

From the Standpoint of Properties

Heavy Oil is High Heating Value,
but High Viscous Oil such as Residues from CDU and VDU.

(Especially High-Sulfur and High-Metal Fuel Oil Case)
What is the Heavy Oil?

From the Standpoint of Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Heating Value</td>
<td>⇒ Good Fuel (used only for Fuel)</td>
</tr>
<tr>
<td>High Sulfur Content</td>
<td>⇒ Air Pollution (Acid Rain, Oxidant etc)</td>
</tr>
<tr>
<td>High Viscosity (High Pour Point)</td>
<td>⇒ Heating (during Transport, Storage etc)</td>
</tr>
<tr>
<td></td>
<td>Mal Atomizing</td>
</tr>
<tr>
<td>High Metal Content</td>
<td>⇒ Corrosion Catalyst Poisonous</td>
</tr>
</tbody>
</table>
Heavy Oil

High Sulfur, high Metal, high Heating Value and high Viscous as Residues from CDU and VDU

High MW & Low H/C ratio

Light Oil

To change the Heavy Oil to the High Quality Light Products (Especially Lighter Fractions, low Sulfur and low Metal Products are good).

Low MW & High H/C ratio
**Heavy Oil Upgrading Process**

**What do the Upgrading Processes mean?**

*From the Standpoint of Properties*

<table>
<thead>
<tr>
<th>Properties</th>
<th>Before Processing</th>
<th>After Processing</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Heating Value</td>
<td>Good Fuel</td>
<td>Various Products (not only for Fuel but also Petrochemical feed etc)</td>
</tr>
<tr>
<td>(used only for Fuel)</td>
<td>(used only for Fuel)</td>
<td></td>
</tr>
<tr>
<td>High Sulfur Content</td>
<td>Air Pollution (Acid Rain, Oxidant etc)</td>
<td>Low Sulfur</td>
</tr>
<tr>
<td>High Viscosity (High Pour Point)</td>
<td>Heating (during Transport, Storage etc) Mal Atomizing</td>
<td>Low Viscosity (Lighter Fractions) not Necessary more Heating Good Atomizing</td>
</tr>
<tr>
<td>High Metal Content</td>
<td>Corrosion Catalyst Poisonous</td>
<td>Low Metal Products less Corrosive/Poisonous</td>
</tr>
</tbody>
</table>
1. Introduction:

Key for Heavy Oil Upgrading Process Selection
1.1 Introduction

- Gasoline/Middle distillate market demand is increasing.
- New regulations for protecting environment is getting severe.
- Crude oil properties is getting heavier.
- Sulfur contents in crude is also getting heavier.
- Purchasing light sweet crude oil is expensive.

What can we do now?

Install Heavy Oil Upgrading Process in Refinery.
1.2 Introduction: Key Point

There are many different types of Heavy Oil upgrading technology available to meet the refinery’s needs.

By adding upgrading process in refinery, capital cost & revenue is increasing, but profitability is not necessarily improved.

Key Point:
How to produce light oil products efficiently and economically from Heavy Oil.

How to optimize the Refinery Configuration?
1.3 Primary Factors for Upgrading Process Selection

- Price Spread between Light and Heavy Crude
- Price Spread between Crude and Residue
- Products Demand & Specification

Fuel Oil or Gasoline/Gas Oil?
Motor Gasoline or Gas Oil?
Export use or Domestic use?
Spec. Change due to Environmental Regulation?
Marketability of Coke/Pitch?

Feed Properties
- SpGr, Sulfur, Metals, UOPK($3\sqrt{\frac{T_b}{S}}$)
1.4 Primary Factors for Upgrading Process Selection

- Process Configuration of Existing Plant
- Operation Flexibility for Max./Min. Product Rates
  - High Flexibility is required?
- Technology of Heavy Oil Upgrading Process
  - To meet the Needs?
  - Well-Proven?
- Hydrogen & Electric Power’s Price & Consumption
- Economics
  - Maximize Profitability?
  - Maximum Allowable Capital Cost?
2. **Features of Heavy Oil Upgrading Processes**
Technology Improve in Heavy Oil Upgrading Processes

1. Producing more efficient catalysts
2. Upgrading catalytic processes from fixed bed to fluidized bed.
3. Making spare batch reactors to keep process work continuously.
4. Using a wider range of feeds in new processes.
5. Producing new products.
6. Increasing the yield and efficiency of processes.
**Classification of Residue Upgrading**

1. **Hydrogen Addition type**
   
   Hydrogen is added to heavy oil
   
   (Hydrogen, Catalyst, High Temperature & Pressure)

2. **Carbon Rejection type**
   
   Carbon is removed from heavy oil

3. **Gasification type**
   
   Heavy oil is converted to produce hydrogen (H2)
   and carbon monoxide (CO) in the partially oxidation.

   The overall processing employs combinations of carbon rejection and hydrogen addition steps.
Classification of Heavy Oil Upgrading Processes

Category
- Residue Upgrading Process
  - Carbon Rejection
  - Hydrogen Addition
  - Gasification
  - Thermal Cracking
  - Catalytic Cracking
  - Hydroprocesing
    - Hydrotreating
    - Hydroconversion
  - Solvent Extraction
  - Visbreaking
  - Delayed Coking
  - Fluid Coking / HSC
  - Flexi Coking
  - Eureka
  - VGO FCC
  - Residue FCC
    - Fixed Bed Type
    - Moving Bed Type
    - Ebullient Bed Type
    - Slurry Bed Type
2.2 Feed Limitation for Heavy Oil Upgrading Processes

Properties of 650°F+ (343°C+) Boiling Point Residues

- Catalytic Cracking
- Hydroconversing
- Thermal Cracking

Feed Range:
- AbuDabi Murban
- North Sea
- Nigeria
- Alaskan North Slope
- Arabian Heavy
- Arabian Light
- Alaskan Light
- Mexican Maya
- Venezuelan Bachaquero

Ni + V, ppmw
- Catalytic Cracking
- Thermal processing Feed Range
2.3 Features of Thermal Cracking Process

**Merit:**
- Thermal cracking process can handle heavy oils that are not easily processed due to their impurities (Metal, Sulfur, CCR, Nitrogen content).
- Lower Investment Cost
- Easy Operation

**Demerit:**
- Low Octane Gasoline Product
- Low Stability Products
- Low Value Gas ($C_1, C_2$)
- Limited Coke Market
2.4 Features of Catalytic Cracking Process

**Merit:**

- Catalytic cracking process can produce high Octane Gasoline material.
- Catalytic cracking process also produce high value gases (Propylene, Ethylene).
- HP/MP Steam Generation

**Demerit:**

- Feed Limitation: Pre-Treating Unit is required to eliminate Impurities (Metal, Sulfur, CCR, Nitrogen content).
- High Operating Cost (Expensive Catalyst)
- High Investment Cost
- Difficult Operation
2.5 Features of Solvent Extraction Process

Merit:
- Solvent Extraction process can handle heavy oils that are not easily processed due to their impurities (Metal, Sulfur, CCR, Nitrogen content).
- Solvent Extraction process can produce De-Asphalted Oil (DAO) with easy operation.
- Low Investment Cost

Demerit:
- Low Value Pitch (High Sulfur, High Viscosity)
- High Operating Pressure
2.6 Features of Hydroprocessing Process

Merit:
- Hydroprocessing process can produce high Quality Products.
- Hydroprocessing process can remove Asphaltene from heavy oil together with Metal, Nitrogen and Sulfur.
- High Operation Flexibility

Demerit:
- Higher Operating Cost (Catalyst & Hydrogen)
- Higher Operating Pressure
- Higher Investment Cost
- Low Value Pitch or LS fuel oil
# Heavy Oil Upgrading Process

## 2.7 Comparison of Each Categories of Process

<table>
<thead>
<tr>
<th></th>
<th>Hydrogen Addition</th>
<th>Carbon Rejection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Hydrocracking</td>
<td>Catalytic Cracking</td>
</tr>
<tr>
<td><strong>Feed</strong></td>
<td>HGO/VGO</td>
<td>VGO~AR (Required)</td>
</tr>
<tr>
<td><strong>PreTreating</strong></td>
<td>Required</td>
<td>-</td>
</tr>
<tr>
<td><strong>Product Quality</strong></td>
<td>Excellent</td>
<td>Good</td>
</tr>
<tr>
<td><strong>Main Product</strong></td>
<td>Middle Dist.</td>
<td>Middle Dist</td>
</tr>
<tr>
<td><strong>By-Product</strong></td>
<td>LS Fuel Oil</td>
<td>Low Value Pitch</td>
</tr>
<tr>
<td></td>
<td>( Rx, Comp’r)</td>
<td>High ( Rx, Comp’r)</td>
</tr>
<tr>
<td><strong>Investment Cost</strong></td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>( Cat.,H2)</td>
<td>(Cat.,H2)</td>
</tr>
<tr>
<td><strong>Operation Cost</strong></td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>(Cat.,H2)</td>
<td>(Cat.,H2)</td>
</tr>
</tbody>
</table>
Heavy Oil Upgrading Process

Gasification

Dirty Feedstock (Heavy Oil)

Gasifier

Gas Cooler

Gas Purifier

Carbon Extractor

Clean Product (Syngas)
2.8 Classification of Commercial Thermal Cracking Process

Processes

- **Visbreaking**
- **Delayed Coking**
- **Fluid Coking**
- **Flexi Coking**
- **Eureka / HSC**

Commercial Process / Licensor

- **Coil type: Foster Wheeler/UOP**
  **Soaker type: Shell/ABB Lummus**

- **Foster Wheeler/UOP, ABB Lummus, Conoco/Bechtel**

- **Exxon Mobil**

- **Eureka: Kureha/ Chiyoda/ Fuji Oil**

- **HSC (High-conversion Soaker Cracking): Toyo Engineering & Mitsui Kozan Chemicals**
2.9 Classification of Commercial Catalytic Cracking Process

Processes

- VGO FCC
- Residue FCC

Commercial Process / Licenser

- UOP, Exxon/Mobil, Shell, Kellogg BR, Axens, Stone&Webster, ABB Lummus
- RCC: UOP
- R2R: Axens/Stone&Webster
- LRFCC: Shell
- HOC(Heavy Oil Cracking): Kellogg BR
- Flexicracking: Exxon/Mobil
- DCC: Stone&Webster
Heavy Oil Upgrading Process

Why FCC/RFCC is installed in Refinery?

⇒ Utilizing Value-less Heavy Oil Feedstock.
⇒ Production of 40-55 wt% Gasoline Yield.
⇒ Production of Propylene & Butylenes.
⇒ No Use of Hydrogen.
2.10 Classification of Commercial Hydroprocessing Process

- **Hydroprocessing (Hydrotreating/Hydroconversion)**

  - **Fixed Bed Type**
    - Commercial Process / Licenser
      - RCD Unibon: UOP
      - RDS/VRDS: Chevron
      - HYVAHL: Axens
      - Residfining: Exxon/Mobil
      - Unicraking: UOP
      - MAK-LCO: Kellogg BR
      - OCR(Onstream Catalyst Replacement): Chevron
      - HYCON: Shell
      - H-Oil: Axens
      - LC-Fining: ABB Lummus/Amoco Oil
      - T-Star: Axens
      - VCC(Veba Combi Cracking): Veba Oel
      - Microcat RC: Exxon/Mobil
      - (HC)3: Aostra/ARC

- **Moving Bed Type**

- **Ebullated Bed Type**

- **Slurry Bed Type**
Heavy Oil Upgrading Process

Hydrotreating process

Following are representative reactions, which occur in hydrotreating process.

- Hydrocracking
- Hydrodesulfurization
- Hydrodenitrification
- Hydrodemetallization
- Saturation of aromatics
- Olefin hydrogenations

- All the reactions are exothermic.
The H-Oil process was developed by HRI and commercialized by HRI and City Service, but now it is licensed by IFP.

The H-Oil Process is a unique, catalytic process for hydrogenation of residue and heavy oils in an ebullated bed reactor to produce upgraded petroleum products.

The purpose of the unit is quite same as the Chevron OCR/VRDS Process.

The ebullated-bed reactor was designed to overcome problems encountered with a fixed-bed reactor.

Temperature: 400-450 °C and Pressure: 180-220 kg/cm²
OCR, or Onstream Catalyst Replacement, is a counter-current, moving-bed technology that removes metals from feedstocks for fixed-bed residuum hydrotreating reactors.

In the OCR reactor residuum and hydrogen flow upward through the reactor and the catalyst flows downward.

This process removes the metals from previously uneconomical feeds for further downstream conversion.

OCR's ability to efficiently remove metals enables refiners to process more difficult feeds or achieve deeper desulfurization.
Heavy Oil Upgrading Process

2.11 Classification of Commercial Solvent Extraction Process

Commercial Process / Licensor

- SDA (Solvent Deasphalting): Foster Wheeler/UOP
- DEMEX: UOP
- ROSE: Kellogg BR
- SOLVAHL: Shell
3. Feasibility Study for Typical Model Case
3.1 Process Configuration for Typical Refinery

Heavy Oil Upgrading Process

Crude

CDU

Cat.-Reformer

Gasoline Blender

Dist.-HDS

VDU

VGO HDS

FCC Complex

Conversion Process

Fuel Oil Blender

Gasoline

Jet Fuel

Kerosene

Diesel

Fuel Oil

Crude
3.2 Feasibility Study Case Definitions

Candidate Process:

Most often selected (well-proven) Technologies

- Residue Hydrocracking (Hydroconversion)
- VR-HDS / Residue FCC (Catalytic Cracking)
- SDA (Solvent Extraction)
- Visbreaking (Thermal Cracking)
- Delayed Coking (Thermal Cracking)
# 3.3 Comparison of Candidate Processes

<table>
<thead>
<tr>
<th>Process</th>
<th>Residue Hydrocracking</th>
<th>Residue FCC</th>
<th>SDA</th>
<th>Visbreaking</th>
<th>Delayed Coking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operation Type</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Semi-Batch</td>
</tr>
<tr>
<td>Pressure, psig</td>
<td>1000~2500</td>
<td>10~35</td>
<td>300~600</td>
<td>140~350</td>
<td>15~100</td>
</tr>
<tr>
<td>Temperature, deg. F</td>
<td>770~840</td>
<td>900~970</td>
<td>120~450</td>
<td>840~930</td>
<td>900~950</td>
</tr>
<tr>
<td>Yields, vol%(wt%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Naphtha</td>
<td>7~10</td>
<td>50~60</td>
<td>-</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Gas Oil</td>
<td>55~70</td>
<td>12~20</td>
<td>30~65</td>
<td>17</td>
<td>55</td>
</tr>
<tr>
<td>Residue</td>
<td>25~40</td>
<td>6~10</td>
<td>35~70</td>
<td>75</td>
<td>(30)</td>
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<tr>
<td>(Condition)</td>
<td>(Liquid)</td>
<td>(Liquid)</td>
<td>(Liquid)</td>
<td>(Liquid)</td>
<td>(Solid)</td>
</tr>
<tr>
<td>Investment Cost</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Middle</td>
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</tbody>
</table>
### 3.4 Feasibility Study Case Definitions

**Main Process Units for Study Cases**

<table>
<thead>
<tr>
<th>Case Description</th>
<th>Base</th>
<th>R-HCR</th>
<th>VRDS/RFCC</th>
<th>SDA</th>
<th>Visb.</th>
<th>Delayed Coker</th>
</tr>
</thead>
<tbody>
<tr>
<td>CDU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VDU</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cat.Reformer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dist. HDS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VGO FCC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alkylation</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Residue HCR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>VRDS / RFCC</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SDA</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Visbreaking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Delayed Coking</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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**Case Description**

- **Base**: Base case for the study, containing all the main process units.
- **R-HCR**: Includes Reforming-Hydrotreating-Compounding operations.
- **VRDS/RFCC**: Includes Vacuum Residues Desulfurization/Regeneration and Fluid Catalytic Cracking units.
- **SDA**: Includes Steam Desulfurization and Alkylation processes.
- **Visb.**: Includes Visbreaking operations.
- **Delayed Coker**: Includes Delayed Coking operations.

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**Heavy Oil Upgrading Process**

NIORDCHeavy Oil Upgrading Process

36
4. Process Configuration in Existing Domestic Refinery
4.1 Trend of Major Heavy Oil Upgrading Process in the World

- **Crude Unit**
  - As of January 1.2003: 81,877,646 BPSD

- **Catalytic Cracking**
  - 14,195,514 BPSD

- **Thermal Cracking**
  - 7,871,204 BPSD

- **Catalytic Hydrocracking**
  - 4,437,289 BPSD

Data source: Oil & Gas Journal / Dec. 23, 2002
# Heavy Oil Upgrading Process

## 4.2 Capacity of Heavy Oil Upgrading Process in the World

<table>
<thead>
<tr>
<th></th>
<th>Thermal Cracking</th>
<th>Solvent Extraction</th>
<th>Hydroprocessing</th>
<th>Catalytic Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No of Units</td>
<td>Capacity MBPSD</td>
<td>% of Crude</td>
<td>No of Units</td>
</tr>
<tr>
<td><strong>United States</strong></td>
<td>72</td>
<td>1,989</td>
<td>13.0</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>610</td>
<td>4.0</td>
<td>12</td>
</tr>
<tr>
<td><strong>Japan</strong></td>
<td>5</td>
<td>85</td>
<td>1.7</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>605</td>
<td>12.5</td>
<td>8</td>
</tr>
<tr>
<td><strong>Europe</strong></td>
<td>136</td>
<td>2,792</td>
<td>10.7</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>176</td>
<td>0.7</td>
<td>4</td>
</tr>
<tr>
<td><strong>Rest of World</strong></td>
<td>122</td>
<td>2,866</td>
<td>10.5</td>
<td>6</td>
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<tr>
<td></td>
<td>28</td>
<td>1,000</td>
<td>3.6</td>
<td>24</td>
</tr>
<tr>
<td><strong>Total World</strong></td>
<td>335</td>
<td>7,732</td>
<td>10.5</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>66</td>
<td>2,391</td>
<td>3.2</td>
<td>48</td>
</tr>
</tbody>
</table>
### 4.3 Total Capacity of Heavy Oil Upgrading Process in the World

#### Total Capacity of Heavy Upgrading Processes

<table>
<thead>
<tr>
<th></th>
<th>No of Units</th>
<th>Capacity MBPSD</th>
<th>% of Crude</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>United States</strong></td>
<td>111</td>
<td>3,489</td>
<td>22.8</td>
</tr>
<tr>
<td>Japan</td>
<td>31</td>
<td>956</td>
<td>19.7</td>
</tr>
<tr>
<td>Europe</td>
<td>149</td>
<td>3,195</td>
<td>12.2</td>
</tr>
<tr>
<td>Rest of World</td>
<td>180</td>
<td>4,705</td>
<td>17.2</td>
</tr>
<tr>
<td><strong>Total World</strong></td>
<td>471</td>
<td>12,345</td>
<td>16.7</td>
</tr>
</tbody>
</table>
Heavy Oil Upgrading Process

5. Summary
5.1 Summary

Key Point:
- How to produce light oil products efficiently and economically from Heavy Oil.
- How to optimize the Refinery Configuration.

Primary Factors:
- Price Spread between Light and Heavy Crude
- Price Spread between Crude and Residue
- Products Demand & Specification
- Feed Properties
- Process Configuration of Existing Plant
- Operation Flexibility
- Technology of Heavy Oil Upgrading Process
5.2 Summary

As per the Feasibility Study of Typical Model case and Consideration for Recent Trend on Heavy Oil Upgrading Technologies, Following Application seems to be reasonable for Modernized Green Project.

(1) Provision of SDA or Delayed Coker to produce more Middle Distillate and minimize Residual Fuel Oil

(2) Introduction of MHC Technologies to produce more high Quality Middle Distillates

Heavy Oil Upgrading Process

5.3 Summary

Application towards Zero Residual Fuel Oil Production

- Vacuum Residue
- SDA or Delayed Coker
- Pitch or Coke
- Gasification
- FCC Mild Hydrocracker
- Power Steam Hydrogen Petrochemicals Fuels

DAO or Coker Gas Oil