Achieving Ultra-Low Sulfur Diesel with IsoTherming® Technology

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ERTC Annual Meeting

13 – 15 November, 2017
Agenda

1. Introduction to DuPont Clean Technologies
2. IsoTherming® Hydroprocessing Technology
3. Grassroots Unit Case Study
4. Revamp Unit Case Study
5. Summary
DuPont Clean Technologies

IsoTherming®
Hydroprocessing Technology

Unique technology for removal of sulfur to ultra-low levels from diesel & intermediate petroleum products

STRATCO®
Alkylation Technology

Leading technology for the production of low-sulfur, high octane gasoline blend stock

MECS® Sulfuric Acid Technology

Leading technology for the production of sulfuric acid and related high performance products

BELCO® & DynaWave®
Scrubbing Technologies

Leading technologies for air emissions reduction in FCCs & SRUs for SOx, NOx, and particulates

DOWNSTREAM OIL & GAS

MIDSTREAM OIL & GAS

PETROCHEMICAL

FERTILIZER, METALS, CHEMICALS
Proven Experience

25 Licenses

- Grassroots: 21
- Revamps: 4
- Operating: 11
- 2017 Startups: 4

Applications

- Diesel Hydrotreating
- Kerosene Hydrotreating
- Transmix Hydrotreating
- FCC Pretreat / Mild Hydrocracking
- VGO & LCO Mild Hydrocracking
- Dewaxing
- Gas-to-Liquids Upgrading
Lower Capital and Operating Expenses

- Two-Phase Reactor
- Once Through Liquid
- Gas Recycle
- Hydrogen diffuses into liquid as it is consumed in the catalyst bed
- Distribution critical

Conventional Trickle-bed Hydrotreating

- Liquid Phase Reactor
- Liquid Recycle
- All hydrogen in solution within the catalyst bed
- Distribution less critical

IsoTherming® Technology
Advantages of IsoTherming® Technology

<table>
<thead>
<tr>
<th>Lower Capital Costs</th>
<th>Lower Operating Expense</th>
<th>Better Energy Recovery</th>
<th>Reliable and Safe</th>
</tr>
</thead>
<tbody>
<tr>
<td>✓ Fewer pieces of high pressure equipment</td>
<td>✓ 30 to 60% reduction in fuel gas usage, as Heat of reaction is absorbed by liquid recycle and used to heat the feed</td>
<td>✓ 30 to 50% increase in integrative/heat recovery allowing for steam or power generation</td>
<td>✓ Quick recovery from unit upsets</td>
</tr>
<tr>
<td>✓ Elimination of gas recycle loop equipment</td>
<td>✓ 30 to 40% reduction in power consumption by using a reactor recycle pump vs. recycle gas compressor</td>
<td>✓ Optimized heat integration/heat recovery allowing for steam or power generation</td>
<td>✓ No runaway reaction</td>
</tr>
<tr>
<td>✓ Smaller foot print</td>
<td>✓ 30 to 40% reduction in power consumption by using a reactor recycle pump vs. recycle gas compressor</td>
<td>✓ Optimized heat integration/heat recovery allowing for steam or power generation</td>
<td>✓ Lower greenhouse gas emissions</td>
</tr>
</tbody>
</table>
Case Study #1: Grassroots Unit in China

- **Throughput:** 3.75 MMTPA
- **Product Target:** S < 10 wppm (China V)
- **Design Feed Composition:** 60% SRD, 40% cracked stock
- **DuPont Catalyst:** 3 year cycle length
- **Reactor #2 operates without recycle**
- **Project successfully completed as scheduled**
Case Study #1: Grassroots Unit in China

Performance Guarantee Test Run

Charge Pump Flow Rate

ULSD Sulfur

446.3 t/h Design Total Fresh

<10 wppm Design
Case Study #1: Grassroots Unit in China

Consistent Performance

- Unit consistently produces diesel product with sulfur between 7 to 10 ppmw
- Ease of operation
Case Study #2: Revamp in India

Unit History (Pre-Revamp)

- Operating at 1.65 MMTPA
- Diesel product sulfur of 50 ppmw

Revamp Feed Design Basis

- 73 wt% Straight Run Diesel
- 27 wt% Light Cycle Oil

Two Year Cycle Length

Unit Start-up in 2015

<table>
<thead>
<tr>
<th>Specification</th>
<th>Units</th>
<th>Combined Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow Rate</td>
<td>MMTPA</td>
<td>2.28</td>
</tr>
<tr>
<td>Specific Gravity @ 15.6°C</td>
<td>ppmw</td>
<td>0.859</td>
</tr>
<tr>
<td>Sulfur</td>
<td>ppmw</td>
<td>13,300</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>ppmw</td>
<td>294</td>
</tr>
<tr>
<td>Bromine Number</td>
<td>g/100g</td>
<td>5.8</td>
</tr>
<tr>
<td>Aromatics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mono</td>
<td>wt%</td>
<td>21.7</td>
</tr>
<tr>
<td>Di</td>
<td>wt%</td>
<td>15.1</td>
</tr>
<tr>
<td>Tri+</td>
<td>wt%</td>
<td>0.5</td>
</tr>
<tr>
<td>ASTM D-86 Distillation</td>
<td>°C</td>
<td></td>
</tr>
<tr>
<td>IBP</td>
<td>°C</td>
<td>150</td>
</tr>
<tr>
<td>50 vol%</td>
<td>°C</td>
<td>272</td>
</tr>
<tr>
<td>90 vol%</td>
<td>°C</td>
<td>326</td>
</tr>
<tr>
<td>EP</td>
<td>°C</td>
<td>357</td>
</tr>
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</table>
Case Study #2: Revamp in India

**Challenges and Goals**

**Revamp Project Goals**

- Maximize throughput increase: 1.65 MMTPA to 2.28 MMTPA (~38%)
- Upgrade product quality from BS-IV to BS-V diesel product
  (<10 ppmw sulfur)

**Revamp Project Challenges**

- Low reactor pressure of 51 kg/cm\(^2\) (g)
- Feed stock variations
- Plot space constraints
- Minimize capital cost and maximize reuse of existing equipment
Case Study #2: Revamp in India
Case Study #2: Revamp in India

Reactor R-01 Conversion

• Utilized existing nozzles (no new nozzles needed)
• All internal parts pre-fabricated and were installed through existing the manway
• Reused support rings
• No PWHT needed for conversion to an IsoTherming® Reactor
## Revamp in India – Startup in July, 2015

*Actual data taken 8 months after initial startup of DHDS IsoTherming® Unit*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>UOM</th>
<th>Pre-Revamp</th>
<th>Revamp Design</th>
<th>Actual</th>
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<tbody>
<tr>
<td>Capacity</td>
<td>T/D</td>
<td>4950</td>
<td>6825</td>
<td>6800</td>
</tr>
<tr>
<td>Pressure</td>
<td>kg/cm²-g</td>
<td>47.3</td>
<td>51.8</td>
<td>51.8</td>
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<tr>
<td>LCO</td>
<td>wt%</td>
<td>20%</td>
<td>27%</td>
<td>27%</td>
</tr>
<tr>
<td>Specific Gravity</td>
<td></td>
<td>0.86</td>
<td>0.859</td>
<td>0.86</td>
</tr>
<tr>
<td>Feed Sulphur</td>
<td>wt%</td>
<td>1</td>
<td>1.33</td>
<td>1.1</td>
</tr>
<tr>
<td>Product Sulphur</td>
<td>ppmw</td>
<td>50</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>H₂ consumption</td>
<td>T/D</td>
<td>26.0</td>
<td>56.2</td>
<td>48</td>
</tr>
<tr>
<td>Charge heater Duty</td>
<td>MMkcal/hr</td>
<td>5.82</td>
<td>3.61</td>
<td>3.6</td>
</tr>
<tr>
<td>H₂ consumption</td>
<td>kg/Ton of Feed</td>
<td>5.3</td>
<td>8.2</td>
<td>7.1</td>
</tr>
<tr>
<td>Fuel Consumption</td>
<td>kg/Ton of Feed</td>
<td>3.8</td>
<td>1.5</td>
<td>1.5</td>
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</table>
Summary

• IsoTherming® is a reliable & robust process for grassroots or revamp HDT Units, allowing refiners to efficiently achieve Euro 5 diesel specifications

• Lower Capital Expense

• Lower Operating Expenses

• Better Energy Recovery

• Reliable and Safe