Increasing Refinery Product Slate Flexibility by Revamping the Cat Feed Hydrotreater (CFHT)

Advances in Mild Hydrocracking Technology

Venkata Josyula
Axens North America, Inc.
US Distillate Market Analysis

- 5% annual increase
- Result of various diesel projects

Trend Projected to Continue

Source: EIA. www.eia.gov
US Distillate Export Market

Driven Mostly by Latin American Demand

Source: EIA. www.eia.gov
World On-Road Diesel Forecast

- North America: AAGR 2014-2020 = -0.4%, AAGR 2020-2035 = +0.5%
- Europe: AAGR 2014-2020 = +1.9%, AAGR 2020-2035 = +0.3%
- CIS: AAGR 2014-2020 = +2.1%, AAGR 2020-2035 = +1.8%
- World: AAGR 2014-2020 = +1.9%, AAGR 2020-2035 = +1.2%
- Latin America: AAGR 2014-2020 = +2.2%, AAGR 2020-2035 = +1.6%
- Africa: AAGR 2014-2020 = +3.6%, AAGR 2020-2035 = +2.5%
- Middle East: AAGR 2014-2020 = +2.1%, AAGR 2020-2035 = +2.2%
- Asia & Pacific: AAGR 2014-2020 = +2.6%, AAGR 2020-2035 = +1.6%
World On-Road Diesel Market

DEMAND, MMb/d

World

<table>
<thead>
<tr>
<th>Year</th>
<th>2014</th>
<th>2020</th>
<th>2035</th>
</tr>
</thead>
<tbody>
<tr>
<td>Demand Mb/d</td>
<td>+1.9%</td>
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<td></td>
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Latin America

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<tr>
<th>Year</th>
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AAGR 2014-2020

-0.4% +0.5%

World

0 5 10 15 20 25

2014 2020 2035

North America

Europe

CIS

Asia & Pacific

Demand Mb/d

0 2014 2020 2035

+0.3%

8th AIChE Southwest Process Technology Conference | October 6-7, 2016 | Galveston, TX
US Diesel v Gasoline Price

- $20/bbl seasonal swings
- Median spread favors diesel $2.25
- >60% of the year, incentive to swing to diesel
Options for Increasing Diesel

**CRUDE CHANGE**

**CUTPOINT MODIFICATION**

**CDU**

- VGO
- VR

**CFHT**

- Conversion unit
- Cracked VGO

**FCC**

**HYK**

**NEW HYDROCRACKER**

**Product Pools**

**FCC CONSTRAINTS**

- Modest yield shift
- Gasoline octane
- DHT limits LCO
- Increased fuel oil

**CFHT REVAMP**

- Maximize Diesel
- Improve FCC feed quality
- Low cost
- Quick construction

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Maximize Distillates

- Switch to hydrocracking catalyst load
- Conversion **15-35%** achievable in most **existing** reaction systems
- Excellent **selectivity** towards **diesel**
Catalyst Solutions

1. Pretreatment catalyst
   - Sulfur removal
     - NiMo
     - CoMoNi
     - Max HDN
     - Max HDS

2. Cracking catalyst
   - Conversion Activity
     - Nitrogen tolerance
     - HDK Series
     - HYK 700 Series
     - Amorphous
     - Zeolite

Tailor-made Solution Based on Objectives
Catalyst Diesel Selectivity

Axens Catalysts Developed for the Diesel Market

- R&D Geared toward European Diesel Demands
- Excellent Diesel Selectivity
  - Commercial results demonstrate 10:1 Diesel to Naphtha yields
- Variety of Feedstocks (SR, CGO, DAO, LCO)
- In-line with goal of maximizing Diesel in the US Market

10:1 Selectivity
Revamp Considerations

Feed Quality & FCC Yields
- Increased FCC feed quality (aromatics saturation)
- Increased selectivity towards gasoline and LPG
- Decrease in LCO and Slurry
- Increased product quality (lower S, N)
FCC and Alkylation Impact

Hydrocracking increases FCC Feed Quality

- Increased Middle Distillate Production
- Reduced Air Blower Demand & Catalyst Consumption
- Reduced SOx and NOx Emissions
- Decreased Slurry Yield
- Increase C3=, C4= & alkylate
- Increase gasoline yield
- Decrease WGC load

VGO → Mild HCK → FCC → Gas, LPG, Gasoline, LCO, Slurry

SOx / NOx
FCC Pretreating – $H_2$ Content

Hydrogen Addition Improves FCC Performance

FCC Yield Sensitivity

Conversion

Gasoline

Slurry

Feed H2 Content, wt%
Revamp Considerations

Areas of Focus

- Reactor ΔP
- Reactor Internals
- Heater Limitations
- Compressors
- Stripper top Section
- Fractionation
- SAFETY SYSTEMS
Revamp Considerations

- Catalytic System
- FCC Impact
- Engineering Evaluation
- Pool Benefits

**Improvements**
- Shift D/G Ratio
- Increase overall liquid yields (volume swell)
- Reduced FCC gasoline post-treating requirements

**Case Study**
Axens Case Study Results

Gasoline Mode

- Payout < 2 years, independent of crude pricing
  - New (or Revamped) fractionator and M/U compressor
  - Modified catalyst load (Hydrocracking)
- Maintain continuous ULSD production
- Maximize Octane-Barrels during summer season

Diesel Mode

- Refinery D/G Ratio 1.0

Operational Flexibility

Refinery D/G Ratio

- Axens Case Study Results

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Axens Case Study

1. Base Case (Current Operation)
   - Existing operation
   - FCC Feed S Target of 2,000 ppm
   - 36 month cycle in the CFHT

2. MHC Revamp Case (Distillate Mode)
   - Revamp CFHT to Mild Hydrocracker
   - Maximize Distillates
   - MHC Diesel treated in existing DHT unit

3. MHC Revamp Case (Gasoline Mode)
   - Mild Hydrocracker Revamp is complete
   - Minimize conversion & adjust cut-points
   - Maximize FCC gasoline production

4. HyC-10 Case (Integrated Diesel HDT)
   - Mild Hydrocracker Revamp is complete
   - Integrate new polishing reactor
   - Produce ULSD directly from the MHC

Constant Gasoline Pool RON for All Cases
Case Study Configuration

Diagram of the Case Study Configuration showing various units and streams such as CDU, VDU, NAP, DSL, VGO, VR, and G. The diagram includes a legend indicating XX MBPSD.
# Revamp – Base Case

<table>
<thead>
<tr>
<th>Conversion</th>
<th>FCC Feed IBP</th>
<th>FCC Gasoline Yield</th>
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</thead>
<tbody>
<tr>
<td>Base Case</td>
<td>10%</td>
<td>480 °F +</td>
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CFHT / MHC -> STRIPPER -> FCC

FCC IBP: 480°F

G -> LPG
Revamp – Max Diesel

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<td>Base Case</td>
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<tr>
<td>Max Diesel</td>
<td>27%</td>
<td>650 °F +</td>
<td>+5.4 v%</td>
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Revamp – Max Gasoline

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## Case Study Results

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<th>Base Case</th>
<th>MHC Case Max Diesel</th>
<th>MHC Case Max Gas</th>
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<td><strong>CFHT/MHC</strong></td>
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<tr>
<td>Conversion (650 +)</td>
<td>10</td>
<td>27</td>
<td>13</td>
</tr>
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<td>H2 Consumption, SCFB</td>
<td>Base</td>
<td>+ 300</td>
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<tr>
<td>FCC, PG+ and Alky</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FCC Feed Rate, %</td>
<td>Base</td>
<td>-30%</td>
<td>Base</td>
</tr>
<tr>
<td>FCC Feed H2, wt%</td>
<td>Base</td>
<td>+0.5</td>
<td>+0.1</td>
</tr>
<tr>
<td>FCC Gasoline yield, wt%</td>
<td>Base</td>
<td>+5.4%</td>
<td>+1.6%</td>
</tr>
<tr>
<td>Gasoline Production, BPSD</td>
<td>Base</td>
<td>-8,400</td>
<td>+570</td>
</tr>
<tr>
<td>ULSD Production, BPSD</td>
<td>Base</td>
<td>+9,650</td>
<td>-320</td>
</tr>
<tr>
<td>Total Trans. Fuels Pool, BPSD</td>
<td>Base</td>
<td>+1,250</td>
<td>+250</td>
</tr>
</tbody>
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| Refinery Fuel Yield, v% | 92.9 | 93.9 | 93.1 |
Mild Conversion – ULSD Challenge

Mild Conversion achievable in existing units
- Shift the D:G Ratio
- Increase overall liquid yield

Flexibility achievable after revamp
- Return to Base Case D:G Ratio
- Extend reactor cycle

ULSD is not possible under mild conversion conditions
- DHT capacity increase is required

Axens Solution
- HyC-10+ Process
- Integrated DHT Polishing Reactor
Axens HyC-10 Process

- VGO
- HCGO
- DAO
- H₂

Off spec Diesel

FCC feed

Polishing section

Naphtha

10 ppm ULSD

LCO? LCGO?
Axens HyC-10 Process

30% CAPEX Savings vs. New Unit

Polishing Reactor Operating Conditions
- Improved \( H_2 \)pp due to pure make-up
- Lower reactor size due to less vapor flow and reduced \( H_2 \)Spp

Major Equipment Savings vs. New DHT Unit:
- 2 compressors, 1 air cooler, HP amine absorber

Unit Integration
- Optimized H2 Usage
- Possibility for heat integration between two sections
- Maximize cycle length
Commercial Results

Market

1. Catalysts

2. Equipment

Profitability!

3. Successful experience
Commercial Revamp 1
Southern European Refiner

Axens Licensed Unit

- Capacity: 37,600 BPSD
- Start-up: 2005
- Catalyst loading: 100% Hydrotreating

2010 Revamp Objectives:

- Net conversion increase
- Maximize Euro V Diesel
- Maintain feed rate
- Maintain cycle length

Axens Solution

- Process Study to identify bottlenecks
- Add EquiFlow® Internals and new catalyst combination: HDT + Cracking Catalysts
Commercial Revamp 1
Southern European Refiner

- Revamp completed: start-up May 2013
- Feedstocks:
  - SRVGO+ Aromatic Lube Extract
  - Polishing reactor treats:
    - MHC DSL + LCO + SRAGO + VB Naphtha

Successful Revamp

<table>
<thead>
<tr>
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<th>Original Design</th>
<th>After Revamp</th>
</tr>
</thead>
<tbody>
<tr>
<td>VGO Net Conversion, wt%</td>
<td>Base</td>
<td>+17%</td>
</tr>
<tr>
<td>Catalyst Cycle Length, months</td>
<td>31</td>
<td>On-going</td>
</tr>
<tr>
<td>MHC Euro-V Diesel Flowrate, BPSD</td>
<td>Base</td>
<td>+ 60%</td>
</tr>
</tbody>
</table>
Commercial Revamp 2
Eastern European Refiner

2014 Revamp Objectives
• Increase net conversion: Maximum Diesel Production
• Maintain Product Quality
• Maintain Cycle Length
• Minimize shutdown time

Axens Solution

- Process Study to identify bottlenecks
- New catalyst combination:
  
  HR 544+ HYK 732
  CoMoNi Zeolite
Commercial Revamp 2
Eastern European Refiner

- Case B: Catalyst Change-Out + Some equipment & internals modifications
  Conversion: 41%

- Case A: Catalyst Change-Out + minor modifications
  Conversion: 32%

- Base Case: Catalyst Change-Out
  Conversion: 25%

Extant of Revamp Investment (TIC)

Conversion
Revamp Economics

Revamp Case Fuel Production and Revenue Increase

Delta Revenue Over Base: $45MM/yr

Revamp Case Delta Revenue Over Base Case

Gasoline Production

Diesel Production

Revamp Economics

CAPEX
- New or Modified Fractionator
- Make-Up Compressor Mods
  - Capacity increase
  - Increase stroke? New machine?
- Reactor Internals

OPEX
- Limited utility consumption increase (< 8%)
- Increased H₂ Consumption

50,000 BPSD CFHT Unit
Flexible Mode MHC
- CAPEX: $MM 30
- Increased Revenue: $MM 45/yr
- Simple Payout: < 10 months

Flexibility → Profitability
Conclusion

Revamp CFHT to Mild Hydrocracker

- Increase diesel production
- Flexible operation for high gasoline margin periods
- Extremely selective catalyst
- Fast-track schedule

HyC-10 Option

- Maintain ULSD production for refiners short on DHT capacity

FAST SCHEDULE  FAST PAYBACK

Reduced CAPEX