Upgrading Fuel Oil to Euro V Gasoline
Residue Hydrotreating and RFCC

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Agenda

Challenges in upgrading residue streams

Impact of heavy feeds on RFCC operation and conversion

RCD Unionfining™ process enables efficient downstream upgrading

UOP RFCC Process: technology solution for economic upgrading of residue to gasoline
Residue Streams are Challenging to Process

- Contaminant levels increase with boiling range in most crudes
- Residue streams typically contain high sulphur, nitrogen, Conradson carbon, organometals and asphaltenes

<table>
<thead>
<tr>
<th>Stream</th>
<th>Atmospheric Residue</th>
<th>Vacuum Residue</th>
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</thead>
<tbody>
<tr>
<td>Sulphur, ppm wt</td>
<td>2.3</td>
<td>3.0</td>
</tr>
<tr>
<td>Nitrogen, ppm wt</td>
<td>2600</td>
<td>4000</td>
</tr>
<tr>
<td>Conradson Carbon, %wt</td>
<td>8</td>
<td>16.3</td>
</tr>
<tr>
<td>Ni + V, ppm wt</td>
<td>83</td>
<td>164</td>
</tr>
<tr>
<td>Asphaltenes, %wt</td>
<td>1.5</td>
<td>3.1</td>
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Impact of Residue Feeds on RFCC Unit Operation

1. **UOP K Factor**: The K factor differentiates between the paraffinicity and aromaticity of the feed, and it indicates the crackability of the feed.

2. **Sulphur**: Increases the sulphur content of the products.

3. **Nitrogen**: Basic nitrogen compounds will neutralize acid sites on the catalyst causing temporary loss of catalyst activity and drop in unit conversion.

4. **Conradson Carbon**: Increases coke yield and could limit the coke burn capacity.

5. **Metals Content**: All metal contaminants have a negative impact on catalyst performance. Vanadium deactivates the catalyst by destroying the zeolite crystal structure. Nickel promotes dehydrogenation reactions.

6. **Hydrogen in Feed**: drives conversion and higher propylene yields.
RCD Unionfining™ Process

• UOP’s licensed residue hydrotreating technology for processing highly-contaminated feedstocks such as AR, VR and DAO

• Combines commercially-proven process technology, proprietary catalyst systems and proprietary reactor internals

• Reduces the contaminant (sulfur, nitrogen, Conradson carbon, asphaltene and Ni+V) contents of feedstocks and adds hydrogen to produce:
  - low sulfur fuel oil
  - upgraded feedstocks for conversion units (FCC, RFCC, Coker, Hydrocracker)

• RCD Unionfining unit commercial experience:
  - First unit licensed in 1967
  - >30 units licensed with a combined capacity of >1,000,000 BPSD
RCD Unionfining Process – Commercial Experience

- Commercial flow schemes include:
  - Single- and two-stage configurations
  - Single- and parallel-reactor trains
  - Stripper or full fractionation configurations

- Feedstock qualities of commercial RCD Unionfining process units:
  - °API: 9 - 18
  - Sulfur: 3 - 5 wt%
  - Conradson Carbon: 5 - 15 wt%
  - Organometallics (Ni+V): 10 - 200 ppm wt
  - Viscosity: 25 - ~1000 cSt@100°C

- Operating conditions of commercial RCD Unionfining process units:
  - Throughput: 5600 - 75,000 BPSD
  - Pressure: 80 - 205 barg
  - LHSV: 0.10 - 1.2 hr⁻¹
  - Operating cycles: 6 - 24 months (typical economic optimum ~12 months)
RCD Unionfining Process – Typical Flow Scheme

Number of reactors depends on specific service
Specialist Catalyst Systems

• Over 120 catalyst loadings

• Proprietary catalysts designed for specific functions:
  - Pressure drop control – high efficiency particulate traps
  - Metals removal / accumulation
  - Metals removal / desulfurization
  - Conradson carbon reduction
  - Desulfurization

• Pilot plant facilities available to verify estimated performance, produce product samples, etc.
Optimized Catalyst Loading

Pressure Drop Control, Low Activity HDM + High Activity HDM Catalysts

Transition HDM/HDS Catalysts

Higher Activity HDS Catalysts

Feed

Pressure Drop Control + Low Activity HDM Catalysts

Product

Tailored catalyst loadings optimise residue hydrotreating unit performance and economics
RCD Unionfining Process Summary

• RCD Unionfining Process enables efficient upgrading of residue streams via RFCC
  - Reduces metals, Conradson carbon, sulphur, nitrogen and asphaltenes
  - Adds hydrogen → higher RFCC conversion and gasoline yield

• Specialist process design & catalyst system required to achieve good cycle length

• Processing targets need to be optimised together with RFCC operation considering
  - Overall capital cost
  - Overall yields
  - Operating costs (including hydrogen & catalysts)
Agenda – Residue FCC

- Economic Drivers for RFCC Units
- Impact of heavy feeds on RFCC Unit conversion
- UOP RFCC Process: meet economic objectives with technology solutions
RFCC Operating Modes

Distillates Mode RFCC
- Maximum LCO yield
  - Extremely Low Cetane Number ~ 19-20
  - Challenging to route LCO to EURO 5 diesel

Conventional RFCC (Fuels)
- Gasoline and LPG
  - 4-6 wt% propylene
  - 50-58 wt% gasoline
- Typical catalyst system and operating conditions

Fuels and Petrochemicals (Enhanced LPG)
- Gasoline/Alkylate/Petrochemicals
  - 6-12 wt% propylene
  - 38-48 wt% gasoline
- Catalyst system with ZSM-5 and modified operating conditions

Petrochemicals (High Propylene)
- 12+ wt% propylene
- Catalyst system with ZSM-5
- Optimized process conditions (pressure, temp, steam)
- Poor quality of naphtha & LCO - challenging to route to EURO 5 gasoline & diesel

Distillate Mode: Cost to upgrade low cetane LCO negatively impacts economics
RFCC Drivers to Capitalize new Opportunities

UOP RFCC specifically designed to help maximize value by:

- **Producing higher value product – propylene**
  - Ability to produce polymer grade propylene (e.g.- 250+ KMTA from 2.5M MTA RFCC)

- **Simultaneously** helping to maximize RFCC naphtha as a gasoline blendstock whilst making propylene

- **Class V compliant with 95 RON** (low enough aromatics to blend to gasoline)

- **Unmatched licensing experience**
  - 295 units licensed
  - More than 50% of world-wide capacity
  - 70 years of design & operation feedback

Enhanced LPG RFCC significantly improves project economics

**Product Prices, September 2017**

- Ethylene
- Propylene
- Aromatics
- Petrochemicals

Shift to petrochemicals adds significant value
Best in Class FCC Technologies Maximize Processing Versatility and Yields

- VSS™ Riser Termination Device (77 Commissioned)
- AF™ Stripper (76 Commissioned)
- Feed Distribution System (109 Commissioned)
- RxCat™ Technology (8 Commissioned)

Fully commercialised technology
Technology options for improved yields and economics.

**VSS™ Riser Termination**
- Gasoline Selectivity
- Dry Gas, ∆Coke, Trg
- Improved Reliability
- 77 Commissioned

**AF™ Stripper Packing**
- Conversion
- Dry Gas, ∆Coke, Trg
- Improved Reliability
- Improved Ops Flexibility
- 14 Commissioned

**Elevated Feed Distributors**
- Conversion
- Gasoline Selectivity
- Dry Gas, ∆Coke, Trg
- Improved Reliability
- 109 Commissioned

UOP Technology Improves Performance and Operating Flexibility
Options Available for Handling Increased Coke Formation

**Problem:** Contaminated Feeds

**Impact:** Regenerator temperature increases with delta coke

**Solution:** Control regenerator temperature

- High Delta Coke
- Catalytic coke
- Contaminant coke

- Reduces C/O and conversion
- Accelerated catalyst deactivation
- Decreased internal equipment working life
- **Low product margins**

- Inclusion of latest technology that minimize delta coke
- Catalyst cooler
- Partial combustion operation, application of Two-Stage Regenerator
- **High product margins**
UOP’s RFCC Regenerator Technology Portfolio

UOP Technology can process a wide range of feed Conradson Carbon

- Two-Stage Partial burn Cat Cooler
- Single-Stage Full combustion Cat Cooler
- Single Stage Full combustion

Increasing Feed Conradson Carbon

Increasing Capital Cost
UOP’s RFCC Regenerator Technology

Single Stage Combustor

Single Stage – Combustor Operation
- Full combustion (Single Stage Combustor) is simpler approach
  - No CO Boiler required
  - Lower cost flue gas section
- Regenerator operating temperature managed with catalyst cooler
  - For temperature >732°C

Traditional Two Stage Partial Combustion

Traditional Two Stage – Partial Combustion
- Partial mode of operation
- Compared to other Two Stage Regenerator style, UOP design offers:
  - Single flue gas line
  - Easier for power recovery
Significant Experience with Highly Contaminated Residue

RFCC feed quality for Iranian refineries
UOP Two-Stage Regenerator

- To burn high delta coke on catalyst and process highly contaminated feed
- Partial combustion operation
- Proven on feeds of ~10 Wt-% concarbon and 20,000 wppm Ni+V on catalyst
- Maximizes oxygen utilization
  - Excess oxygen in 2nd stage flue gas is used to burn coke in 1st stage
  - Minimizes air blower capacity
  - Single flue gas system
- Operator friendly
  - Result of stacked design and trouble free catalyst circulation
  - Responds well to upsets and turndown

Lowest Capex/Opex solution for contaminated feeds
Processing Heavier Feeds in an RFCC

**When is a Catalyst Cooler Needed?**
- Regenerator temperature too high (> 732°C / 1350°F)
- Process residue feedstocks with high Conradson Carbon (Concarbon)

**What Does a Catalyst Cooler Do?**
- Removes large amounts of heat from regenerator
- Generates HP steam

**What is the Result?**
- Regenerator temperature is reduced and independently controlled
- Cat/oil ratio increases
- Lower catalyst deactivation rate
- Improves conversion and product yields

Commercially proven technology to increase product revenues
Case Study – NE Asia FCC Unit

Revamp basis
• Operation: 53,000 BPSD VGO+AR feed in gasoline mode
• Current configuration: UOP FCC with Combustor style regenerator
• Revamp objective: Increase conversion with same feed blend

Revamp scope  Add single UOP Catalyst Cooler

Result
• Total annual benefit = $18 MM/yr

Approximately 1 year simple payback
Case Study – RFCC operates with one of the world’s most difficult Feed

• Design
  - 75,000 BPD 100% AR Oman crude
  - RFCC with Two-Stage regenerator
  - 18.2 API, 6.9 wt% Con Carbon, 9 wppm Nickel, 10 wppm Vanadium
  - 9 wt% propylene

• Commissioned in 2006
  - Poorer quality feedstock – more contaminated than design
  - Some initial equipment and operation issues
  - 17.3 API, 8.9 wt% Con Carbon, 20 wppm Nickel, 17 wppm Vanadium
  - 8 wt% propylene
  - Up to 110% capacity on more difficult feedstock

• Recent operation
  - Con Carbon 8.5 to 9.5 wt%
  - Total feed metals to 44 wppm ~ 50/50 Nickel and Vanadium
  - Ecat metals around 14,000 wppm (about 7000 ppm each)

Unit has achieved C3= yield >8 wt%
Conclusions

Iranian Refiners have an **incentive to process heavier feeds** in RFCC Units that are heavily contaminated by metals and CCR and require a robust technology.

UOP’s **RFCC technology solutions** designed to handle feeds with a broad range of Conradson carbon and Metals.

UOP’s RFCC helps **maximize conversion & yield selectivity**; is flexible, proven & extensively commercialized.

UOP’s RFCC technology has **successfully been proven with one of the world’s most difficult feed** achieving C3= yield of 8 wt.%