Update On High Olefins Options With Focus On A New Advanced Process, HS-FCC™

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High Olefins Options of FCC Technologies

- FCC and RFCC – ZSM-5 added to produce some propylene
- DCC – Ethylene and Propylene production from VGO and good quality Resids
- R2P™: Resid to Propylene – Ethylene and Propylene production from Resids
- HS-FCC™: High Severity FCC – Ethylene and Propylene production from VGO and Resids
Why cat cracking has been important?

- 20% of every barrel of crude oil go through FCC
- Half of all the gasoline produced in the world is supplied by FCC
- 1/3 of worldwide propylene is made from FCC

Cat Cracking unit has been a “must” for a modern refinery & PC Complex

Source: science.howstuffworks.com
HS-FCC™ – A Worldwide Cooperation

- Saudi Aramco (Saudi Arabia)
- KFUPM (Saudi Arabia)
- JX (Japan)
- Technip Stone & Webster Process Technology (United States)
- Axens (France)
Catalytic Cracking Technologies

Propylene Yield %wt

Incremental gains with recycles

► HS-FCC, a new member of the family
Let’s get aligned

What is the biggest hurdle for your company investing in a new technology?

A. Resistance to change within company
B. Lack of references for new technology
C. Price of new technology
D. Perceived risk more than offsets reward of becoming the industry leader
HS-FCC™ Technology – Key features

- **Maximum Propylene Yield**
  - High ROT (580-620°C)
  - Ultra short contact time (0.5-1s)
  - High C/O Ratio (25-30)

- **Proprietary Catalyst**
  - Rare earth free catalyst
  - Low acid site density
  - Patented formula

- **Unique Reaction System**
  - Downflow reactor
  - Tempest™ Separator
  - Technip FIT

**Reaction Conditions**
Selectivity by Short Contact Time

FCC Riser

HS-FCC™ Down flow

Feed + Catalyst
## Comparative Typical Operating Conditions

<table>
<thead>
<tr>
<th></th>
<th>Conv. FCC</th>
<th>HP FCC</th>
<th>DCC</th>
<th>HS-FCC™</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROT</td>
<td>530°C (986°F)</td>
<td>550°C (1022°F)</td>
<td>580°C (1076°F)</td>
<td>600°C+ (1112°F+)</td>
</tr>
<tr>
<td>Contact time</td>
<td>2 - 5 s</td>
<td>2 - 5 s</td>
<td>10 s</td>
<td>0.5 - 1 s</td>
</tr>
<tr>
<td>C/O</td>
<td>5</td>
<td>10</td>
<td>12-15</td>
<td>25</td>
</tr>
<tr>
<td>Recycle</td>
<td>None</td>
<td>LCN</td>
<td>LCN</td>
<td>None</td>
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</table>
Comparative Yields (Hydrotreated VGO)

<table>
<thead>
<tr>
<th>Process</th>
<th>RON 96</th>
<th>RON 96</th>
<th>RON 98+</th>
<th>RON 98</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCC</td>
<td>2% Fuel Gas</td>
<td>2% Fuel Gas</td>
<td>6% Fuel Gas</td>
<td>2% Fuel Gas</td>
</tr>
<tr>
<td></td>
<td>1% Ethylene</td>
<td>1% Ethylene</td>
<td>4-5% Ethylene</td>
<td>4% Ethylene</td>
</tr>
<tr>
<td></td>
<td>10% Sat. C3+C4s</td>
<td>10% Sat. C3+C4s</td>
<td>10% Sat. C3+C4s</td>
<td>6% Sat. C3+C4s</td>
</tr>
<tr>
<td></td>
<td>7% Propylene</td>
<td>11% Propylene</td>
<td>19% Propylene</td>
<td>10% Propylene</td>
</tr>
<tr>
<td></td>
<td>55% Coke</td>
<td>48% Coke</td>
<td>14% Coke</td>
<td>16% Coke</td>
</tr>
</tbody>
</table>

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HS-FCC™ – Technology Development

1996-2001
- 0.1 BPSD pilot at KFUPM, Saudi Arabia

2001-2004
- 30 BPSD Demonstration plant in Ras Tanura, KSA

2007-2013
- 3,000 BPSD Semi-commercial unit in Mizushima, Japan

2014
- 76,000 BPSD Commercial unit

Successful scale-up

Small step

3 DFRs to minimize scale-up risk

X300
X100
X8.5
Semi-Commercial HS-FCC™ Unit

- JX refinery: 400,000 BPSD
- Location: Mizushima, Japan
- 3,000 BPSD HS-FCC™ unit
- Operating Period: 2011-2014
- Objectives Met
  - Confirmed yields
  - Demonstrated operability & reliability
  - Confirmed scale-up criteria
  - Validated benefits of HS-FCC™ technology
Semi-commercial HS-FCC™ Schematics

Feed injection

Catalyst down flow

Down flow reactor

Regenerator

Flue Gas

Hydrocarbon product

Catalyst / Product separator

Catalyst up flow

Stripper using structured packing
HS-FCC™ Semi-commercial Plant Operation

<table>
<thead>
<tr>
<th></th>
<th>VGO + 90 % HC Btm (Feb.2012)</th>
<th>100% HDT VGO (March.2014)</th>
<th>VGO + 50% DAO (Sept.2012)</th>
<th>VGO + 90% AR (Feb.2014)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed SG</td>
<td>0.845</td>
<td>0.860</td>
<td>0.891</td>
<td>0.92</td>
</tr>
<tr>
<td>Reactor T, °C</td>
<td>575</td>
<td>600</td>
<td>580</td>
<td>600</td>
</tr>
<tr>
<td>C/O, wt/wt</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
<tr>
<td>Conv, w%</td>
<td>93.2</td>
<td>88.1</td>
<td>83.0</td>
<td>83.6</td>
</tr>
<tr>
<td>Light Olefins, w%</td>
<td>39</td>
<td>39.8</td>
<td>30.8</td>
<td>32.8</td>
</tr>
<tr>
<td>C2=</td>
<td>4.0</td>
<td>3.7</td>
<td>3.2</td>
<td>4.8</td>
</tr>
<tr>
<td>C3=</td>
<td>19.3</td>
<td>19.9</td>
<td>14.8</td>
<td>16.6</td>
</tr>
<tr>
<td>C4=</td>
<td>15.7</td>
<td>16.2</td>
<td>12.8</td>
<td>11.4</td>
</tr>
<tr>
<td>C5-220 Gasoline(C5-220°C), w%</td>
<td>34.7</td>
<td>33.5</td>
<td>36.5</td>
<td>30.4</td>
</tr>
<tr>
<td>RON</td>
<td>98.5</td>
<td>96.4</td>
<td>98.1</td>
<td>97.6</td>
</tr>
</tbody>
</table>

Catalyst formulation fine tuned over time.
HS-FCC™ Feed Sources

Feedstocks with > 12wt% hydrogen are preferred to maximize propylene yield

- Vacuum Gasoil VGO
- De-asphalted oil DAO
- Atmospheric residue AR
- Vacuum residue VR
- Coker
- HCGO
- Optional HDT
Commercial Unit Configuration

- Flue Gas outlet
- Withdrawal well (WW)
- Regenerated Catalyst Standpipe (RCSP)
- Regenerator
- Downflow reactors (DFR) and Tempest Separator
- Regeneration air inlet
- Feed inlet
- Hydrocarbons outlet
- Spent catalyst lift line
- Disengager/Stripper
- Lift air inlet
- Spent Catalyst Standpipe (SCSP)
HS-FCC™ RETROFIT Study

Objective
► Maximum increase in propylene production with minimum investment

Technip S&W R2R selected for initial study
► Two stage regeneration
► Processing Resid
► Catalyst cooler

Feedstock Types HS-FCC Downer Reactor
► HT-VGO
► Full range Naphtha
What was determined?

- HS-FCC reactor capacity
- Required regenerator modifications
- Verified pressure balance
- Verified heat balance
- Mechanical design confirmed
HS-FCC RETROFIT Preliminary Economics: Payout time sensitivity to propylene price
HS-FCCTM Integrated refinery-petrochemical complex
Core: R2P ↔ DCC

C2: ERU

C3-C4: FlexEne

C4-C5: Omega
Summary: Higher IRR for Omega, FlexEne™ and ERU
Conclusion

**HS-FCC™ Technology:**

- Turns FCC upside down to achieve higher selectivity cracking
  - Utilizing high severity-ROT, Cat/oil and catalyst formulation
- Uses already commercially proven FCC technology hardware
- Retrofit of existing FCC Units with HS-FCC™ feasible
  - Additional retrofit studies in progress
- Offers refinery/petrochemicals integration opportunities for greater profits
- Demonstrated on VGO and resid feedstock in a semi-commercial plant
- Available conversion/extraction technologies for C2 to C5 streams from FCC can further enhance adaptability and profitability