Optimizing FCC Catalyst Selectivity for Processing Difficult Feeds

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Background

• The FCC unit is the heart of most modern high conversion refineries
  – Very flexible unit, can process a wide variety of feeds

• As crude supply gets tighter, this is affecting the FCC:
  – Feed quality to most FCC units is becoming heavier
  – Feed quality is no longer constant on most FCC’s

• As more crude is imported, the crude quality changes depending on the source
  – FCC Feed quality is rarely constant any more

• How can we help the FCC respond to these changing feeds?
FCC Optimisation

• Much attention is paid to FCC unit optimisation
  – Online product analysers
  – Offline simulation & optimisation models
  – Advanced DCS Control Systems
• But, what about the biggest single variable affecting unit yields?
  – FCC Catalyst Selectivity………
• The only catalyst variable that is regularly adjusted is addition rate
• Selectivities are only changed once every 2-3 years during catalyst selection studies
  – Does this really make sense any more?
How Much Does Feed Quality Vary?

- US East Coast FCC running 3 primary crude types
  - Data from 1.5 years operations
- Feed quality between 0.91 - 0.92 for 67% of the time
- 33% of operations are above or below this band – mostly above
- Even though feed quality is relatively constant, there is still a significant amount of variation
How Much Does Feed Quality Vary? - 2

- US East Coast FCC running opportunity crudes
- Large variation in feed quality as different crudes are processed
- Can one catalyst really be optimised for all of these feed types?
- Opportunity for improvement is very significant on this unit

Example 2 – Variable Feed

![Graph showing frequency vs. feed density](image-url)
Example Impact of Feed Changes - 3

Raw Operating Data from Indian Refinery – 7 months operation. Changes are Huge!!

Vertical bars denote periods of feedstock changes

Gasoline yield varies from 22 – 34 wt%

Bottoms yield varies from 8 – 20 wt%
Typical approach is to carry out a catalyst selection study every 2-3 years.

Catalyst formulation is then optimised for one specific feed and one set of product economics.

A range of feeds may be given, but the catalyst vendor can only design the catalyst for one feed.

The FCC unit will only run this feed part of the time:
  - For the rest of the time the catalyst formulation therefore cannot be optimised.

We can look at the implications of this using one of our previous examples:
Example 1 – Opportunity!

- Catalyst designed for the most common feedstock
  - Unshaded region of this graph
- Shaded area represents “non-standard” feedstocks
  - These make up 34% of unit operations
- How to deal with this?
  - Optimise base catalyst for “most common” feedstock
  - Use additives to optimise during non-standard feed operations
- Easy to do with “State-of-the-art” catalyst addition technology

```
<table>
<thead>
<tr>
<th>Density</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.913</td>
<td>16%</td>
</tr>
<tr>
<td>0.913 - 0.923</td>
<td>67%</td>
</tr>
<tr>
<td>&gt;0.923</td>
<td>18%</td>
</tr>
</tbody>
</table>
```
Catalyst Optimisation Strategies

• In the following slides we will examine several possible catalyst optimisation strategies
  A. Single Additive Strategy: (eg. High Y-Zeolite Additive)
  B. Dual Additive Strategy: (eg. As above plus a Bottoms Cracking Additive)

• Note that other additives can also be used in the same way:
  – Vanadium Trapping Additives
  – ZSM-5 Additives
(A). Single Additive Optimisation - Zeolite

- This is the simplest strategy
  - The base catalyst is already designed for the most common feed
- As the feed lightens, increase Y-zeolite additive addition to maximise conversion
  - Total catalyst addition rate remains constant
- The lighter the feed, the more Y-Zeolite Additive that can be used
  - Yield benefits increase accordingly
Increasing Concentration of Y Zeolite FCC Additive
(B). Dual Additive Optimisation

• The next logical step is to use two different FCC additives
  – Use Y-Zeolite Additive for feeds that are lighter than average
  – Use Bottoms Cracking Additive for feeds that are heavier than average (pure matrix additive)

• FCC Unit will be much better optimised by increasing zeolite and matrix activity only when required

• This is shown graphically on the following slide:
Dual Additive Catalyst Optimisation

Increasing High Y-Zeolite Additive

Increasing Bottoms Cracking Additive

Frequency (days)

Feed Density

0.89  0.91  0.93  0.95
Benefits of Multi-Additive Strategy

• When adding Matrix and Zeolite components separately, it now becomes possible to alter the Zeolite:Matrix ratio online.

• Why would we want to do this?
  – Changing catalyst Z:M ratio shifts product yield patterns
    • High Z:M produces more gasoline, less LCO
    • Low Z:M produces less gasoline, more LCO

• As product pricing changes, this provides ability to switch FCC catalyst from “Gasoline Mode” to “LCO Mode”

• Provides flexibility similar to using ZSM-5 to adjust LPG yields
One question that is often asked is “why not just use two grades of base FCC catalyst instead?”

The Answer:

- The second base catalyst contains not just zeolite, but also inert material (binder) and matrix
  - We don’t need either of these
  - The magnitude of yield changes will be less than with pure Y-Zeolite addition
  - Unit response to addition of High Y-Zeolite additives is much faster
  - Same applies to Bottoms Cracking Additives

- Fast response to additions is crucial for rapidly optimising FCC yield selectivity
How To Operate a Multi-Additive Strategy?

• To design and operate a multi additive strategy, important to start with a good set of yield vectors
  
• This can be done in the laboratory, but preferred strategy is to carry out simple step testing of each additive component on the live FCC unit
  
  – Each component can be base loaded to a set concentration (e.g. 5% or 10%) and true yield vectors measured

• These yield vectors can be incorporated into the FCC LP Model, or the Refinery Planning LP Model

• FCC Engineers/Planners can then run the model weekly, and advise which additives (if any) should be used
  
  – Decision will be based on current refinery economics, unit constraints, and on current FCC yield patterns
How to Add Catalyst Components

• Now that we have decided which components to add, how do we get them into the FCC?
• Catalyst addition system technology has advanced significantly in recent years
• Several types of addition system now available for adding more than one catalyst simultaneously to the FCC
• INTERCAT Addition Systems are well established as the leading technology in this area
  – Standard Addition Systems
  – Multi-Compartment Addition Systems
Multi-Compartment System Option

Main Vessel Contains Three Compartments - 2 x 1 ton, 1 x 2 ton

IMS-MC Controller

Three Outlet Lines, Each with it's own Everlasting Valve
Case Study Examples

- The following examples are from refineries which use additives to actively optimize their catalyst formulation.
- Each refiner chose their own solution independently, without following the structured approach outlined above.
- These examples are given to illustrate the benefits that can be obtained by using this more structured approach.
Example 1 – US Refinery

- US Rocky Mountain Refinery needed to increase FCC Conversion on certain feeds
  - Not able to make a significant increase to fresh catalyst addition rate
- A High Y Zeolite Additive was therefore used at a concentration of 7% of inventory
- At this concentration, conversion increased by 2.5 wt%
  - Dry gas and coke remained unchanged
- Additive used only when required
- Results are shown on following slide
### Example 1 – Yield Changes With Hi-Y

<table>
<thead>
<tr>
<th>Wt% Yields</th>
<th>Base Case</th>
<th>With Hi-Y</th>
<th>Δ Yield</th>
</tr>
</thead>
<tbody>
<tr>
<td>DG</td>
<td>4.57</td>
<td>4.57</td>
<td>+0.00</td>
</tr>
<tr>
<td>LPG</td>
<td>10.65</td>
<td>12.04</td>
<td>+1.39</td>
</tr>
<tr>
<td>Naphtha</td>
<td>42.59</td>
<td>43.64</td>
<td>+1.05</td>
</tr>
<tr>
<td>LCO</td>
<td>24.69</td>
<td>23.82</td>
<td>-0.87</td>
</tr>
<tr>
<td>DCO</td>
<td>11.20</td>
<td>9.61</td>
<td>-1.59</td>
</tr>
<tr>
<td>Coke</td>
<td>6.29</td>
<td>6.32</td>
<td>+0.03</td>
</tr>
<tr>
<td>Riser Temp °C</td>
<td>535</td>
<td>535</td>
<td>0</td>
</tr>
<tr>
<td>Hi-Y additions</td>
<td>---</td>
<td>7.0%</td>
<td>7.0%</td>
</tr>
</tbody>
</table>
Example 2 – Bottoms Cracking Additive

- Non-US Refiner used a Bottoms Cracking Additive to reduce bottoms yield
  - Heavy residue feed operation
- BCA-105 used at three different concentration levels to assess operational effects
- Bottoms reduction found to increase with concentration up to 12%
  - Higher concentrations not tested
- Yields of converted products changed as Bottoms Cracking Additive concentration increased
  - Yield effects reflect gradual shift in Zeolite:Matrix ratio
## Example 2 – Yield Shifts with BCA

<table>
<thead>
<tr>
<th>Operations</th>
<th>Base</th>
<th>6% BCA</th>
<th>9% BCA</th>
<th>12% BCA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed density</td>
<td>0.925</td>
<td>0.933</td>
<td>0.927</td>
<td>0.920</td>
</tr>
<tr>
<td>Reactor Temp, C</td>
<td>525</td>
<td>525</td>
<td>525</td>
<td>525</td>
</tr>
<tr>
<td>Regen Temp, C</td>
<td>738</td>
<td>744</td>
<td>749</td>
<td>747</td>
</tr>
<tr>
<td>Preheat Temp, C</td>
<td>208</td>
<td>205</td>
<td>188</td>
<td>202</td>
</tr>
<tr>
<td>Delta Yields (wt%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drygas</td>
<td>Base</td>
<td>+0.1</td>
<td>0.0</td>
<td>-0.1</td>
</tr>
<tr>
<td>LPG</td>
<td>Base</td>
<td>0.0</td>
<td>+0.9</td>
<td>0.0</td>
</tr>
<tr>
<td>Naphtha</td>
<td>Base</td>
<td>+2.3</td>
<td>+1.7</td>
<td>+2.0</td>
</tr>
<tr>
<td>LCO</td>
<td>Base</td>
<td>-0.5</td>
<td>-0.3</td>
<td>+2.0</td>
</tr>
<tr>
<td>Slurry</td>
<td>Base</td>
<td>-1.8</td>
<td>-2.3</td>
<td>-3.9</td>
</tr>
</tbody>
</table>

**Gasoline:LCO Ratio changes with catalyst Zeolite:Matrix ratio**
We are not aiming for perfection – just to get closer to the optimum formulation each day. The faster the inventory changeover, the closer the formulation will be to the daily optimum.
Conclusions

- FCC feeds are forecast to get heavier, and more variable
- Catalyst selectivity in most FCC units is optimised for only a small percentage of the time
- Technology now exists to rectify this situation
  - High activity catalyst additives (Matrix & Zeolite)
  - Addition System Technology allows several catalyst components to be added at the same time
- Allows catalyst selectivities to be adjusted on an ongoing basis
  - Minimises catalyst costs, optimises unit operation
- Dynamically changing catalyst formulation can significantly improve FCC unit profitability
Any Questions........?