Case Study

10 PPM SULFUR GASOLINE OPPORTUNITIES

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FCC PRE-TREATMENT VS. PRE-TREATMENT & POST-TREATMENT COMPARISON

A thorough analysis was needed to identify the best scenario required to comply with ULSG (Ultra Low Sulfur Gasoline) regulations: Severe FCC feed pre-treatment alone or milder pre-treatment combined with FCC gasoline post-treatment. This analysis paid close attention to CFHT (Cat Feed Hydrotreater) cycle length requirements, with and without post-treatment, in order to measure their impact.

An existing refinery reconfigured to process Heavy Canadian Crudes while maintaining its FCC Unit was used as an example. The VGO feedstock comprises a 55,000 BPD blend of straight run VGO and Heavy Coker Gas-Oil with 4.2 wt% sulfur. The refractory nature of this feed requires to be hydrotreated in a high-pressure unit before feeding the FCCU. The gasoline we are left with constitutes about one third of the total gasoline pool and all of the pool sulfur.

Consider the following case studies:

- **Case 1**: A high HDS CFHT unit and FCC capable to produce a 10-wppm Gasoline pool sulfur without the need of a FCC Post-treatment unit with a CFHT cycle length of 4 years to match the FCC.
- **Case 2**: A moderate HDS CFHT designed for a 4-year cycle length with a FCC Post-treatment unit (Prime-G+) designed for a 4-year cycle length to meet ULSG pool specifications.
- **Case 3**: Similar to Case 2 but with a 2-year cycle length target for the CFHT unit combined with a Prime-G+ unit designed for a 4-year cycle length. During the CFHT catalyst change-out, the Prime-G+ unit will operate at a higher severity to meet pool sulfur requirements.

For all cases, a relatively high pressure was selected for the CFHT to ensure good hydrogen addition during the whole run. Reactor residence time was adjusted to meet the CFHT HDS and cycle length requirement – Figure 1. The very severe level of HDS and 4-year cycle length in Case 1 naturally leads to a much larger CFHT than the other cases. High purity hydrogen is supplied from a SMR plant.

The economic evaluation was based on a Discounted Cash Flow (DCF) analysis assuming a depreciation period and a project duration of 10 years. In addition, a profitability index comparison in terms of Net Present Values (NPV) and Internal Rate of Return (IRR) was conducted. The prices for investment, catalysts, utilities, feedstock and finished products were based on 2011 averaged values assuming the plant to be located in the USA serving a domestic market. Prices are presented in Table 1.

For all three cases considered, projections on CFHT and FCC operations were conducted leading to expected product yields and hydrogen requirement. As one could have expected, the implementation of a high severity CFHT (Case 1) leads to better product yields in the FCC but has a major drawback of driving hydrogen consumption up. Results in terms of main product yields and hydrogen cost for each case are presented in Table 2. The evaluation was based on a Natural Gas price of $4/MMBTU resulting in a hydrogen cost of $1400/t of hydrogen.

The hydrogen cost for Case 1 is almost 25% higher than that of Case 2 or Case 3; however, the yield improvement
is quite significant over the lower severity CFHT cases. Between the lower severity CFHT cases, the yields and hydrogen consumption are rather similar with the more severe and longer cycle Case 2 providing a slight improvement in terms of yields over Case 3 commensurate with the small increase in hydrogen consumption.

With regards to the operating cost (OPEX) of the different cases, the study took into consideration the hydrogen, octane and utility costs. Compared to the other factors, the hydrogen cost was by far the major contributor to the OPEX. In addition to the operating cost, a detailed Total Capital Investment (TCI) was developed to estimate the CAPEX for each case.

The TCI trend illustrated in Figure 3 clearly shows that Case 1 has a much higher capital requirement than the other two cases due to the significantly higher...
TABLE 2 STUDY RESULTS – PRODUCT YIELDS & HYDROGEN REQUIREMENT

<table>
<thead>
<tr>
<th>Case New Units</th>
<th>Case 1 CFHT 4 yr</th>
<th>Case 2 CFHT + Post-treat 4 yr + 4 yr</th>
<th>Case 3 CFHT + Post-treat 2 yr + 4 yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasoline Yield, Vol.% / VGO Feed</td>
<td>61.9</td>
<td>56.3</td>
<td>55.0</td>
</tr>
<tr>
<td>Diesel + LCO Yield, Vol.% / VGO Feed</td>
<td>27.2</td>
<td>27.6</td>
<td>28.0</td>
</tr>
<tr>
<td>Propylene Yield, Vol.% / VGO Feed</td>
<td>7.8</td>
<td>7.5</td>
<td>7.3</td>
</tr>
<tr>
<td>Butenes Yield, Vol.% / VGO Feed</td>
<td>8.8</td>
<td>8.3</td>
<td>8.1</td>
</tr>
<tr>
<td>Hydrogen Cost, $/bbl Feed</td>
<td>4.71</td>
<td>3.73</td>
<td>3.66</td>
</tr>
</tbody>
</table>

desulfurization and cycle length requirements for the CFHT.

Both Net Present Value (NPV) and Internal Rate of Return (IRR) comparisons are shown in Figures 4 and 5. The high severity CFHT without post-treatment, Case 1, was considered as the basis and the IRR and NPV of the other cases were compared to Case 1.

The NPV results favor Case 1 with a high HDS/long cycle length CFHT and no post-treatment over more moderate HDS CFHT cases coupled with a post-treatment unit. On the other hand, the IRR is most favorable for Case 3 with the lowest cost CFHT option (moderate and 2-year cycle) coupled with a 4-year cycle post-treatment Prime-G+ unit.

A sensitivity case was examined to determine the impact of Natural Gas (NG) cost on the NPV results. The findings are highlighted in Table 3. Assuming a higher NG price (6 vs. 4 $/MMBTU), the cost of hydrogen increases and the difference in NPV between the three cases diminishes somewhat. From and IRR perspective, the advantage of Case 3 increases when hydrogen cost increases and the gap in NPV between Case 1 and 3 decreases.

Surprisingly, Case 2 with a 4-year CFHT cycle in sync with the FCC cycle does not show an NPV or IRR advantage over the shorter cycle Case 3 for either NG pricing scenario. One could have assumed that designing a CFHT in sync with the downstream units compared to limiting the CFHT cycle length to only 2 years would be an advantage. However, the 4-year cycle post-treatment unit brings the additional flexibility to continuously operate during a CFHT catalyst change-out. Despite higher feed sulfur (that could be partially limited with a change in crude diet during the CFHT catalyst change-out) the design of the post-treatment unit with the Prime-G+ technology is robust enough to handle this higher severity requirement during the catalyst change-out.

This flexibility is clearly illustrated in Figure 6 which shows operating data on a Prime-G+ unit in a refinery processing heavy processing crudes and equipped with a FCC CFHT pre-treater. When the CFHT is in operation the normal feed sulfur to the Prime-G+ unit is typically below 200 wppm. Despite turnarounds or operation upsets on the CFHT unit, which can lead to feed sulfur as high as 900 wppm, the product sulfur from the Prime-G+ unit can be maintained to the target value of 20 wppm at all times.

When processing Full Range Cut Naphtha (FRCN), the sulfur content in

FIGURE 3 TOTAL CAPITAL INVESTMENT (TCI) IMPACT

[Graph showing TCI, % / Case 1 with Case 1, Case 2, and Case 3 compared]
the product is maintained at the target value (20 ppm), as shown in Figure 6, despite variations in FCN quality thanks to the FCC pretreatment option.

The flexibility brought by adding a post-treatment to the compulsory FCC pretreater when processing heavy crudes should be underlined and is a major advantage over the pre-treatment alone solution. In order to produce a gasoline pool with less than 10-wppm, the refinery becomes a chemical plant with no margin for error; relying on the CFHT alone leaves little flexibility.

In summary, coupling a CFHT with a FCC Naphtha post-treatment unit brings the following advantages:

- The CFHT severity is lowered which offers the possibility to revamp an existing CFHT.
- It is possible to design the CFHT unit for a cycle length of 2 years instead of 4 years.
- The Prime-G+ post-treatment design is simplified to typically a single-stage unit.
- The refinery reliability and flexibility is improved:
  - CFHT upset may be compensated by the Prime-G+ post-treatment unit.
  - CFHT severity may be decreased if needed/ permitted.
  - FCCU operation is more flexible in terms of fractionation quality.
  - FCC gasoline end-point may be increased when margins favor gasoline production while still controlling FCC naphtha sulfur through post-treatment.

### Table 3: Study Results — Hydrogen Cost Sensitivity Study

<table>
<thead>
<tr>
<th>Case Study</th>
<th>Case 1</th>
<th>Case 2</th>
<th>Case 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>NPV @10% : Nat. Gas = 4 $/MMBTU</td>
<td>Base</td>
<td>Base x 0.93</td>
<td>Base x 0.93</td>
</tr>
<tr>
<td>NPV @10% : Nat. Gas = 6 $/MMBTU</td>
<td>Base</td>
<td>Base x 0.94</td>
<td>Base x 0.94</td>
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</tbody>
</table>
The issue of SOx and NOx control in FCC flue gas is not addressed in the above analysis. The high severity CFHT (Case 1) may allow the typical 50 and 40 ppmv targets for SOx and NOx to be achieved directly while a flue gas scrubber would be necessary to meet such constraints with Cases 2 and 3. The addition of the scrubber for Cases 2 and 3 decreases the IRR differential to Case 1 by one point while conversely the NPV advantage over Case 1 is increased by approximately 1%.

It is important to note that in spite of a trend in favor of Case 3, the conclusion drawn from this particular study is case specific and cannot be generalized to other cases that may have different configurations and project premise.

CONCLUSION

A great number of nations are now aiming at a 10 wppm limit in transportation fuels’ sulfur levels. Meeting with new ULSG regulations while taking into account current FCC post-treatment assets can be achieved after a thorough review of commercial best practices. Low refinery margins coupled with capital constraints will most certainly give the upper hand to the revamping of existing FCC post-treatment units.

Although no two situations are similar, a mix of pre-treat and post-treat solutions around the FCC Unit will often result in higher flexibility and benefits. As a licensor of CFHT, FCC and FCC post-treatment technologies, Axens is in a premium position to provide the service tailored to each need.

References:

J. Bonnardot et al, Direct Production of Euro-IV Diesel at 10 ppm Sulfur via the HyC-10 Process, ERTC 9th Annual Meeting, Nov. 2004


D. Largeteau et al, Benzene Management in a MSAT 2 Environment, AM-08-11, NPRA Annual Meeting, March 2008

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