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Conversion Unit Yield Analysis

2008 Fuels Refinery
Performance Analysis

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Introduction

Since 2000, Solomon's *Fuels Refinery Performance Analysis (Fuels Study)* has compared the gross margins of study participants to that of better performing peers as a measure of *competitiveness*. In the 2008 *Fuels Study*, Solomon introduced Conversion Unit Yield Analysis as an *efficiency* measure for gross margin performance. We estimate the potential value of improving unit yield performance at constant feed quality by correlating the world's best achieved yields versus key feed characteristics for four major processes. This paper describes the Conversion Unit Yield Analysis methodology and optional customized analyses that provide more detailed processing data, what we refer to as "3D Analysis". These analyses are available only to *Fuels Study* participants.

Gross Margin Analysis

Solomon compares a participant's margins to a high-performing peer group to determine a competitive gap. In the 2008 *Fuels Study*, the world average refinery net cash margin (NCM) gap was US $[redacted] per barrel net input. We then calculate throughput and process yield differences. The throughput calculation of the variance analysis demonstrates configuration differences between the study participant's refinery and the peer group. For example, if the peer group has greater coking or gas oil conversion capacity as a percentage of net input, their net cash margin typically benefits.

The yield calculation of the variance analysis shows the difference in process unit gross margin between the peer group process unit average and the participant's unit. The yield calculation is often dominated by differences in pricing due to feed quality. Because the peer unit rarely has identical feed quality to the participant's unit, this comparison does not indicate whether the participant's unit yields are "good". While this comparison provides understanding of why the economic performance is different, closing the gap may require investment.

Conversion Unit Yield Analysis

In an effort to provide more actionable information, the 2008 *Fuels Study* added the analysis of conversion unit yields given the participant's feed qualities as an *efficiency* measurement. Conversion unit yield differences are based on comparison of the participant's unit to a "world best" operation with similar feed. This means of comparison eliminates impact of feed quality, so the difference is solely due to lower value product slate versus the best performers. Solomon defines "world's best" as the frontier performance of the best individual process units from all three *Fuels Study* regions:

- North and South America
- Europe, Africa, and the Middle East
- Asia/Pacific/Indian Ocean

Solomon generates an incremental yield pattern based on the world's best performance and the participant's operation, and applies *Fuels Study* refinery location pricing to the incremental yields. Only incremental yields are valued; thus, there is no penalty or credit for the reported yields not in mass balance. The analysis does, however, depend on the accuracy of feed properties and key product yields.

Although the conversion unit yield differences do not include any opportunity for changing feed stocks, the magnitude of the opportunity is significant relative to the competitive NCM gap. Approximately 20% of the refineries in the 2008 *Fuels Study* had conversion unit yield gaps exceeding 25% of their NCM gap, and 10% had conversion unit yield gaps in excess of 50% of their NCM gap. The Conversion Unit Yield Analysis results ranged from US $[redacted] to greater than US $[redacted] per barrel net input.

We have developed conversion unit yield differences for delayed coking, catalytic cracking, catalytic reforming, and hydrocracking. Each participant's gaps and pricing for each refinery are summarized in the workbook (*_YieldGap.xls*) attached. A description of the methodology for each process follows.

Delayed Coking

Delayed coker performance is defined by coke yield versus feed Conradson Carbon (ConCarbon). The analysis results represent the value of converting excess coke yield to liquid and gas products. Data from the 2008 *Fuels Studies* is graphically represented in Figure 1. The figure shows the best performer frontier as well as a common industry correlation of these two parameters.

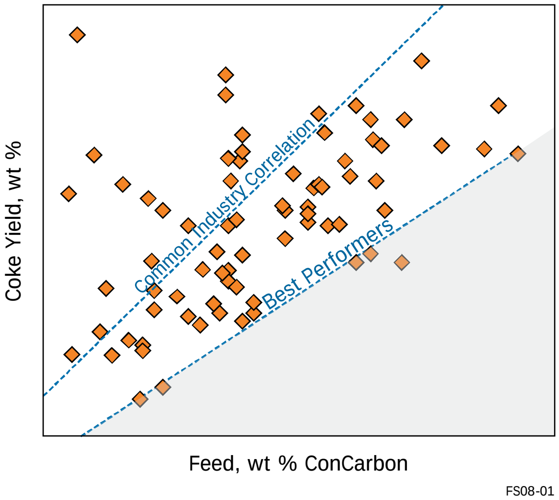

Figure 1 – Delayed Coking Yields

Study input forms instructions state "Coking charge rates should be based only on fresh feed to the coker heater. Exclude any light oil that flashes in the fractionators or feed scrubber, and exclude recycle and slop volumes". Weight percent coke yield is based on reported coke production divided by this stated average charge rate. If the feed ConCarbon is inconsistent with the charge rate definition, the calculated yields will be in error. Consider the following example:

Operating Parameters

- Feed ConCarbon = 20 wt %, coke yield = 30 wt % of fresh feed

Calculations

- If the world's best yield = 1.4 x ConCarbon, best coke yield would be 20 x 1.4 = 28 wt %
- Delta 2 wt % coke = 2 wt % liquid and gas product increase

The analysis is performed for fuel and anode-grade coke operation. Fuel coke is a very low value product, so increased liquid yields are very profitable. Delayed coker gaps are typically larger than other unit gaps (where the price differential between unit products is smaller). Gaps are typically due to operating parameters, including recycle, drum pressure, and temperature.

Fluid Catalytic Cracking

FCC performance is defined by conversion versus feed UOP K and ConCarbon. The analysis results represent the value of increasing conversion at constant coke yield. Data from the 2008 *Fuels Studies* is graphically represented in Figure 2. Hydrogen deficient feeds (lower UOP K value) yield lower conversion at a given coke yield (or must make more coke to achieve comparable conversion). A small number of refineries report feed UOP K values that are inconsistent with feed distillation and gravity.

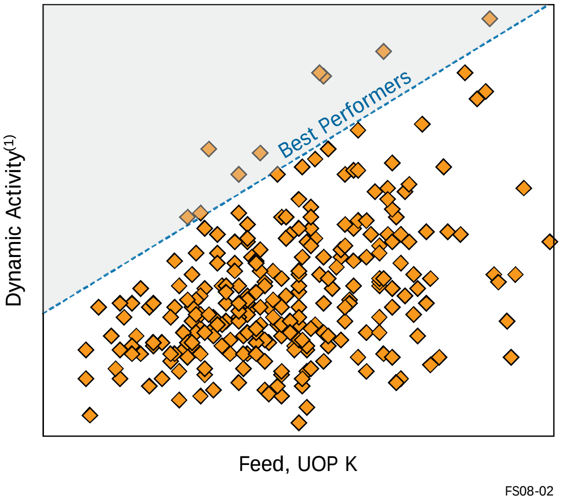

Figure 2 – Fluid Catalytic Cracking Yields

Operating Parameters

- Dynamic Activity (DA) = Second Order Conversion / (wt % Coke – 0.7 x Feed ConCarbon, wt %)

Calculations

- Second Order Conversion = wt % Conversion / (100 – wt % Conversion)
- Wt % Conversion = vol % Conversion + 1.79 x UOP K – 23.8 (Correlated from Pilot Plant Data)

The Conversion Unit Yield Analysis is calculated by increasing participant conversion to match the DA of the world best performer line at participant feed UOP K and coke yield. Incremental yield pattern is dependent on participant Light Cycle Oil (LCO)/bottoms and LPG/gasoline ratios—as conversion increases, both of these ratios increase. Incremental yields are mass balanced. Solomon calculates UOP K from reported feed distillation and density. If reported FCC feed UOP K differs from calculated by more than 0.15, we preferentially use the calculated result.

Base yield optimization (e.g., higher LCO/bottoms or lower LPG/gasoline ratios) at constant conversion is not included in the gap calculation. An example calculation is:

Operating Parameters

- Feed UOP K = 12.0, ConCarbon = 0.3 wt %
- Coke = 3.8 wt %, Conversion = 73.1 vol %
- Wt % Conversion = 73.1 + 1.79 x 12 – 23.8 = 70.8 wt %
- Second Order Conversion = 70.8 / (100 – 70.8) = 2.42
- DA = 2.42 / (3.8 – 0.7 x 0.3) = 0.67

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[1] Second Order Conversion/(wt % coke – 0.7 x feed wt % ConCarbon)

Calculations

- If the world best DA at 12.0 UOP K was = 0.9
- World Best Second Order Conversion at Feed Conditions and Coke = 2.42 x 0.9 / 0.67 = 3.25
- World Best wt % Conversion = 100 x 3.25 / (3.25 + 1) = 76.5 wt % = 78.8 vol %

Thus, conversion would increase 5.7 vol % (73.1 to 78.8) at constant coke.

FCC hardware (feed nozzles, riser termination, and spent catalyst stripping) strongly influences DA. Operating conditions such as steam rates, temperatures, and recycle and catalyst properties can also affect DA.

Some refiners maximize distillate production by reducing FCC conversion (increasing LCO yield). Reducing conversion by lowering severity will also reduce coke production, and DA remains fairly constant for a given feed.

Catalytic Reforming

Reformer performance is defined by C_5+ reformate yield versus feed volume percent naphthenes and aromatics (N+2A). The Conversion Unit Yield Analysis results represent the value of increasing C_5+ yield versus C_1–C_4 yield. Data from the 2008 *Fuels Studies* is graphically represented in Figure 3. Defining world best operation requires normalizing octane, pressure, and feed distillation. Figure 3 data is at 100 RON, 40 psig, and 260 °F (127 °C) feed 50% distillation point (T_{50}). Note the relatively large number of data points in the shaded area. We do not adjust yields for catalyst formulation, and continuous regeneration units often employ advanced catalyst systems claiming to give superior yields. We reinforce during study validation that refiners are to report C_5+ reformate (exclude butanes), but the data suggest that a few continue to report as-produced reformate yield.

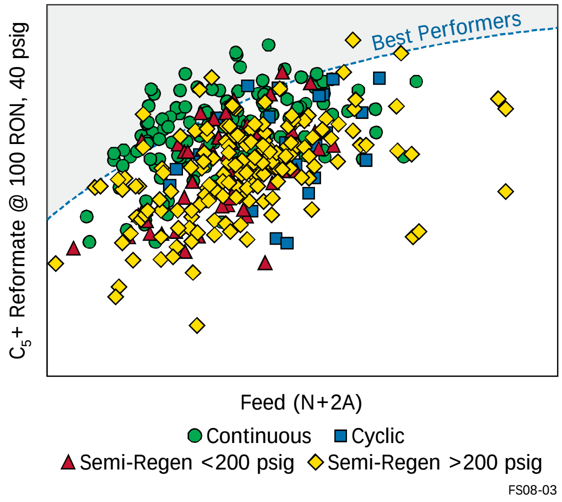

Figure 3 – Catalytic Reforming Yields

Gaps are calculated at participant (N+2A), T_{50}, RON, and pressure. As such, the world best point is first adjusted to participant operating conditions. Incremental yields are mass and hydrogen balanced. An example calculation is:

Operating Parameters

- (N+2A) = 64, T_{50} = 260 °F (127 °C), RON = 98,
- Separator pressure = 300 psig (20.6 barg), C_5+ yield = 78 vol %

Calculations

- If world best C_5+ yield at 100 RON, 40 psig (2.8 barg), 260 °F (127 °C) T_{50} = 85 vol %
- World best C_5+ yield at 98 RON, 300 psig (20.6 barg), 250 °F (121 °C) T_{50} = 83 vol %
- C_5+ gap = 83 – 78 = 5 vol % (C_1–C_4 yield 8% lower, H_2 yield 1 FOE % higher by mass and H_2 balance)

Yield gaps are strongly influenced by catalyst properties and feed contaminants, and catalyst regeneration is very important for good yields. Consequently, reactor flow distribution is critical—localized hydrocracking can significantly increase light ends yields. Semi-regen unit cycle length can influence reported yields if the data year represents end-of-run conditions, particularly if the cycle is extended too far as end-of-run yields can be poor.

Hydrocracking

Hydrocracker performance is defined by C_1–C_4 yield versus feed °API gravity and UOP K. The Conversion Unit Yield Analysis results represent the value of increasing C_5+ yield versus C_1–C_4 yield. Data from the 2008 *Fuels Studies* is graphically represented in Figure 4. Operating conditions are normalized—light ends yields are higher when severity (represented as hydrogen consumed net of H_2 to remove sulfur and nitrogen) increases. An example calculation:

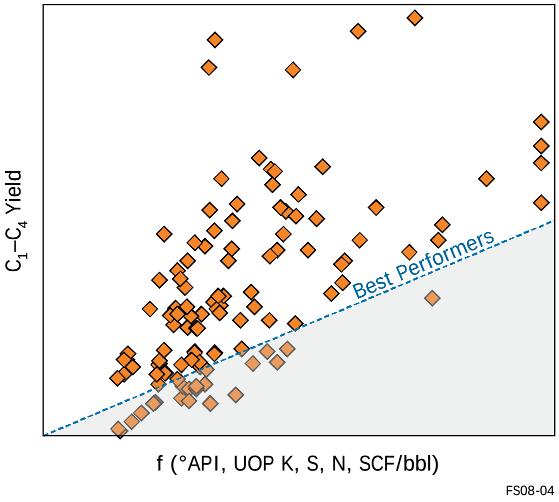

Figure 4 – Hydrocracking Yields

Operating Parameters

- Feed UOP K = 11.0, 27 °API, 0.9 wt % S,
  1,100 ppmw N (light virgin and cracked gas oils)
- Product $C_1 + C_2$ = 4 FOE vol %, $C_3 + C_4$ = 10.8 vol % = 7 FOE % at 1,600 SCF/bbl (270 nm^3/m^3) H_2 consumed

Calculation

- If the world best C_4- yield = 4 FOE vol % at this severity and feed type:
- C_1 – C_4 yield would be 7 FOE vol % lower (11% – 4%). C_4+ yield increases 6 vol %,
- H_2 consumed 1 FOE vol % lower (H_2 calculation is by hydrogen balance)

Hydrocracker yield selectivity is influenced by catalyst properties, reactor distribution, and temperature profile, as well as end-of-run conditions. Extending cycles can substantially increase light ends yields.

3D Analysis

Solomon's CPA studies are driven by a proprietary database representing the majority of the world refining capacity. Maintaining high participation in our biennial *Fuels Study* as well as our *Worldwide Paraffinic Lube Refinery Performance Analysis (Lube Study)* is critical to Solomon's business. We are aware that many study participants are sensitive to the cost of these studies. As such, we decided not to include the cost of developing Conversion Unit Yield Analysis in the base study price. Instead, we chose to report the opportunity to all of our participants and let them decide if they desired more data analysis at additional cost.

For participants desiring additional information, Solomon offers custom "3D Analysis". 3D modules provide insights into causes of yield gaps and are available for any of the conversion units described in this paper (as well as for energy, maintenance, turnarounds, and investment strategy). Conversion unit example slides are shown in the following figures. If you have any questions or would further information, please contact Kevin Proops at kevin.proops@solomononline.com.

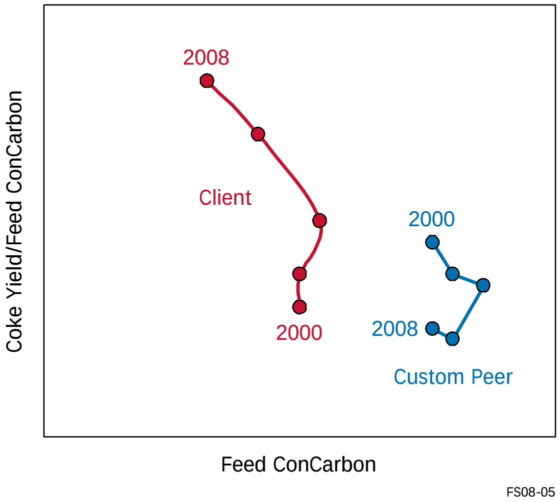

Figure 5 – Delayed Coking Yield Trend

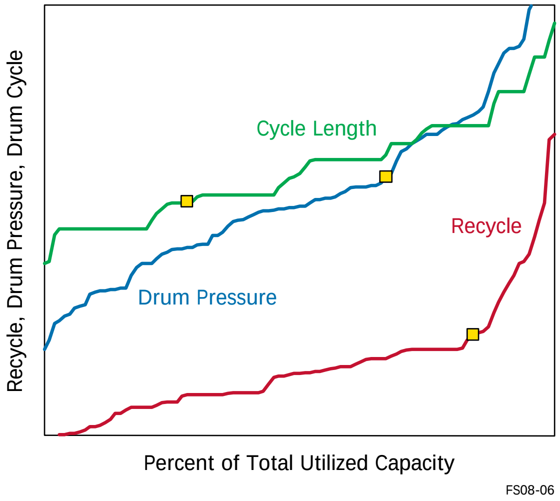

Figure 6 – Delayed Coker Operating Conditions Distribution

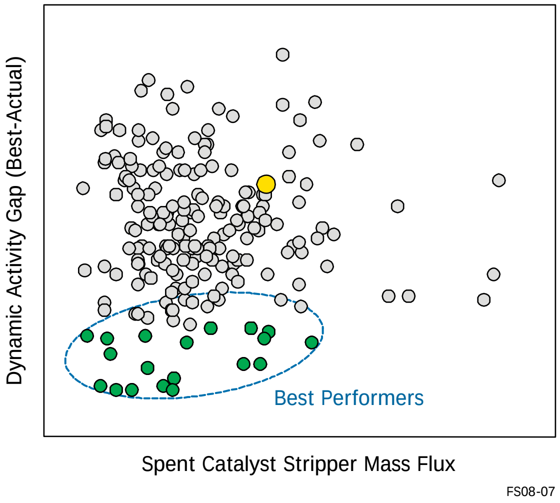

Figure 7 – FCC Operating Conditions

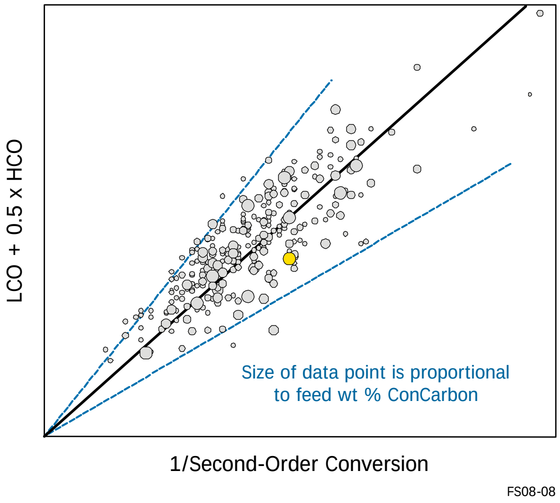

Figure 8 – FCC Yield Selectivity

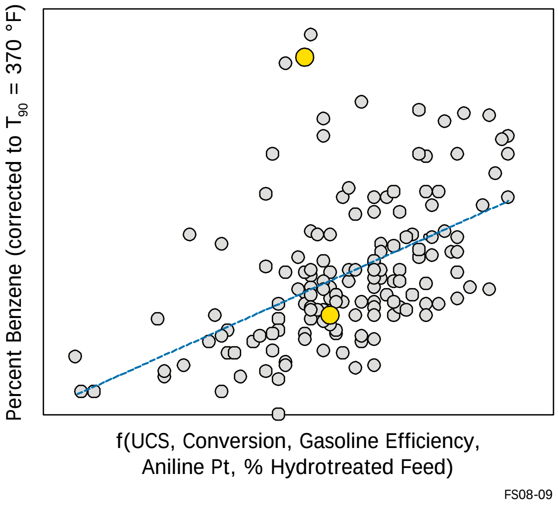

Figure 9 – FCC Gasoline Benzene

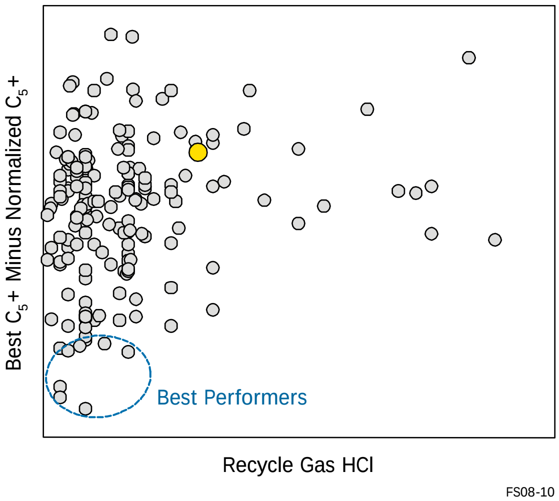

Figure 10 – Reformer Recycle Gas HCl