The Art of Evaluating
Laboratory Fixed Bed and Fixed Fluid Bed
Catalytic Cracking Data

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Introduction

The Fluid Catalytic Cracking (FCC) community has used small, laboratory fixed bed units for many years to evaluate catalytic cracking results. Such units are typically used to evaluate the differences in the performance of various cracking catalysts and also are used to provide some insight into the effect of process variables and feedstock effects.

One such laboratory unit, which was used extensively in the later part of the twentieth century, was the Microactivity Test unit (MAT) (1). The test, as first described by Ciapetta et al (2) in 1967, consisted of a small bed (5 gms) of 3/32 inch pellets through which a small amount of feed (~1 cc) was injected downflow. The test was quickly modified (3) to allow evaluation of catalysts in the fluid catalyst form, to improve mass transfer and heat transfer effects.

More recently, a small fixed fluid bed unit utilizing essentially the same quantities of fluid cracking catalyst and FCC feed has been developed and is licensed by Kayser Technology Inc. The unit, designated as the Advanced Cracking Evaluation (ACE) Technology unit, has better heat and mass transfer characteristics than the MAT unit and has been gradually replacing MAT units since 1997 (4).

Since both the ACE test and the MAT test utilize a fixed bed of catalyst, there are significant differences between the cracking environment in these tests and the environment in a riser reactor, as typically used in a commercial Fluid Catalytic Cracking Unit (FCCU). Nevertheless, the laboratory test results from these units provide very useful information, and provide it in a cost effective manner. Both of these units provide data that allows for a comparison of the cracking activity of the various cracking catalysts of interest and also a comparison of the product selectivity of the various catalysts.

Such tests are usually run at a temperature chosen to simulate a particular commercial operation. The catalyst / oil weight ratio (C/O) is varied at either 1) constant on-stream time (t) by varying feed rate, or 2) by varying on-stream time at constant feed rate, hence constant weight hourly space velocity (WHSV). Either technique provides a range of conversions and hence a range of product yields. In these tests, the three variables time, C/O, and WHSV are related as:

\[ t = \frac{3600}{(C/O)(WHSV)} \]
t in seconds

Frequently, in these tests, only a small number of C/O variations are used (3-5) and hence only a small number of data points are available to develop the required conversion and product yield correlations. In addition, a considerable amount of experimental error is associated with each set of data, making the proper correlation even more problematic.

It is the purpose of this paper to describe practical techniques that can be applied to the handling of these types of laboratory data to obtain the maximum amount of reliable information.
Experimental

The data used in this paper to discuss these techniques were obtained via ACE unit testing. The ACE unit was operated at the following run conditions:

- Reaction initial temperature: 543°C (1010ºF)
- Reaction time: 60 seconds of feed
- Feed rate: 1.30 grams / minute
- Catalyst weight: variable to give ~ 3, 4, & 6 C/O

The feed stock was a mid-continent gas oil with the following properties:

- Density: 0.9064 gms/cc
- UOP K: 11.8
- Sulfur: 5300 ppmw
- Total nitrogen: 1340 ppm
- Conradson Carbon: 0.415 wt%

The product was collected in a water displacement receiver and analyzed with an on-line gas chromatograph. The liquid product was collected in a chilled glass receiver. The boiling point distribution of the products was determined by standard simulated distillation GC procedures, ASTM 2887. Coke on catalyst was determined by in-situ air calcination of the spent catalyst and measurement of product carbon dioxide with an infrared analyzer. Mass balances were calculated and only runs with balances >95 wt% were accepted for the data correlations. Product yields were expressed on a weight percent of feed basis.

The three FCC catalysts evaluated for this paper were blends of a base equilibrium catalyst and various laboratory deactivated shape selective zeolite additives. The additives were deactivated in a cyclic deactivation unit using 50 cycles of cracking over a gas oil feed at 565°C (1050ºF) and air/steam regeneration at 788ºC (1450ºF).

Correlating Conversion Data

In small scale laboratory FCC testing at a constant reactor initial bed temperature, tests are frequently carried out by varying C/O ratio, thus achieving a range of conversions. As in all laboratory testing, experimental error exists resulting in considerable data scatter. The question is – What is the best way to correlate the data to get the most accurate understanding of the effect of C/O ratio on conversion?

It is tempting, in this age of computer developed technology, to let the computer determine the best statistical fit to the data. This however is generally not the best approach. In many cases, only 3-4 data points are available to develop the correlation since only 3-4 C/O ratios were evaluated, and frequently replicate runs are not made. With the experimental error that exists, the statistical fit can generate nonsensical lines. If several catalysts are being tested with a single feed, the computer-
generated C/O versus conversion lines will typically cross each other at curious angles, a highly unlikely situation.

It is always useful, in developing correlations, to have one point which is known to have little or no experimental error, and, through which, the correlation can be forced. In the case of the relationship between conversion and C/O, the conversion at zero C/O is fairly well defined. At zero C/O, the conversion might be expected to be 0.0 wt%. There is, however, some conversion at essentially zero C/O caused by the nearly instantaneous thermal cracking that occurs when the feed contacts the hot catalyst environment. When the feed is constant, the thermal cracking at zero C/O would be constant for all the catalysts. Thus the conversion at zero C/O represents an anchor point through which all the plots must pass. The conversion at zero C/O is in the range of 25 wt% for most feeds, when the initial reaction temperature is in the range of 525 – 550ºC. This concept is particularly useful when several catalysts are being evaluated with one base case feed.

A further question is whether to directly use the measured conversion, defined as:

\[
\text{FCC Conversion, wt\%} = 100 - (\text{wt\% Light Cycle Oil} + \text{wt\% Heavy Cycle Oil})
\]

as the dependent variable, or to use some more fundamental value related to conversion.

If the traditional FCC conversion value as defined above is used, two difficulties arise:

1) Including the thermal conversion at zero C/O results in a very wide axis for the dependent variable, conversion. The conversions measured at the various C/O test conditions then become fairly close in value (typically in the 70 – 80 wt% range). Differentiating between the catalyst correlations and how each correlation passes through the zero C/O point becomes difficult.

2) The relationship between the actual conversion value and C/O is strongly non-linear. Given the experimental error that exists, and the few points available to develop a correlation, a reliable characterization of the correlation that must best fit the data points, must pass through the zero C/O point, and must have the proper non-linearity is difficult.

A more useful technique is to approach conversion from a kinetic point of view. Although pure hydrocarbons have been found to crack according to a kinetic first order process (5,6), cracking of a multi-component FCC gas oil feed has been found to be well approximated by a 2nd order reaction (7). The rationale for this observation is that the cracking rates for the components in the FCC feed cover a wide range, and these rates decrease as the conversion progresses and the compounds become more difficult to crack. Combining all the varying 1st order rates results in one overall rate that approaches 2nd order. The concept of 2nd order conversion, is thus a useful tool in correlating FCC conversion data, with 2nd order conversion defined as:

\[
\text{Conversion: 2nd Order} = \frac{\text{wt\%Conversion}}{100 - \text{wt\%Conversion}}
\]

The use of the 2nd order concept has several advantages.

1) Correlating 2nd order conversion against C/O provides a nearly linear fit of the data (8), particularly in the conversion range from 0 to 80-85%
2) The linear relationship readily encompasses the low conversion point at zero C/O.

3) The 2\textsuperscript{nd} order concept provides a more useful spread of the conversion data, with the data points being compressed at the low conversion range, while the data points at the high conversion range spread apart. For example, on a 0-100\% conversion scale, the distance between 33 and 50\% conversion seems quite large, whereas on the 2\textsuperscript{nd} order scale it is only \(\frac{1}{2}\) a number (the difference between 0.5 and 1.0). Likewise the difference between 75 and 80\% conversion on the 0-100 scale seems relatively small, while on the 2\textsuperscript{nd} order scale it is a whole number (the difference between 3.0 and 4.0).

4) Since the values at low conversion are compressed, the exact 2\textsuperscript{nd} order intercept value at zero C/O is not critical in defining the correlation anchor point. For example, if the conversion at zero C/O is 30 wt\% rather than 25 wt\%, the 2\textsuperscript{nd} order value only changes from 0.33 to 0.43, a trivial difference on the conversion vs. C/O plot.

Figure 1 illustrates the technique, using data from a typical three catalyst comparison test done in UOP’s ACE unit for a constant feed case. The data for Catalyst A and Catalyst B show little experimental error and provide reasonable linear fits, which define the zero Cat/Oil intercept. The data for Catalyst C have considerable experimental error.

![Figure 1: Cat/Oil Effect Upon Conversion](image)

A linear fit through the intercept determined by Catalysts A & B gives the best representation of the Catalyst C data.

**Correlating Yield Data**

Of considerable interest in comparing catalyst performance is the comparison of catalyst selectivity, i.e., the comparison, between catalysts, of a particular product yield at a given conversion. For many of the products produced in catalytic cracking, 2\textsuperscript{nd} order conversion is a better correlating parameter than actual conversion in evaluating the effect of conversion on product yield.

The benefits of 2\textsuperscript{nd} order conversion here are similar to the benefits found in the correlation of C/O ratio vs. conversion.

1) In many cases, 2\textsuperscript{nd} order conversion provides a much more linear fit of the yield data.
2) 2\textsuperscript{nd} conversion compresses the conversion scale at the low conversion region and allows the use of the 0\% conversion point to be conveniently included in the relationship. The 0\% point is the most reliable point in the set of data.

**Coke Selectivity**

For the more common conversion ranges (in the range of 75 wt\% or lower – 2\textsuperscript{nd} order conversions of 3 or less), coke yield has a nearly linear relationship, as typified by ACE unit data in Figure 2.

![Figure 2](image-url)

As noted in Figure 2, the coke yield at zero conversion, as determined by extrapolation, is a common value for all low metals contaminated catalysts in a constant feed study, but is not zero. The intercept appears to be related to the Conradson carbon (also designated as the carbon residue) of the feed. Typically the intercept is in the range of 50 –75\% of the Conradson carbon value. It is believed that this high molecular weight feed material deposits nearly instantaneously on the catalyst as a result of the thermal shock when feed first contacts hot catalyst. This shock creates a pulse of coke yield before any other significant conversion occurs. This coke pulse provides the offset noted in the coke vs. conversion plot.

**Dry Gas Selectivity** (Hydrogen, Methane, and Ethane + Ethylene)

As with the coke data, the use of the 2\textsuperscript{nd} order conversion values to correlate dry gas yields provides a more useful means of correlating the data. A linear correlation exists in the lower regions of conversion and the intercept at zero conversion provides a fixed point to anchor the correlation. Also, as with the coke data, the zero conversion intercept is not at 0\% dry gas yields. The nearly instantaneous
thermal shock at the point of contact with the hot catalyst provides a dry gas yield offset, as it does with the coke yield. This is illustrated in Figure 3, using data from the testing of Catalyst B.

**Figure 3**  
ACE Dry Gas Data - Catalyst B

![Graph showing LPG correlations](image)

**LPG Correlations**

For all the LPG yields, it is reasonable to assume that at zero conversion there is zero yield of these products. Thus any correlation of the yields of these products should pass through the point: zero yield at zero conversion. As seen in the subsequent sections, the inclusion of the (0,0) point helps significantly in defining the yield/ conversion relationship.

**Propane, n-Butane and i-Butane**

The use of 2nd order conversion gives linear plots that pass through the origin for propane, n-butane, and i-butane yields. For propane, the yield – conversion relationship is obtained via a computer generated least squares regression passing through the data points and the origin, as seen in Figure 4.
**LPG Olefins – Propylene and Butylenes**

In correlating the LPG olefins, zero yield at zero conversion again provides a fixed data point which helps define the relationship. The use of 2\textsuperscript{nd} order conversion helps to compress the conversion scale at the low conversion range so that the zero point can be a useful anchor. However, 2\textsuperscript{nd} order conversion no longer provides a linear relationship, as it did with propane and n-butane, since the olefinic products participate in secondary reactions and thus tend to go through a maximum at high conversion. The data are now nicely represented by a 2\textsuperscript{nd} order polynomial. This type of least square
regression going through the origin is shown in Figure 5 for propylene.

A common error in correlating these data is to ignore the requirement that the relationship must go through the (0,0) origin. Figure 6 illustrates the nonsensical plots that occur if the data are regressed without including the origin as a fixed point.

![Figure 6 Effect of Conversion on Propylene Yields - ACE Data Correlations Do Not Go Through the Origin](image)

**Correlating Gasoline Data**

The gasoline product is typically defined as that material boiling in the n-pentane to n-dodecane range and referred to as the material in the C\textsubscript{5} – 221ºC TBP product fraction. By definition, conversion is the sum of all the gasoline and lighter products plus coke:

\[
\text{Conversion} = \text{Gasoline} + \Sigma \text{C}_4^- + \text{Coke}
\]

Thus the gasoline yield can be defined as:

\[
\text{Gasoline} = \text{Conversion} - (\Sigma \text{C}_4^- + \text{Coke})
\]

Since the relationship with conversion for all the C\textsubscript{4}− products has been established in the previous sections, those values can be used to define the correct gasoline relationship. This approach to obtain the gasoline relationship is illustrated for Catalyst A.

For Catalyst A, the following regression equations for the product yields, in wt\%, were obtained as:

<table>
<thead>
<tr>
<th>Component</th>
<th>Yield – wt%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coke</td>
<td>1.4538X + 0.20</td>
</tr>
<tr>
<td>\text{H}_2</td>
<td>0.0216X + 0.0425</td>
</tr>
<tr>
<td>Methane</td>
<td>0.1399X + 0.3354</td>
</tr>
<tr>
<td>Ethane + Ethylene</td>
<td>0.1673X + 0.859</td>
</tr>
</tbody>
</table>
Component | Yield – wt%
--- | ---
Propylene | \(-0.6864X^2 + 4.7667X\)
Propane | \(0.422X\)
n-Butane | \(0.315X\)
i-Butane | \(1.4567X\)
i-Butylene | \(-0.4825X^2 + 2.3586X\)
n-Butylenes | \(-0.663X^2 + 4.0906X\)

For all of these relationships, \(X = 2\)\(^{nd}\) order conversion.

Using these relationships, the gasoline yield over a range of conversions can be determined by difference. Table 1 illustrates this approach, using conversions at 50, 66.7, 75, and 80 wt% (1.0, 2.0, 3.0, and 4.0 \(2^{nd}\) order conversion). The individual yields at these conversions are shown in the table. The gasoline yield at these conversions is then obtained by subtracting the sum of these products from the related conversion.

**Table 1**
Gasoline Yields for Product A – ACE Catalyst Testing
Obtained by Difference from Product Yields for Catalyst A

<table>
<thead>
<tr>
<th>Conversion – wt%</th>
<th>50.0</th>
<th>66.7</th>
<th>75.0</th>
<th>80.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion – (2^{nd}) Order</td>
<td>1.00</td>
<td>2.00</td>
<td>3.00</td>
<td>4.00</td>
</tr>
<tr>
<td>Product Yields – wt%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coke</td>
<td>1.65</td>
<td>3.11</td>
<td>4.56</td>
<td>6.02</td>
</tr>
<tr>
<td>(\text{H}_2)</td>
<td>0.064</td>
<td>0.086</td>
<td>0.107</td>
<td>0.129</td>
</tr>
<tr>
<td>(\text{C}_1)</td>
<td>0.48</td>
<td>0.62</td>
<td>0.76</td>
<td>0.89</td>
</tr>
<tr>
<td>(\text{C}_2 + \text{C}_3)</td>
<td>1.03</td>
<td>1.19</td>
<td>1.36</td>
<td>1.53</td>
</tr>
<tr>
<td>(\Sigma) Dry Gas</td>
<td>1.57</td>
<td>1.90</td>
<td>2.23</td>
<td>2.55</td>
</tr>
<tr>
<td>(\text{C}_3)=</td>
<td>4.08</td>
<td>6.79</td>
<td>8.12</td>
<td>8.08</td>
</tr>
<tr>
<td>(\text{C}_3)</td>
<td>0.42</td>
<td>0.84</td>
<td>1.27</td>
<td>1.69</td>
</tr>
<tr>
<td>(\Sigma) (\text{C}_3)s</td>
<td>4.50</td>
<td>7.63</td>
<td>9.39</td>
<td>9.77</td>
</tr>
<tr>
<td>(\text{nC}_4)</td>
<td>0.31</td>
<td>0.63</td>
<td>0.94</td>
<td>1.26</td>
</tr>
<tr>
<td>(\text{iC}_4)</td>
<td>1.46</td>
<td>2.91</td>
<td>4.37</td>
<td>5.83</td>
</tr>
<tr>
<td>(\text{iC}_4)=</td>
<td>1.88</td>
<td>2.79</td>
<td>2.73</td>
<td>1.71</td>
</tr>
<tr>
<td>(\text{nC}_4)=</td>
<td>3.43</td>
<td>5.53</td>
<td>6.30</td>
<td>5.75</td>
</tr>
<tr>
<td>(\Sigma) (\text{C}_4)s</td>
<td>7.08</td>
<td>11.86</td>
<td>14.34</td>
<td>14.53</td>
</tr>
<tr>
<td>(\Sigma) (\text{C}_4) – Coke</td>
<td>14.80</td>
<td>24.50</td>
<td>30.52</td>
<td>32.89</td>
</tr>
</tbody>
</table>

\[\text{Gasoline} = \text{Conv} – (\Sigma\text{C}_4\) + Coke\]

| | 35.20 | 42.17 | 44.48 | 47.11 |
As with all the previous yield correlations, a reliable correlation of the gasoline data must include the gasoline yield at zero conversion. Thus, in Figure 7, the gasoline vs. conversion points (small dots) are combined with the (0,0) point to develop the gasoline relationship shown in Figure 7. Also shown in Figure 7 are the ∆, ●, and ■ data points representing the experimental gasoline yield data points for Catalysts A, B, and C respectively, which, as expected, closely agree with the line obtained by differences.

Since gasoline is an intermediate product, which cracks to lighter products, the gasoline yield typically goes through a maximum at high conversion.

![Figure 7](image)

**LCO Yields (430° to 650°F TBP Cut)**

When correlating light cycle oil (LCO) yields versus conversion, consideration needs to be taken for the LCO yield at both zero conversion and 100% conversion. Generally, there is some LCO in the feed, i.e., that material in the feed boiling below the defined initial boiling point of the material defined as “true feed”. “True Feed” is typically defined as material boiling above 650°F (343°C). The feed in this study contained 8% of material boiling below 650°F. Thus at 0% conversion, 8% of the feed was already LCO. The 0% conversion intercept for this study is thus 8%, which becomes a fixed point on the LCO plot.
The conventional definition of FCC conversion is given as:

\[
\text{Conversion} = 100 - (\text{LCO} + \text{HCO})
\]

At 100% conversion, the LCO yield, by definition, is therefore zero. Thus, the LCO yield versus conversion has a second fixed point of 0% at 100% conversion.

2nd order conversion is not a convenient parameter to use when plotting LCO yields. As conversion approaches 100%, 2nd order conversion approaches infinity, which makes its use impractical. The plot of LCO conversion vs. standard conversion is shown in Figure 8.

![Figure 8: Effect of Conversion on Light Cycle Oil Yields](image)

Heavy Cycle Oil Yields (650°F+ TBP Cut)

By convention, the heavy cycle oil (HCO) yield is defined as the amount of material in the liquid product boiling above 650°F (343°C). As mentioned above, the feed for this study contains 8% LCO (8% boiling below 650°F) and thus at zero conversion, there is only 92% boiling above 650°F, hence only 92% HCO. This becomes a fixed point on the HCO yield vs. conversion plot.

As with LCO, the definition of conversion requires the HCO yield to be 0% at 100% conversion. This becomes a second fixed point on the HCO yield vs. conversion plot. The resulting HCO yield plot is seen in Figure 9.

Because the HCO scale covers a much wider range (0 – 100 wt%), the differences between catalysts at any given conversion is sometimes hard to discern in these plots. For example, in Figure 9, it
is difficult to see that the HCO yields for Catalyst A lie between the HCO yields for Catalyst B and the HCO yields for Catalyst C. As an alternative, the HCO yields, at any given conversion, can be determined from the LCO plots in Figure 8, using the relationship:

\[ \text{HCO} = \text{Conversion} - \text{LCO} \]

**Figure 9**

*Effect of Conversion on Heavy Cycle Oil Yields*

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**How to Compare Catalyst Test Results**

Having completed the testing of a series of catalyst, the question then becomes: How best to compare the results from different catalysts to arrive at a decision as to which catalyst best meets the requirements of the intended refinery.

One school says that results should be compared at constant conversion. Another group says -- no, no -- commercial FCCU operations are heat balanced and thus results should be compared at constant coke make.

The constant coke argument has some intuitive appeal, but would only be true if the type of coke measured in the laboratory test was the same type of coke obtained in a commercial FCCU. To settle this argument, it is necessary to consider some basic concepts related to coke formation.

The coke on catalyst prior to regeneration is a combination of two components.

\[ C_{\text{On Cat}} = C_{\text{Hard Coke}} + C_{\text{Soft Coke}} \]

1) Hard coke is the catalytically produced coke. This highly carbonaceous material, containing only 3-4 wt% hydrogen, is firmly attached to the acid sites present on the zeolite and on the active
matrix components of the catalyst, and is a result of the cracking reactions that took place on the catalyst. The hard coke is essentially unaffected by stripping.

2) Soft coke, itself, consists of two components:
   a) Hydrocarbons lightly adsorbed on the surface of the larger entrance pores (the macropores) of the catalyst and on the external surface of the catalyst particle. Adsorbed soft coke is sometimes referred to as “extractable” coke, since it can be removed from the catalyst in a laboratory test by extracting it with a solvent, such as carbon tetrachloride.
   b) The hydrocarbons that are in the vapor space in the catalyst pores and between the catalyst particles.

   The combined hydrogen content of these two soft coke components is in the range of 11 – 12 wt%.
   The quantity of this soft coke material is strongly influenced by stripping conditions, the better the stripping, the less soft coke.

   After the catalyst has been exposed to the hydrocarbon feed, it is stripped with steam or nitrogen in both the commercial FCCU and in the laboratory cracking tests to reduce the amount of carbonaceous material on the catalyst, prior to regeneration. Under the very severe stripping conditions which exist in the laboratory test (typically a stripping time of 10 – 15 minutes), the material remaining on the catalyst after stripping is essentially all hard coke.

   Commercial stripping, however, is much less intensive, with stripping times typically in the range of 30 – 45 seconds. As a result, in addition to the hard coke going to the regenerator, a significant amount of soft coke is also present in the coke going into a commercial regenerator. The amount of soft coke going to a commercial regenerator will depend upon the stripper conditions, but typically is in the range of 25% of the total coke. The hydrogen content of the coke in a commercial, well stripped FCCU, is typically around 6 wt%, reflecting the presence of both hard and soft coke.

   Since the type of coke measured in the laboratory tests is different from the type of coke occurring commercially, both testing concepts (constant conversion or constant coke) are wrong. Since the coke produced in the laboratory test is only hard coke, the comparison must take this into consideration. This is illustrated in Figure 10.
For the demonstration case shown above, using a hypothetical data set, where the base case and a proposed new catalyst have equal activity but different coke selectivity characteristics, i.e., the same conversion at a given C/O, but different product yields, the base case has a hard coke yield of ~5.0 wt% (Point 1) at 74% conversion. The new case has a lower hard coke yield of ~3.6% (Point 3) at 74% conversion.

For constant stripping conditions, yielding a constant amount of soft coke, the lower hard coke yield would result in a lower total coke yield at constant conversion. In commercial operations, to stay in heat balance (constant coke yield), the catalyst circulation rate would have to increase, increasing conversion to provide the necessary increase in hard coke and soft coke. Thus constant conversion is not correct. For a proper comparison, the new catalyst would have to run at a somewhat higher C/O and somewhat higher conversion than constant conversion would dictate.

The constant hard coke comparison of the two catalysts is equally faulty. If one catalyst produces less hard coke than the other at constant conversion, constant hard coke would have to be achieved by increasing the conversion, via an increase in C/O, i.e. going from Point 1 at 74% conversion to Point 2 at 83% conversion.

However, since increasing C/O also increases soft coke in a commercial operation, the total coke yield in a commercial operation at 83% conversion would exceed the base case coke yield. Thus, to achieve a constant coke yield in a heat balance operation, the hard coke in the more selective case would have to be less than the base case hard coke, not equal. The proper laboratory comparison would require that the new catalyst case would have to run at a somewhat lower C/O and somewhat lower conversion than a total hard coke comparison would require.
Thus the proper comparison of laboratory data for the two catalysts lies somewhere in-between the conversion required for constant conversion and the conversion required for constant coke, starting from the base case conversion and coke.

Since the hard coke is typically ~ 75% of the total coke, at a constant total coke yield (as dictated by the heat balance), the actual change in hard coke would only be ~75% of the coke change required to bring the ACE or MAT result to a constant coke level. Thus the proper conversion for the catalyst comparison is at the conversion that gives that 75% ACE or MAT coke change.

This point is also illustrated in the example in Figure 10. The new catalyst at 74% conversion has a hard coke yield of 3.6%, which is 1.4 wt% lower than the 5.0% hard coke yield of the old base catalyst. The actual coke yield of the new catalyst, for comparison purposes should then be 3.6 + 0.75(1.4) = 4.6. At 4.6 wt% coke yield, the new catalyst conversion is ~ 81 wt% (point 4 in Figure 10), which is the conversion to use to compare product yields of the new catalyst with yields from the base catalyst at 74 wt% conversion.

**Conclusion**

A simple procedure is described, that provides reliable correlations of small scale laboratory FCC test results, even though there may only be a very limited amount of data and the data may be badly scattered.

The method uses the yield of the individual products at zero conversion as an anchor point through which the regressed data for each product yield must pass. In these regressions, the anchor point at zero conversion is not necessarily 0 wt%, and techniques are disclosed as to how to position such anchor points. For the correlation of LCO and HCO yields, an additional anchor point of 0 wt% at 100% conversion is also applied.

The coke yield, and all the hydrocarbon yields of the C4 and lighter products are correlated against second conversion. For many of these products, second order conversion provides a linear correlation with product yield.

Gasoline yield is obtained by difference, using the relationship:

\[
\text{Gasoline} = \text{Conversion} - (\text{Coke} + \Sigma \text{C}_4) \]

Since the laboratory tests and commercial unit operations have fundamentally different coke yields, a new method is proposed to allow for the interpretation of laboratory test results at conditions relevant to potential commercial FCC unit operations. This procedure facilitates the accurate comparison of various catalysts and their potential commercial cracking performance.
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