# Using Additives For Real Time FCC Catalyst Optimization

**Martin Evans, C.Eng. FIChemE**
***Director of Technical Service***

*INTERCAT Inc.*
*PO Box 412, Sea Girt, NJ, 08750 USA*
*E-mail: info@intercatinc.com*

## Introduction

The FCC unit has long been considered the heart of a high conversion modern refinery due to its unique capability of processing a wide range of feedstocks under an equally wide range of process conditions. The FCC unit has matured in terms of control systems over the past six decades with most units now being operated under advanced distributed control systems. Additionally, many units are also equipped with multiple online analyzers and kinetic based simulators all designed to integrate with the control systems to maximize unit profitability. One striking exception to this trend is found in an independent variable which has remained elusive in terms of online, real-time optimization: *the composition of the FCC circulating inventory*.

For very good reasons, most refiners limit catalyst evaluations to once every 2 to 3 years. Thorough testing and selection of catalyst technology is typically a medium to long-term process requiring dedicated laboratory equipment and as much as six months or more before decisions can be finalized. The FCC unit however responds to feedstock variation and operating changes in a matter of hours. The ease of catalyst additions combined with the equilibrium nature of the circulating inventory make the FCC unique among all refining processes in terms of real-time optimization. However, the ability to actually optimize the circulating inventory composition remains an attractive yet allusive independent variable potentially providing an additional degree of freedom in the maximization of FCC profitability. **Figure 1** demonstrates the actual variability of feedstock composition in a typical North American refinery. As the feed composition shifts, the aggressive refiner may easily fine-tune the circulating inventory composition.

Two factors have discouraged most refiners from attempting to optimize their circulating catalyst inventory composition in real time: the first limitation being hardware related (multi-component addition systems & catalyst hoppers) and the second limitation being the catalytic components themselves. Most operating units today are equipped with one fresh catalyst hopper and possibly one additive addition system added to the unit subsequent to startup. Significant advances have recently been made in both catalyst and additive addition technology and catalytic technology which now combine to make possible the real-time, online optimization of the FCC circulating inventory. This paper presents a viable solution to this little considered challenge which is both commercially proven and simple to implement.

## Additive Systems

Intercat has developed a full range of automated, state-of-the-art catalyst and additive addition systems. These systems are the most widely accepted addition system technology currently available in the refining industry with more than 250 Intercat additive systems currently in use around the world. These systems deliver excellent control and reliability to ensure that the exact amount of additive that is targeted is actually added to the units in small consistent shots throughout the day. These units are equipped with feedback control systems to ensure that the targeted addition levels are actually achieved. The hallmark of these systems has been their high accuracy, reliability and low maintenance.

Intercat has developed multiple compartment catalyst & additive hoppers capable of accurately dosing three separate materials into an FCC unit simultaneously. These systems deliver to the refiner the ultimate level of flexibility and control with respect to catalyst additions.

Intercat loaders present multiple advantages for the innovative refiner choosing to eliminate bottlenecks limiting maximum operating flexibility. The most obvious of these include the capability to begin optimizing the FCC circulating inventory in real-time. These loaders provide refiners the capability add an additional degree of freedom to the operation of their units. Specifically, the circulating catalyst composition can be manipulated with the same degree of precision as preheat or riser outlet temperatures. Furthermore, refiners are capable of achieving precision additions from nonstandard containers such as tote bins or supersacks enabling multi-component catalytic system trials without the necessity to first invest in hopper capacity.

The end result will be a system designed to deliver both the capacity and capability to begin manipulating circulating inventory compositions. This can be achieved via a combination of Intercat's wide range of catalyst component technologies designed to maximize refinery profitability together with state-of-the-art catalyst and additive addition technology.

## FCC Circulating Inventory Optimization

Very few refiners in the 60+ years of FCC operations have ever had the capability to manipulate the composition of their circulating beyond the simple addition of a single additive, such as ZSM-5. The addition system technology described above represents a substantial step forward in operating freedom for the FCC unit operator. This new flexibility will prove most beneficial for those units experiencing a wide range of feed qualities &/or faced with rapidly changing market economic conditions.

The capabilities being presented to refiners in this paper are both far-reaching and profound. They include the capability to simultaneously inject a high accessibility, active aluminum technology (BCA-105 & BCA-110) for maximum slurry conversion, a high zeolite bearing additive (Hi-Y) for activity enhancement, a metal trapping component (Cat-Aid) to enable higher metal bearing feedstocks to be run on the FCC, and finally, ZSM-5 based technologies (PentaCat-HP, Super-Z, etc.) for maximum propylene production. These technologies are enabling factors allowing the aggressive refiner to maintain their time proven catalyst selection protocols while at the same time optimizing the circulating inventory composition between these changes to accommodate changes in feed slate, operating conditions and market demands.

## FCC Catalyst Selection

The most common methodology used by the leading refiners today is the selection of an FCC catalyst based upon the most common feedstock through testing in an Ace unit &/or pilot plant to verify potential yield and activity advantages. This has been an extremely successful technique for several decades. However, the possibility for a paradigm shift now exists and is demonstrated through the following figures.

**Figure 2** illustrates an "ideal case" of a North American refinery which runs an unusually stable feed slate. This refinery will respond well to standard catalyst selection protocols. However, there still remains an opportunity for this refiner to improve profitability. This data set represents 5 1/2 years of operations. This refinery ran feed densities between 0.913-0.916 86% of the time. This leaves 14% of its operations (9 1/2 months) above or below the mean gravity level. This somewhat non-typical feed operation represents an opportunity for this refinery for further optimization through fine tuning of the circulating inventory composition.

**Figure 1** illustrates a more typical refining situation represented by an East Coast United States refinery which processes three primary crude stocks. This refinery ran 67% of the 1.5 year span of operations within a typical feed slate represented by a density ranging from 0.91 to 0.92. It is noteworthy that more than one third of its operations (> 6 months) are operated outside this normal band range. It is this period of operations that presents an opportunity for the aggressive refiner to improve yield selectivities through controlled optimization of the circulating inventory composition

**Figure 3** illustrates a more extreme yet not atypical East Coast North American refinery which regularly charges opportunity crudes available at discounted pricing. Subsequently, this refinery may likely be the most profitable of the three examples presented here. The standard catalyst selection protocols will result in one catalyst to be utilized for all feedstocks. The challenge for this operator is the selection of the proper base feed for the catalyst selection study. A logical choice may be a feedstock having a feed density of approximately 0.893. However, this represents $\leq$ 50% of the 100 day run demonstrated below. This will immediately lead to the realization that 50% of the operations will likely be far from optimal.

## Paradigm Shift: Real-time, Online Circulating Inventory Composition Control

The recommended catalyst selection procedure is one in which a relatively long period of operations is selected for feed slate analysis. A histogram analysis plotted as a Pareto chart (as presented in figures 1-3) will quickly identify the most common feedstock to be used as "base case". Additional catalytic technologies are then injected into the unit on an "as needed" basis. The most logical components are described below:

- Bottoms Cracking Technology. A highly accessible, alumina-based catalyst is injected into the unit when the feedstock becomes substantially heavier than the "base case" feed. This component ensures that the unit will continue to upgrade high molecular weight, sterically hindered feedstocks into motor fuels and lighter. Intercat supplies a full range of Bottoms Cracking Additives (BCA-105 & BCA-110) which give the refiner the ability to convert most difficult feeds into motor fuels or lighter products. One example of a refiner potentially benefiting from this technology is shown in **Figure 4** below. This refinery occasionally runs a high nitrogen feedstock which requires robust, highly accessible alumina-based technology for optimal upgrading into LCO and lighter fuels. A commercial example is shown in **Table 1**.
- Ultrahigh Y-Zeolite Technology. A high activity, high zeolite bearing catalyst is injected into the unit when the feedstock becomes lighter than normal. Light feedstocks typically respond best to higher intrinsic activity zeolite based catalysts than to the more stable medium to low zeolite-to-matrix ratio catalytic systems. Intercat supplies a unique product which is composed of a particle containing an ultrahigh level of "Y" zeolite technology. This technology is especially well-suited for those refineries which occasionally run very light or heavily high treated feedstocks. Such feedstocks typically demand high activity and show little response to high stability catalyst technologies. This case can be demonstrated in **Figure 5** which illustrates a refinery which runs opportunity light crudes approximately 16% of the time. These feedstocks will respond most readily to additional zeolitic-based activity. A commercial example is shown in **Table 2**.
- Enhanced Metals Tolerance. Heavy residue feedstocks are typically available at reduced cost to the refiner. However, specialized catalytic technology is required to be able to operate effectively in a high vanadium environment. Intercat supplies an extremely effective additive, CatAid, which has proven itself repeatedly as an additive capable of absorbing vanadium in its most destructive, highest oxidation states. When added to the FCC unit, this technology enables the progressive refiner the ability to run the poorest quality feeds available with little

or no increase in base catalyst consumption. This capability is illustrated in **Figure 6** below. This eastern United States refinery experienced nearly immediate results in the form of a two wt% increase in conversion at constant vanadium level together with a 7% (relative) drop in delta coke from 0.77 to 0.72 wt% when using CatAid.

- Maximum Propylene Additives. Intercat manufactures and supplies the industry's leading quality small pore zeolites designed for maximizing propylene yields and gasoline octane. These additives have a long track record of maximizing refinery profitability against operating constraints.

The successful implementation of the strategy introduced above is contingent upon a thorough understanding of the base catalysts capabilities, and it's limitations. It is recommended that the refinery quantify the key feed qualities at which the base catalyst begins to become constrained (density, CCR, vanadium levels, etc.). A histogram analysis of the percentage of time the FCC operates beyond these constraints will define the value of utilizing additional catalytic components. It is suggested that simple laboratory testing be carried out with these constraining feedstocks together with the base catalyst plus additive at varying compositions to determine yield selectivities and appropriate addition rates. This laboratory testing should be then followed up by commercial step tests on the unit itself. Kinetic modeling may also be utilized to develop centroid-based models for inclusion in the refinery linear model. This will enable full incorporation of this technology into the refinery's crude selection process. Finally, Intercat's catalyst & additive addition systems can be controlled locally or from the FCC control room thus affording the FCC operator complete control of the addition process.

## A New FCC Paradigm Shift: Online, Real Time Catalyst Optimization

The inclusion of a state-of-the-art catalyst & additive loading system will enable the aggressive refiner to incorporate the optimization of the FCC catalyst circulating inventory as an additional independent variable to their control schemes [1,2]. Such refiners will then possess the capability of fine tuning cracking capabilities in real time as needed based upon feed slates and market demands. Such a refiner will be able to maintain its time proven base catalyst selection protocols while adding the capability of fine tuning cracking capabilities as needed on a day by day basis. Each of the four additive technologies described above have been rigorously tested in commercial operations and have proven their capability of fine tuning yield selectivity's and unit profitability.

## Conclusion

Very few refiners during the past 60+ years of operating experience have had the ability to treat their FCC circulating inventory as an independent variable. Intercat has developed a full line of catalyst and additive loading systems with a degree of precision and reliability previously unseen in the industry. These loaders, enable not only the highest level of injection precision, but also allow the refiner to manipulate circulating inventory composition via multi-component loading systems.

Additionally, Intercat has developed a complete line of commercially proven technologies giving every refinery the capability to fine tune its circulating inventory with additional zeolite, additional bottoms cracking functionality, enhanced contaminant metals tolerance and maximum propylene producing capabilities.

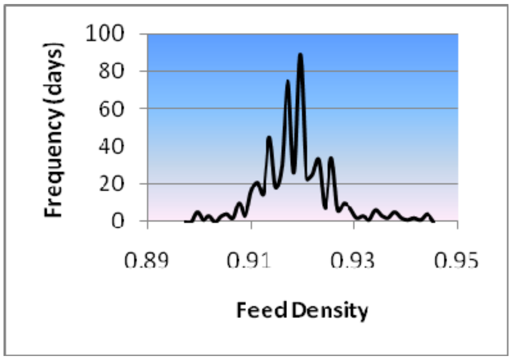

Figure 1: Typical Refinery Feedstock Variation

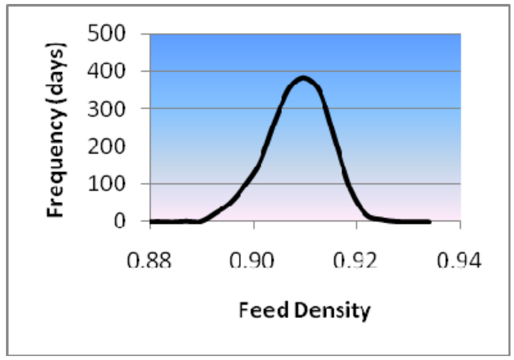

Figure 2: Highly Ideal Feed Slate

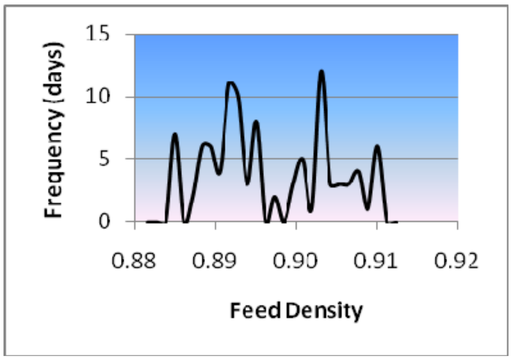

Figure 3: Refinery Charging Opportunity Feedstocks

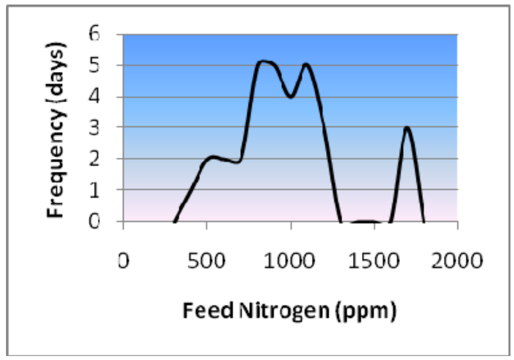

Figure 4: Refinery Benefiting From BCA Technology

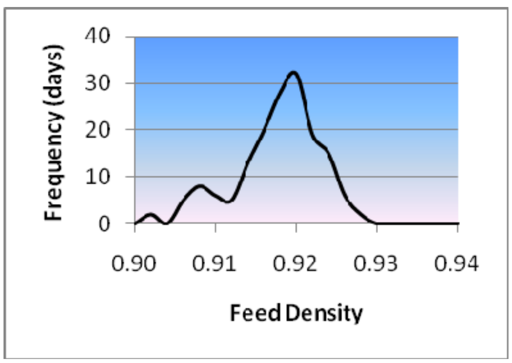

Figure 5: Refinery Benefiting From Hi-Y Technology

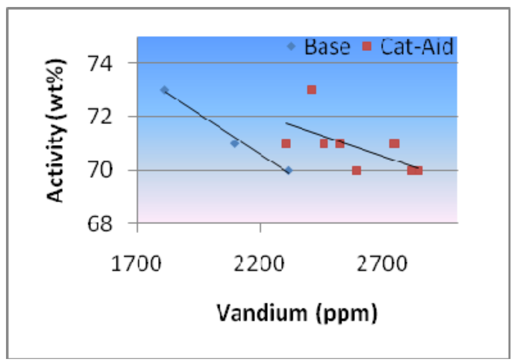

Figure 6: Refinery Benefiting From Cat-Aid Technology

**Table 1: BCA Commercial Experience**

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

**Table 2: Yield Benefits of Hi-Y**

| | Base Case, wt% | Hi-Y, wt% | Delta |
|---|---|---|---|
| **Hi-Y Addition, %** | 0 | 7 | |
| **Conversion** | 64.1 | 66.6 | +2.5 |
| **Drygas** | 4.6 | 4.6 | 0.0 |
| **LPG** | 10.7 | 12.0 | +1.3 |
| **Naphtha** | 42.6 | 43.6 | +1.0 |
| **LCO** | 24.7 | 23.8 | -0.9 |
| **Slurry** | 11.2 | 9.6 | -1.6 |
| **Coke** | 6.3 | 6.3 | 0.0 |