TECHNOLOGY

Catalyst Feature

Optimizing the FCC Catalyst Circulating Inventory

Despite the continual improvement in terms of productivity and profitability of the FCC unit, one aspect of the process, the composition of the FCC catalyst circulating inventory, has not been studied or analysed with the same level of scrutiny. This paper makes a study of this aspect of the FCC unit.

The FCC unit has progressed through a history of over 65 years of continual optimization and improvement. Substantial attention has been placed upon limiting the variability of the process through feedback, and in some cases, feed forward control loops. This has resulted in a level of stability and profitability far surpassing many contemporary industrial chemical processes. 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 catalyst circulating inventory*.

For very good reasons, many refiners generally limit catalyst evaluations to once every two to three 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 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.

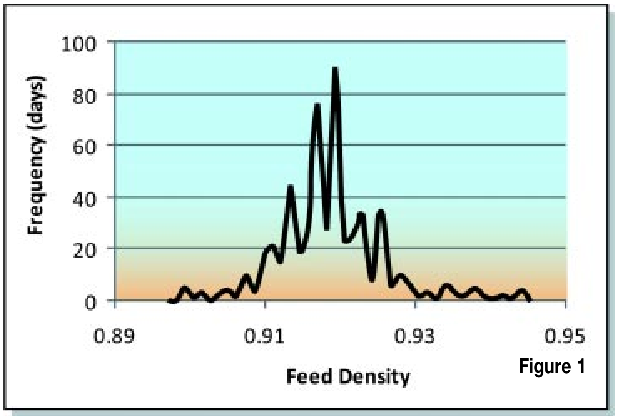


Figure 1

In addition to feedstock variation, today's FCC operator faces an increasingly dynamic market sometimes subject to significant volatility. Many fuel markets are observing a transition in which diesel is being favored over gasoline. Propylene markets continue to evolve seemingly from week to week. The refiner which blends ZSM5 additive into their base catalyst will often times be at a competitive disadvantage to the competitive refiner which injects "on-demand" as the market demands. The ability to alter product slates with dexterity may determine, in the long run, which refineries are profitable vs. marginal. The ability to control the circulating catalyst inventory in real time will be an additional enabling factor allowing rapid response to market demands.

Two factors have eliminated the possibility for most refiners 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 in catalyst and additive addition technology, and catalytic technology, have been achieved which now permit the real-time, online optimization of the FCC circulating inventory. This paper presents a viable solution to this often overlooked independent variable which is both commercially proven and simple to implement.

Overcoming Existing Technology Barriers

The two barriers preventing implementation of real-time FCC catalyst circulating inventory control are related to hardware and the long lead times necessary for catalyst selection. These two barriers are described below.

The Catalyst Evaluation Barrier

A significant barrier to the implementation of online, real-time FCC catalyst circulating inventory control is the long evaluation time required for the minimum risk catalyst selection procedures currently in place among most refiners. An example of a typical catalyst selection protocol in terms of timing is demonstrated in Table 1. This table demonstrates that for most refineries the catalyst selection procedure can require up to 50 weeks from the time of issuing bid requests until the new catalyst formulation selectivities have been achieved. The time impact of each element of the standard procedure is described below.

1. Bid & Sample Preparation. Typically four to five weeks are required for catalyst suppliers to develop yield projections, terms of supply and the delivery of a catalyst sample for laboratory.
2. Laboratory Testing. Laboratory testing remains one of the most critical steps in the selection procedure in terms of both catalyst evaluation but also in terms of the time requirement. This step can require 10-14 weeks for completion depending upon the availability of laboratory hardware and manpower.
3. Evaluation. Two to three weeks will typically be required for the refinery to analyze the results of laboratory testing together with the commercial offer before a decision can be reached. Many times, kinetic modeling is required to accurately assess the profitability of each catalyst sample in the operating unit.
4. Negotiation. An additional two to three weeks will often be required for negotiation with potential suppliers prior to reaching a final decision.
5. Production Scheduling. Today's FCC catalyst suppliers operate extremely complex manufacturing processes which often require careful planning prior to the manufacture of each formulation. Some time will be required for the manufacturer to actually schedule and produce the agreed-upon formulation after agreement has been. This may require two to three weeks before production is completed.
6. Inventory Management. Most catalyst suppliers maintain a strategic stock of up to 50 tons of fresh catalyst for each customer within their manufacturing plant. There may exist FCC catalyst in transit to the refinery depending upon the size of the FCC unit and its distance from the manufacturing plant. Finally, many refiners will maintain 50 to 75 tons of catalyst in their fresh catalyst hopper which will also need to be consumed prior to charging the new formulation. An additional 10-14 weeks may be required for the consumption of this material.
7. 50% Change Out. Finally, time will be required once the new formulation begins to enter into the FCC unit before the selectivity changes will be observed. For most units, selectivity changes begin to become measurable at about 35% change out and typically the selectivity shifts are fully present at about 50% change out. Depending upon the unit inventory and the catalyst addition rate this may require an additional 10-12 weeks.

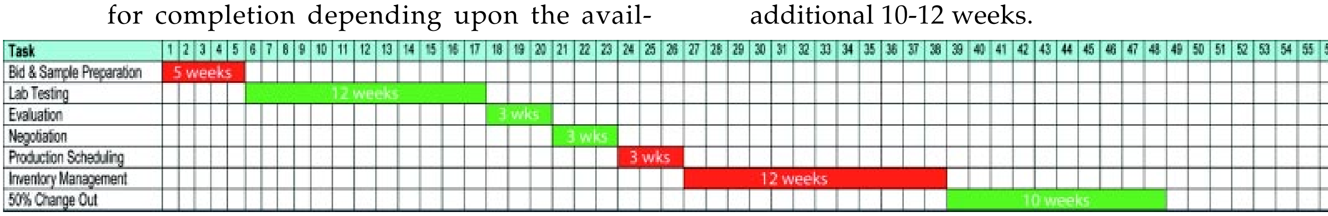


Table 1

In summary, from the point in time in which the refiner decides to improve its catalyst formulation until the point that the unit is 50% changed out to the new formulation may take 40-50 weeks for completion. The operating unit however responds to feedstock changes in a matter of hours while the fuels market is dynamic and typically changes weekly. The ability for a refiner to manipulate its FCC catalyst circulating inventory will remain a significant variable impacting profitability.

The ability to optimize the circulating inventory with dexterity is possible with the combined use of multi-source catalyst loading systems together with FCC additives. A limited example of this approach which is already being applied in many refineries is the use of ZSM-5 to increase the propylene producing capability of the base catalyst.

Several catalytic components are currently available to refiners today as enabling technologies. These include the capability to simultaneously inject a high accessibility, active aluminum technology (BCA-105) 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, ZSM5 based technologies (PentaCat, PentaCat Plus, 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 to accommodate changes in feed slate, operating conditions and market demands.

The Catalyst & Additive Hardware Barrier

Intercat has developed a full line of automated, state-of-the-art catalyst and additive addition systems. These systems are the most widely accepted addition systems 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 catalyst or 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 (see Table 2). The standard precision observed with Intercat loaders is typically a 99% plus approach to target. This is observed for both fresh catalyst and additive addition systems.

	Product	Target	Actual	Delta	Accuracy
Example #1	Catalyst	10323	10302	-21	99.8
Example #2	Catalyst	3025	3002	-23	99.2
Example #3	Catalyst	2557	2525	-32	98.7
Example #4	Catalyst	1622	1616	-6	99.6
Example #5	Catalyst	1447	1441	-6	99.6
Example #6	Catalyst	1400	1401	1	100.1
Example #7	Additive	427	429	2	100.5
Example #8	Additive	418	415	-3	99.3
Example #9	Additive	230	229	-1	99.6
Example #10	Additive	191	191	0	100.0
Example #11	Additive	85	85	0	100.0
Example #12	Additive	81	81	0	100.0
Example #13	Additive	42	42	0	100.0
Example #14	Additive	16	16	0	100.0

Table 2

Intercat has developed multiple compartment catalyst & additive hoppers capable of accurately injecting three separate materials into an FCC unit simultaneously (See Figure 2). Hopper capacities range from 1 to 120 tons. These systems deliver to the refiner the ultimate level of flexibility and control with respect to catalyst additions.

Figure 2

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 to add an additional degree of freedom to the operation of their units. Specifically, the circulating inventory can be manipulated with the same degree of precision as preheat or riser outlet temperatures.

Furthermore, refiners are capable of achieving precision addition rates from wide range of containers such as tote bins, super sacks, and drums 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 selective additive technologies designed to maximize refinery profitability together with state-of-the-art catalyst and additive addition system technology.

Optimizing the FCC Circulating Inventory

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 multi-component addition system technologies developed by Intercat represents a substantial step forward in operating freedom for the FCC unit operator. Two very clear examples of when the capability to manipulate the FCC circulating catalyst inventory in real time will be profitable include feed quality shifts and/or dynamic market conditions which change rapidly.

Catalyst Selection Protocols for Market Demand Variation

Catalyst systems are designed assuming a continuous, steady state product demand. While necessary for designing catalyst technologies, this is rarely observed in reality. Two recent examples of the volatility of the fuels markets, which demonstrate recent shifts in the gasoline, diesel and propylene markets as observed in Northern Asia, may be observed in Figures 3 & 4. Figure 3 demonstrates a marked shift in diesel demand. Had this refiner been limited by operating with a gasoline catalyst they would have experienced a significant lost opportunity during the upswing in diesel demand. However, had this refiner then chosen to reformulate its catalyst, the market would have shifted prior to the catalyst even reaching the unit. The result would have been lost opportunity, but in this case, after the fact. The refiner would have been forced to inject a diesel catalyst while the market was demanding gasoline. The standard paradigm of operating with one catalyst system for three years without modification has past. The aggressive refiner achieving the highest profit potential will be that refiner capable of manipulating its circulating inventory on-demand.

Figure 3

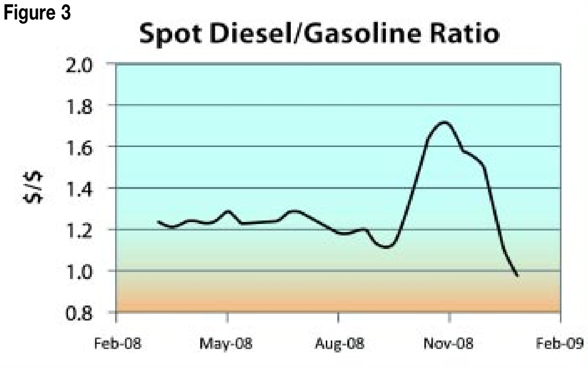
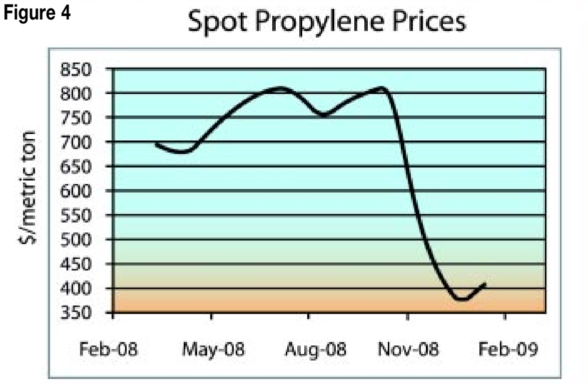


Figure 4



Catalyst Selection Protocols for Feedstock Variation

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 normal distribution (as presented in Figure 1) will quickly identify the most common feedstock to be used as "base case". The most common methodology used by refiners today processing VGO's is to design their FCC catalyst based upon the most typical feedstock quality. An alternative approach used frequently among operators of heavy oil crackers is to test based upon the heaviest feedstocks typically charged to the unit. This has been a successful selection strategy for decades. However, the possibility for a paradigm shift now exists and is demonstrated through the following examples.

Typical feedstock variations for refiners today can be illustrated by an East Coast United States refinery in Figure 1 which processes the three primary crude stocks in addition to a host of others. This refinery ran 67% of the 1.5 year span of operations within a typical crude slate represented by a feed density of 0.90 while 33% of its operations or six months are operated outside this normal band range. This period of operations represents an opportunity for the aggressive refiner to further advance its profitability optimization.

A more extreme yet not atypical operation in seen in Figure 5 represented by another North American refinery which regularly charges opportunity crudes available at discounted pricing. Subsequently, this refinery is likely be the more profitable of the two 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. A logical choice may be a feedstock having a feed density of approximately 0.893. However, this represents only 50% of the 100 day run demonstrated below. Fifty percent of the operations will then be far from optimal.

Figure 5

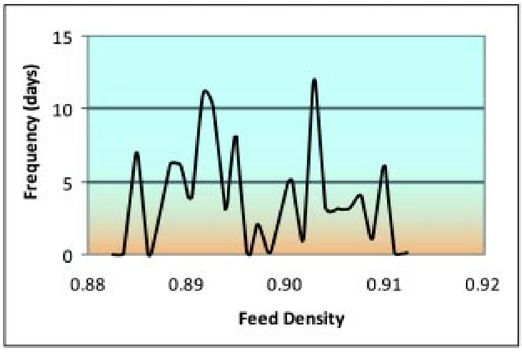


Figure 6 demonstrates a very typical United States West Coast refinery processing VGO feedstocks which also processes heavier residue when market and process conditions allow. The typical feedstock density for this unit is approximately 0.925 and represents the logical feedstock to be used for catalyst

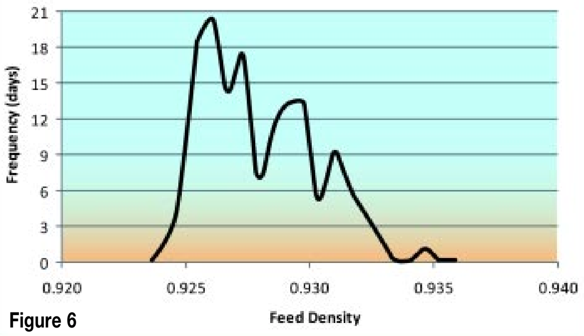


Figure 6

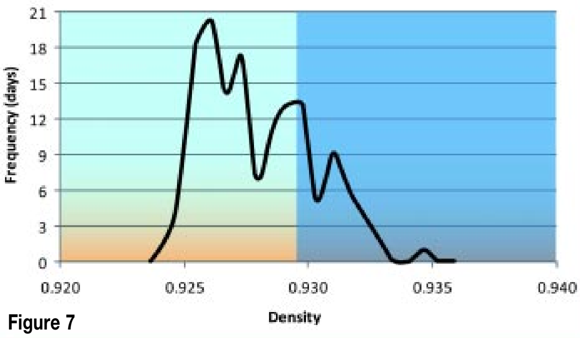


Figure 7

design. Figure 7 highlights the non-typical feedstock property ranges being processed in this unit. It is anticipated that the resulting catalyst will be sufficiently robust to upgrade the heavier feedstocks being processed which represent 45% of the normal operations. The ability to optimize the circulating inventory via injection of a high matrix bearing additive while charging these heavier feedstocks will add substantial flexibility to improve slurry destruction without compromising conversion with lighter feeds.

A second example is demonstrated in Figure 8 which represents an Asian refinery running residue feedstocks. The typical feedstock density for this unit is approximately 0.930 and represents the logical feedstock to be used for catalyst design. Figure 9 highlights the non-typical feedstock property

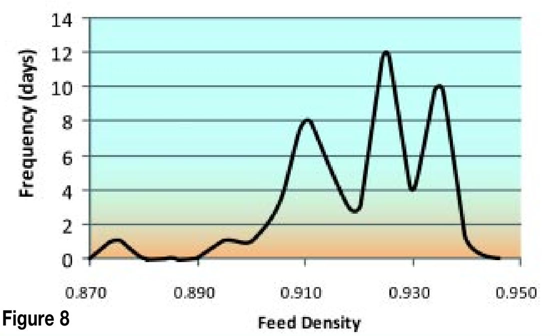


Figure 8

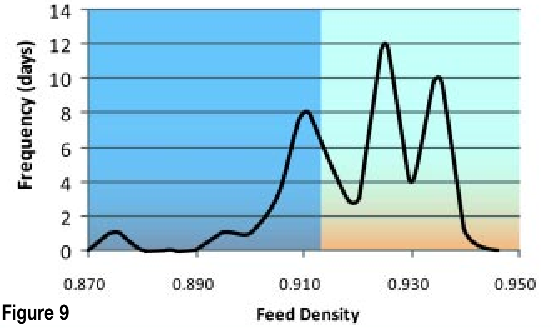


Figure 9

ranges being processed in this unit. It is anticipated that the resulting catalyst will be sufficiently robust to sufficiently upgrade the lighter feedstocks being processed which represent 40% of the normal operations. However, lighter feedstocks generally require a higher zeolite-to-matrix level than in a catalyst designed to upgrade residue feedstocks. The ability to inject a high zeolite bearing additive while running these lighter feedstocks will ensure maximum upgrading at this portion of feedstock.

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

Paramount to this proposed control is a well designed, robust base catalyst which is selected based upon the long term market conditions. Additional catalytic technologies are then injected into the unit on an "as needed" basis depending upon temporary market demands or feed stock variations. The most logical components are described below:

	Base	6% BCA	9% BCA	12% BCA
Operations				
Charge 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				
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 3

- Bottoms Cracking Technology. A highly accessible, alumina-based catalyst is injected into the unit when the feedstock becomes substantially different from 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) which enable 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 10 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 of a BCA-105 operation is shown in Table 3. Furthermore, BCA has proven highly effective at increasing LCO yield for those refiners desiring to increase diesel production.

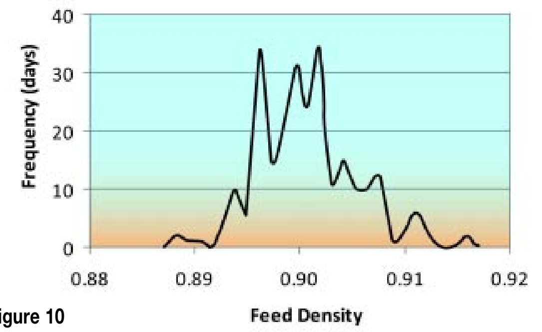


Figure 10

- Ultrahigh 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 typically run with heavier feedstocks. Intercat supplies an extremely unique product which is composed of a particle containing an ultrahigh level of "Y" zeolite. This technology is especially well-suited for those refineries which occasionally run very light or heavily hydrotreated feedstocks.

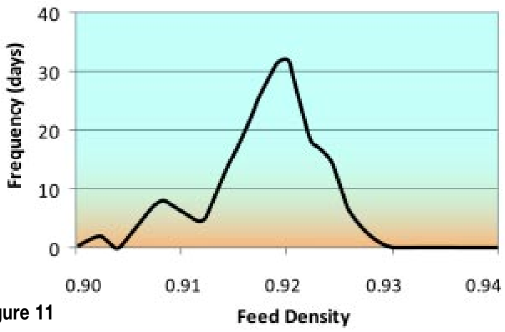


Figure 11

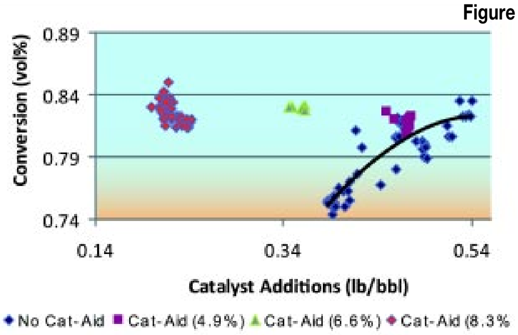
Such feedstocks typically demand high activity and show minimal response to high stability catalyst technologies. This case can be demonstrated in Figure 11 which illustrates a refinery which runs light crudes approximately 16% of the time. These feedstocks will respond most readily to additional zeolitic-based activity. A commercial example of a Hi-Y operation is shown in Table 4.

	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

Table 4

- 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 unique additive, Cat-Aid, 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 12 below. This 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%. Two additional benefits this additive has delivered is the ability to reduce SOx emissions and thereby caustic consumption in those units operating with Flue Gas Scrubbers. Secondly, those refiners adding equilibrium catalyst to control contaminant metals levels have been able to eliminate this usage entirely.

Figure 12



- 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.

Strategies to Control Catalyst & Additive Additions

The successful implementation of the strategy introduced above is contingent upon a thorough understanding of both the base catalyst's capabilities and limitations. It is recommended that the refinery quantify the key feed qualities at which the base catalyst begins to become constrained (density, CCR, nitrogen, etc.). Intercat's experienced Technical Service Engineers are available to assist in this process. A histogram analysis of the percentage of time the FCC operates beyond these constraints will help quantify the value of utilizing additional catalytic components. If laboratory facilities are available, simple laboratory testing can 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. Alternatively, simple low-risk step testing can be carried out on the actual FCC itself. Any laboratory testing should be followed up by commercial step tests on the unit itself in any event.

Close monitoring of the unit operation will be required during the initial implementation of multi-component additions. Additional focus will likely be required by the process engineer since circulating inventory composition control will be a new variable for most refiners. Input from the refinery logistic group will be required to inform the FCC engineer in advance whenever a significant feed quality switch is imminent. Each refinery will undoubtedly develop and employ progressively more sophisticated control systems as experience is acquired.

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. The use of kinetic or linear models will enable the aggressive refiner to manipulate its circulating inventory on-demand depending upon the feed slate being charged and dynamic market demands. 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.

Conclusion: 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. 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.

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 enable the refiner to manipulate circulating inventory composition via multi-component loading systems.

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

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This publication thanks Mr. Ray Fletcher, Senior Technologist with Intercat Europe, for providing this article. Mr. Fletcher graduated from the University of Washington with a Bachelor's Degree in Chemical Engineering in 1987. He began his career with Shell Oil and later worked for Texaco Refining. Ray spent a total of seven years working as a Process Engineer on the several process units including the Fluidized Catalytic Cracker, Hydrotreaters, Catalytic Reformers, Alkylation, and Catalytic Polymerization. Mr. Fletcher was employed by Akzo Nobel, holding a wide range of positions including FCC Technical Service Engineer, FCC Technical Service Manager, & Global FCC Development Manager, before he joined Intercat.