UOP FCC INNOVATIONS DEVELOPED USING SOPHISTICATED ENGINEERING TOOLS

Lisa M. Wolschlag and Keith A. Couch,

UOP LLC, a Honeywell Company
Des Plaines, Illinois, USA

INTRODUCTION

Fluid Catalytic Cracking (FCC) technology has been a part of the petroleum industry since the 1940's. Yet, despite being a very mature technology, continued development is vital, especially as many refiners move their FCC operations from fuels production to higher value products. Advanced diagnostic and design tools are accelerating process developments and have resulted in several innovations.

Through the development and commercialization of world record scale FCC units, technical discoveries have emerged, which have provided opportunities for improvements across all units, independent of size. Through the development and use of sophisticated engineering tools such as Computational Fluid Dynamic (CFD) modeling, combined with radioactive tracer and tomography, physical inspection reports and commercial yield analysis, UOP can deliver new technological innovations, more confidently, faster and with reduced risk.

This paper will highlight advancements in regenerator technology for higher capacity through existing assets, emissions reduction and feed distribution systems for large diameter risers. It will showcase how UOP is using and validating innovative tools to both improve existing FCC designs and move an aged technology towards true growth opportunities.

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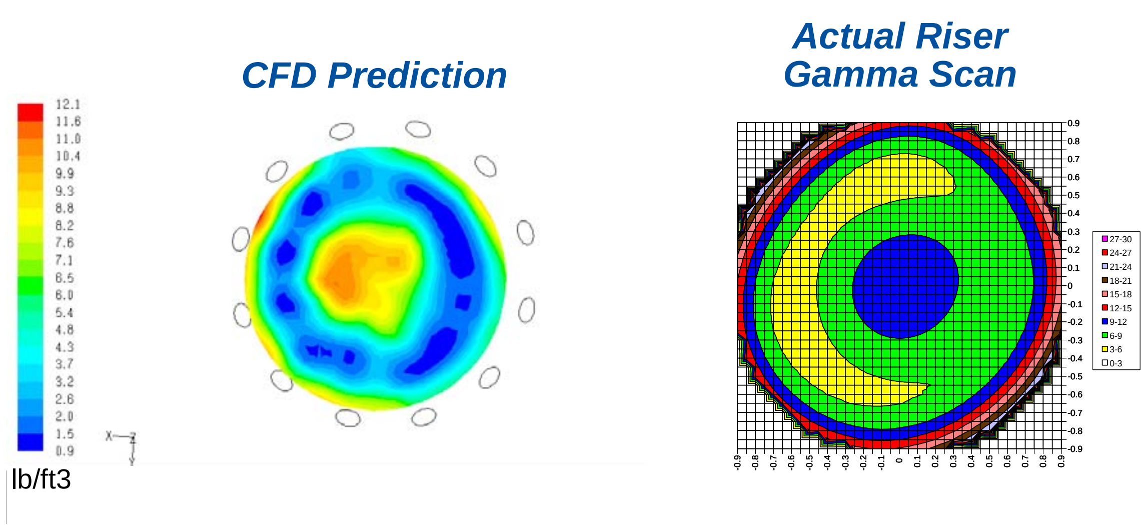
DUAL RADIUS FEED DISTRIBUTORS

As refiners look to capitalize on economies of scale, design throughputs of FCC units have reached record levels. At these scales, opportunities have emerged from the background noise of the data to improve FCC technology. Through pushing multiple constraints to design limits on one particular unit, yields and conversion deviated from benchmark performance with gasoline selectivity lower, conversion lower and dry gas higher than benchmark performance. To get more out of the existing asset, an intensive program was undertaken to achieve benchmark performance.

The riser for this FCC Unit has an inner diameter (ID) of 6.6 feet at the point of feed injection, which expands to 9 feet immediately above. The feed is injected into the riser through a set of circumferentially positioned distributors. The combination of low conversion and high dry gas yield seems counter-intuitive given traditional FCC operations. A hypothesis was raised that the large riser diameter might be preventing the feed from adequately distributing across the full cross-sectional area of the riser. To help test this hypothesis, a Computational Fluid Dynamic (CFD) model of the riser was created to analyze the fluid dynamics of the system. The results of the model supported that raw oil feed would only penetrate the riser a finite distance thus creating a vapor annulus, and that much of the catalyst flowing up the riser would form a high density core.

Based on the results of the CFD model, a tomographic analysis (gamma scan) of the riser was completed. The results of this scan confirmed the CFD model prediction; see Figure 1.

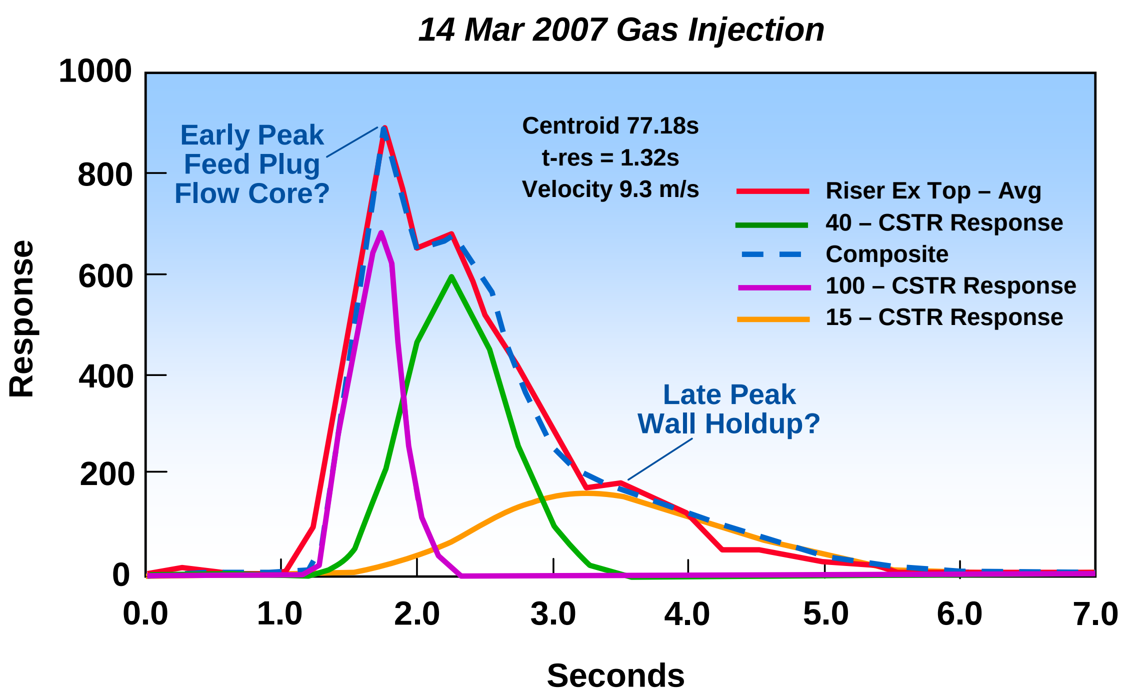
Figure 1
CFD Prediction and Gamma Scan of 6.6 Foot ID Riser



Radioactive tracer work was also completed on the 9 foot ID riser. Irradiated Krypton-79 gas was injected into the base of the riser. Detectors were positioned along the length of the riser and reactor to measure the tracer as it moved through the system. The results indicated that the time of flight of the krypton gas from one detector to another did not provide a sharp response peak. Rather, there was an early peak followed by a secondary peak and a high degree of skewness; see Figure 2 (Riser Ex Top – Avg line).

A mathematical evaluation was performed to determine what type of CSTR response would be needed to emulate the measured data. In order to accurately reproduce the field data plot, required a composite plot modeled as a 100, 40 and 15 CSTR responses; see Figure 2.

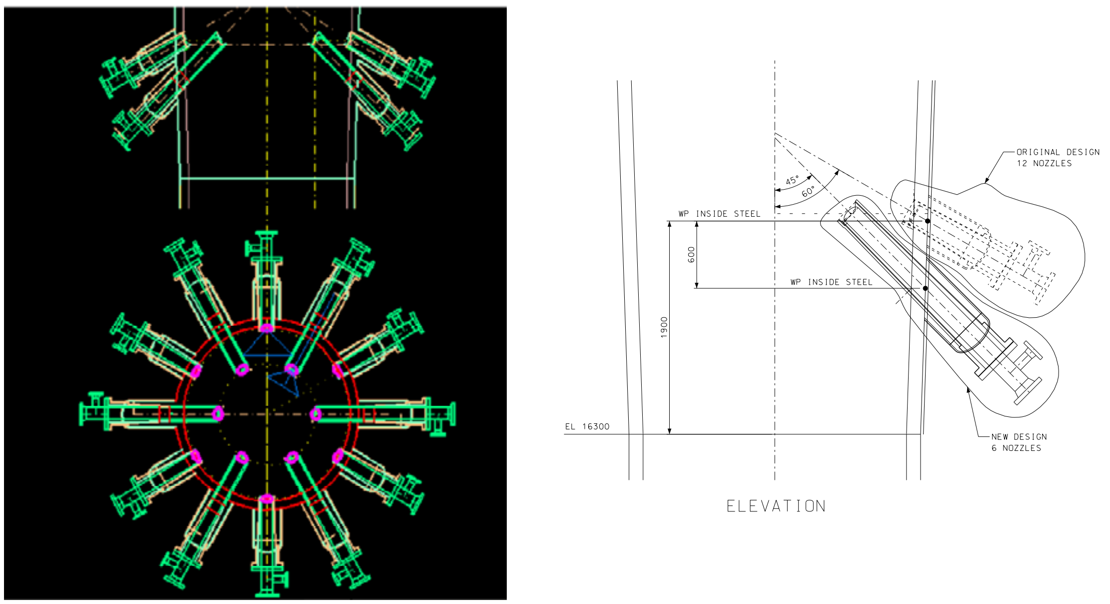
Figure 2
Mathematical Composite



Unit performance, CFD modeling, tracer and tomography tests, and mathematical analysis all indicated the same pathology: that the feed was not adequately accessing the full cross-sectional area of the riser leading to the presence of a high density core of catalyst and a low density annulus which caused conversion to be low and dry gas and coke make to be high. One solution to this problem would be to install two, smaller diameter risers to match more conventional FCC sizes. However, the installation of dual risers, even with a new construction is substantially more expensive. For a 200,000 BPSD FCC Unit, the estimated cost difference between a single, large-radius riser and a pair of smaller risers was cost estimated at $60MM, in 1998 US Dollars.

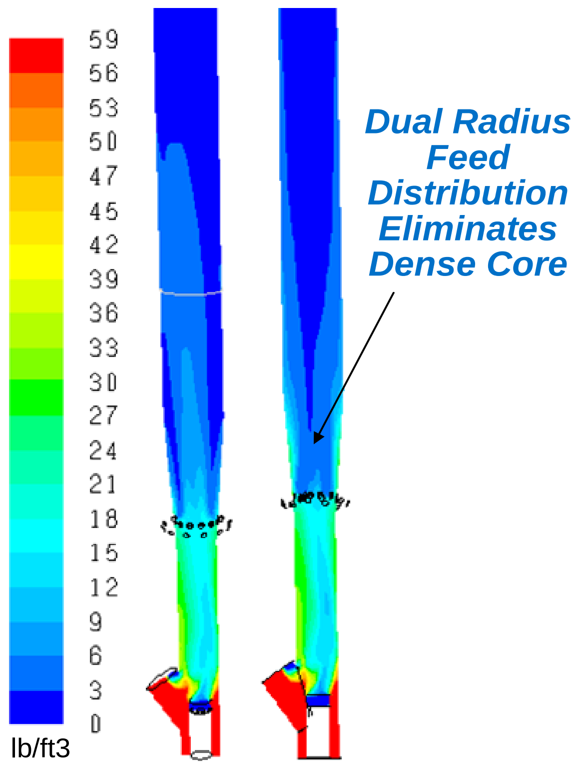
UOP has developed a substantially lower cost solution with implementation of dual radius feed distributors; see Figure 3. This design helps ensure optimal feed distribution across the entire riser, while avoiding adjacent spray impact that could cause undesirable spray interference.

Figure 3
Dual Radius Feed Distributors Schematic



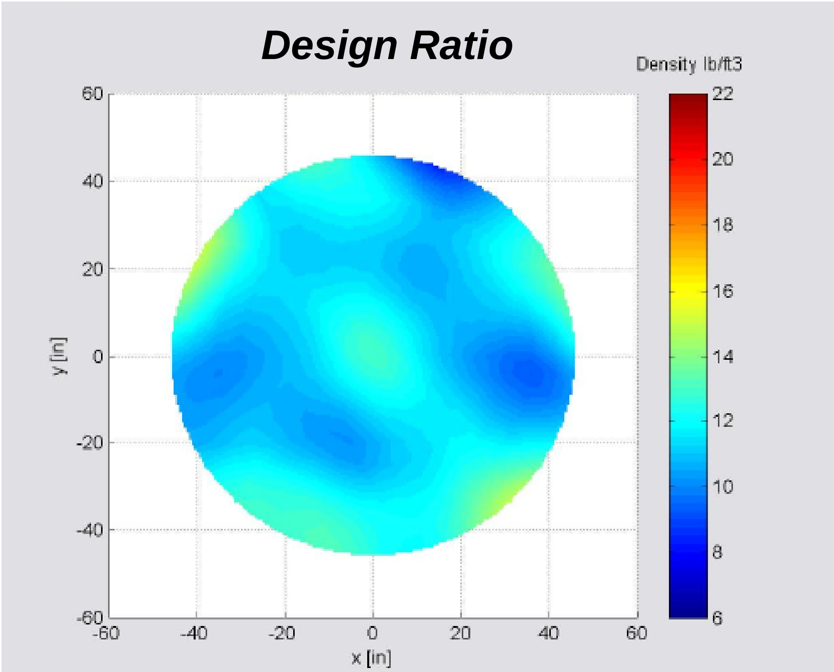
Another CFD model that now incorporated the dual radius feed distributors was created. Figure 4 shows catalyst density profiles of an axial slice of the riser, both with and without dual radius feed distributors. The riser on the left side without the dual radius feed distributors show the high density core of catalyst, the CFD model with the dual radius feed distributors indicates that the dense core of catalyst is effectively eliminated.

Figure 4
CFD Models of the Riser Catalyst Profiles with and Without Dual Radius Feed Distributors



The dual radius feed distributors were installed on a FCC Unit designed with an 8 foot diameter riser at the point of feed injection. The unit was commissioned in May 2009. Results indicate that dry gas yield, conversion and gasoline selectivity are all within expectations. Gamma scans of the riser indicate that the high density core of catalyst was effectively eliminated. The catalyst density profile of the riser at approximately 1 ID above the point of dual radius feed injection indicates that core annular flow has been achieved with a very evenly distributed catalyst density profile; see Figure 5. Additional tomography scans were completed at varying feed ratios, to optimize the distribution of oil and steam across the riser.

Figure 5
Gamma Scan of 8 Foot ID Riser with Dual Radius Feed Distributors



Erosion of the inner feed distributors was a concern of the client. This was mitigated by the use of ceramic feed distributors. Ceramic offers the ultimate in erosion protection and feed distributors with ceramic tips have shown to shown to withstand highly erosive environments with zero discernable erosion.

CERAMIC FEED DISTRIBUTORS

DEVELOPMENT

FCC feed distributor tips are subjected to a high temperature, high velocity erosive environment. To accommodate this harsh environment, FCC feed distributors have historically been fabricated from various erosion resistant materials. While these materials have proven effective at reducing rates of erosion, most erosion resistant materials are, by their nature, generally hard and brittle and can be susceptible to brittle fracture. Erosion and brittle fracture have been an industry-wide issue, and can be induced mechanically or by thermal shock. This must be considered in the design of FCC feed distributors as it can occur when relatively cold oil and/or steam are rapidly introduced to the system in which the tips are hot from circulating catalyst.

UOP has addressed these issues in numerous ways over the sixteen year history of the UOP Optimix™ distributor. In general, following proper operating procedures will avoid thermal shock and avoid the issue of brittle fracture; however, erosion is more a function of operating environment as opposed to improper operation.

In 2007, UOP undertook a comprehensive development project with the objective of using new materials and design tools to improve the mechanical integrity of FCC feed distributors. As a result of the subject development, UOP now has new and improved Optimix (ER) feed distributor tip designs.

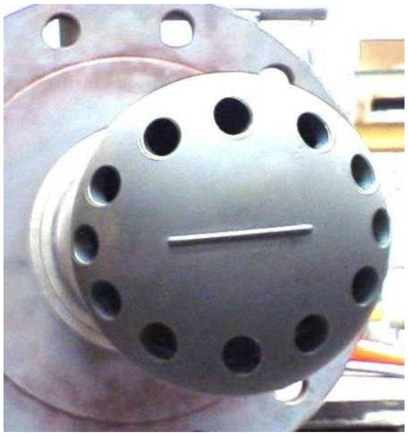
DESIGNS

The Optimix (ER) family of FCC feed distributors includes 3 primary designs: Standard, Weld Overlay and Ceramic. The standard design, which is the new distributor for most FCC applications, balances the issue of erosion and the possibility of cracking due to thermal shock. The standard Optimix (ER) tip incorporates a change to a more erosion resistant metal alloy, a change in the geometry to reduce stress concentrations, and the incorporation of orifice extensions extend the flashing hydrocarbon feed further away from the metal tip. Additional protection can be provided through the application of a very hard diffusion coating over the cobalt based alloy.

The Weld Overlay design is applied to refiners having chronic problems with wet steam and whose installations have a high risk of thermal shock. The erosion resistant weld overlay is applied to a softer, more ductile base metal, for superior thermal shock resistance. To further combat erosion this tip incorporates orifice extensions to move the flashing hydrocarbon feed further away from the tip of the distributor. While a very hard diffusion coating can also be employed to provide additional protection against erosion, the primary goal of this design is resistance to thermal shock, and therefore is recommended only for FCC operations that have proven to be particularly susceptible to thermal shock.

Finally, the Ceramic design represents a step change improvement for superior erosion resistance. UOP has identified how to determine the erosion potential of FCC feed distributors based on the physical properties of the feedstock. Optimix (ER) – Ceramic is used in applications where erosion is projected to be higher than normal, or in units that have previously exhibited high erosion rates. Even though the ceramic material is very hard, quench testing in the laboratory and commercial application have indicated that the new ceramic tip is no more susceptible to thermal shock than traditional fabrications with cobalt based alloys. Figure 6 shows the three Optimix (ER) tip designs, as well as the previous Optimix tip design.

Figure 6
Optimix (ER) Tip Design



Previous Optimix

New Standard Optimix (ER)

Optimix (ER) –
Weld Overlay Tip

Optimix (ER) - Ceramic

CERAMIC TIPS – DESIGN CHALLENGES

Ceramic materials are widely accepted and proven to be more resistant to erosion than metallic materials. The characteristics which impart erosion resistance also tend to make these materials more brittle. The successful application of ceramics in FCC feed injection required that two technical challenges be overcome: selecting a suitable ceramic material that can be fabricated into the required geometry, and developing a means of connecting the ceramic tip to the metallic base assembly of the distributor.

The geometry used for the ceramic distributor tip was the same as the traditional elliptical Optimix feed distributor. The same principles and considerations applied to reducing mechanical stresses and improving thermal shock resistance in metallic tips were applied to address the brittle nature of ceramics. The ceramic tips were subjected to laboratory quench testing to simulate the unique temperature profiles in the feed injection system. The quench testing was used to help select the proper ceramic material, and confirmed that the final material selected was no more susceptible to brittle fracture than the previous generation metallic Optimix tips.

The large differences in coefficient of thermal expansion between the materials provided the next challenge: a means of attaching the ceramic tip to the metallic base assembly. The attachment needs to provide a liquid tight seal at design pressure drop across the distributor, while accommodating a wide range of feed and steam temperatures experienced across startup, normal operation and shutdown of the FCC unit. Creative engineering, Ansys stress modeling, full scale prototyping and thermal cycle testing were all used to develop a proprietary mechanical connection.

With an acceptable ceramic identified and a means of connecting the ceramic to the metal base assembly, the next step was to demonstrate Optimix (ER) in a commercial application.

CERAMIC TIPS – COMMERCIAL EXPERIENCE

As the design details for the new ceramic tip and connection were being finalized, an opportunity presented itself in which two ceramic tips could be installed in the same reactor riser at the same time as metallic tips, providing an ideal side-by-side commercial test. The subject FCC had a history of aggressive feed distributor tip erosion and a trial installation of the ceramic tips was welcomed. Final design details regarding tip connection were addressed and in April of 2007, ceramic tips were commissioned in a commercial FCC reactor riser.

After 18 months of operation, the ceramic tips were inspected and found to be free of erosion and cracking, while the adjacent metallic tips exhibited signs of erosion. In Figure 7, the metallic tip shows significant erosion, while the ceramic tip shows zero discernable erosion.

Figure 7
Metallic and Ceramic Optimix Tips After 18 Months in Operation

Metallic Tip ***Ceramic Tip***

The viability and benefit of using ceramic tips for the UOP Optimix (ER) feed distributor was confirmed. The expected life of the distributors in this application was revolutionized, from imminent failure (with an average run life of 2-3 years), to potentially a life with perpetual success.

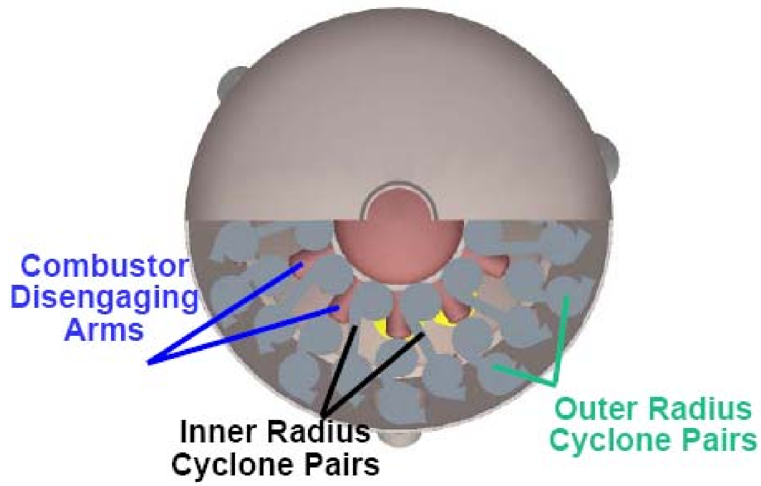
As of Jan 2010, Optimix (ER) Ceramic distributors have been delivered to three refiners in addition to the trial installation. The second installation was placed into service on May 17, 2009, and continues to perform well with two additional project shipments pending. Optimix (ER) Ceramic distributors are currently being recommended and supplied as the premiere offering to improve reliability in installations with aggressive distributor tip erosion.

ELEPHANT ARM COMBUSTOR RISER DISENGAGER

The market drive to maximize returns through economies of scale can present technical challenges with respect to scale-up. A phenomenon was occurring on a large UOP combustor style FCC Regenerator in which flue gas catalyst losses appeared to increase at the higher end of superficial velocities that are typically stable for smaller designs. In this case, the refiner was interested in achieving a higher capacity through their existing asset.

The inside of the upper regenerator has two major pieces of equipment, the cyclones and the combustor disengager. The combustor disengager provides the first-stage inertial separation of catalyst from the combustion products, and the cyclones provide the final separation. The layout of this particular regenerator is unique in that the cyclone pairs are configured on two different radii; see Figure 8. While this has been a common plan view layout for bubbling bed regenerators, this was the first time it was applied to a combustor style unit.

Figure 8
Dual Radius Cyclone System in Regenerator



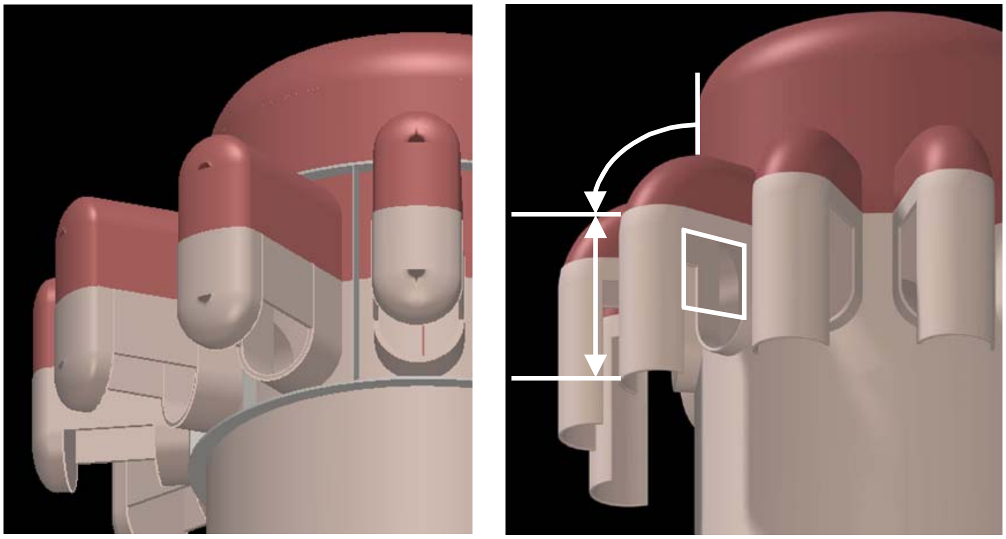
To start the evaluation, a CFD model of the regenerator was created to study the unit specific gas flow paths in the upper regenerator. The model demonstrated that the gas flow exiting the standard tee disengaging arms was in the range of 4-9 m/s; see Figure 11. This velocity range is between 50-100% higher at a 15% lower superficial velocity compared to the next largest combustor style regenerator. The model also indicated that the jet length projected from the disengaging arm was long enough that the high-velocity gas stream moved horizontally in the area of the dipleg termination, which resulted in fines re-entrainment with preferential flow to the inner radius cyclone pair, at a rate that exceeded the catalyst discharge capacity of the cyclones. This result was initially difficult to believe as the primary cyclone inlets on the two different radii were only 18 inches apart. However, the preferential flow was readily apparent upon internal unit inspections at the turnaround six years after commissioning. A perceived small change to the base design had a profound impact on the equipment performance.

SOLUTION

The solution developed was a variation on what has been called the elephant trunk disengager; see Figure 12. While basic elephant trunk disengagers were used in FCC reactor riser disengagers in the late 70s and early 80s, the regenerator application required substantial engineering work to ensure that the proper gas flow paths and catalyst separation efficiencies were achieved. The arm of the disengager was curved to lower the impact transition, reduce catalyst attrition and to improve lining reliability. The shroud was extended to direct the catalyst more into the bed of catalyst but limited in length so as not to provide excessive separation efficiency that would lead increased afterburn and high dilute phase temperatures. The outlet area was optimized to ensure that the combustion gasses bleed off horizontally with minimal cross-wind at cyclone dipleg terminations; see Figure 9.

Figure 9

Tee and Elephant Trunk Arm Disengager

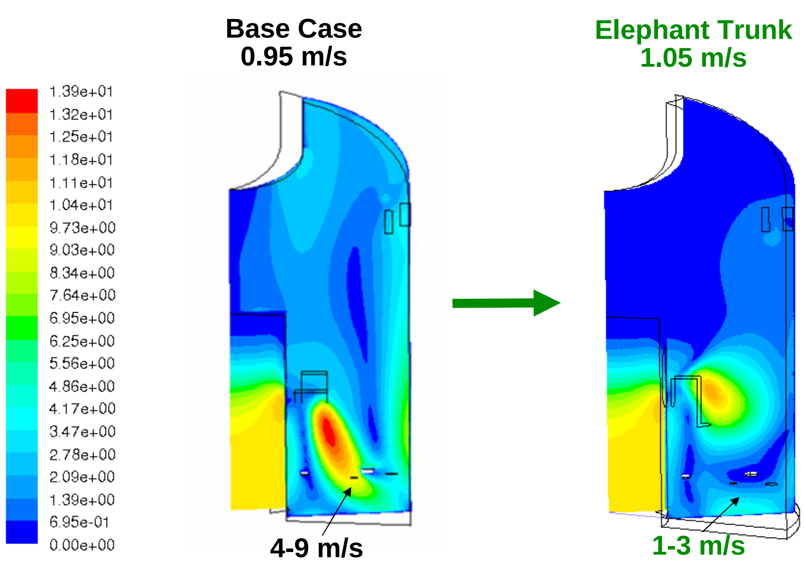


Tee Disengager ***Elephant Trunk Arm Disengager***

The CFD model of the final design indicated that at a superficial velocity of 1.05 m/s, slightly higher than the base case model, the gas velocities exiting the arms of the elephant trunk disengager were significantly lower than the gas velocities for the tee disengager with peak gas velocities reduced by 25% and the horizontal gas velocities at the dipleg outlets reduced to nearly zero; see Figure 10.

Figure 10

CFD Model of the Gas Profiles in the Upper Regenerator with Tee and Elephant Trunk Arm Disengagers



With the original design, ten out of eleven inner cyclones holed-through after six years of operation. With the installation of the elephant trunk disengager, the fines entrained to the inner cyclone set were reduced sufficiently to reasonably expect a 10 year service life. This enables the refiner to either significantly reduces maintenance costs and realize greater on-stream reliability, or to push the system harder for greater operating margin.

CFD Model Validation

CFD models have historically met with substantial skepticism in mixed phase fluidized bed systems. To help validate the CFD modeling efforts, multiple operating regenerators were modeled and the results compared with turnaround field inspection reports. The CFD modeling has proven to be predictive with respect to erosion of both the cyclones and the external support braces when compared with field inspection reports.

To further evaluate the accuracy of the CFD modeling and to help determine the proper boundary conditions for the models, multiple radioactive tracer tests have been completed on regenerators with the tee disengager and the elephant trunk disengager. The downward gas flow predicted with the tee disengager was validated, and the residence time of the flue gas within the upper regenerator was within 6% of the CFD model. Tracer studies of the elephant trunk disengager confirmed a greater amount of gas dispersion, elimination of the regions of high gas velocity, and more effective use of the regenerator volume.

The first commercial combustor riser elephant trunk disengager was commissioned in 2009. Initial results are very promising. Catalyst containment is very good and continues to be closely monitored. The flue gas residence time in the upper regenerator increased by as much as 26%, which has resulted is substantially improved regenerator performance. The design and operation of the unit has resulted in extremely low delta coke operation and a regenerator average dense bed temperature as low as 1198°F. Even with this low regenerator temperature operating at maximum throughput, the average afterburn is only 8°F. This is step-change advancement in regenerator combustion performance and supports that the modeled increase in flue gas residence time has been achieved. See NPRA Annual Meeting Paper AM-04-45 for additional details on regenerator combustion kinetics.

The emergence of the elephant trunk disengager came about as the result of a concerted effort to improve the performance of a very large combustor. CFD modeling, tracer work, unit inspection and operational data collectively contributed to its creation, proof of principle and commercialization. However, through the use of these sophisticated tools, other benefits were discovered that are applicable to all sized units. Eliminating the high velocity regions reduce erosion to internals and associated catalyst attrition. The increased residence time improves the burning capacity of the regenerator, enables lower excess oxygen operation and directionally reduces NOx emissions. As such, the elephant trunk arm disengager has become the standard design for all new combustor style regenerators, with several revamp and new unit designs in progress.

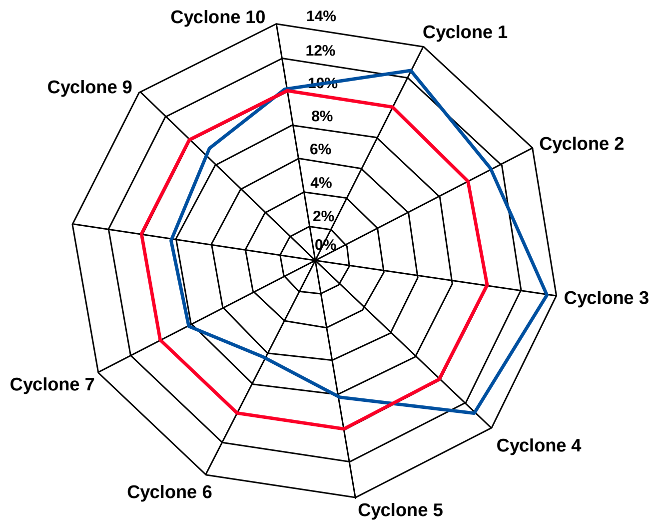
SPENT CATALYST DISTRIBUTOR

PROBLEM

The Engineering tools and the associated skills used to solve the previous problems on very large FCC Units can be used on FCC Units of all sizes and types, to support operating and reliability needs of individual refiners. In one example, an 80,000 BPSD FCC Unit with a bubbling bed regenerator exhibited a regenerator cyclone outlet temperature differential of 100°F from one side of the regenerator to the other. This afterburn differential resulted in a localized hot spot that limited the throughput of the unit against a main air blower constraint. The regenerator was an older design that employed a gull wing spent catalyst distributor design. Catalyst maldistribution in the regenerator causes fuel rich areas in the dense phase with localized hot spots directly above in the dilute phase. Hot spots can be completely invisible within a unit depending on where the TI instrumentation is placed in relation to the spent catalyst inlet.

To help validate the temperature data, catalyst tracer work was completed on the regenerator to evaluate the flow distribution in the unit. With ideal distribution, a radar plot of the detector signals would show perfect symmetry. The actual unit data showed that the catalyst was heavily skewed to one side, which was not a surprise; see Figure 11.

Figure 11
Catalyst Tracer Results for Bubbling Bed Regenerator with Gull Wing Design

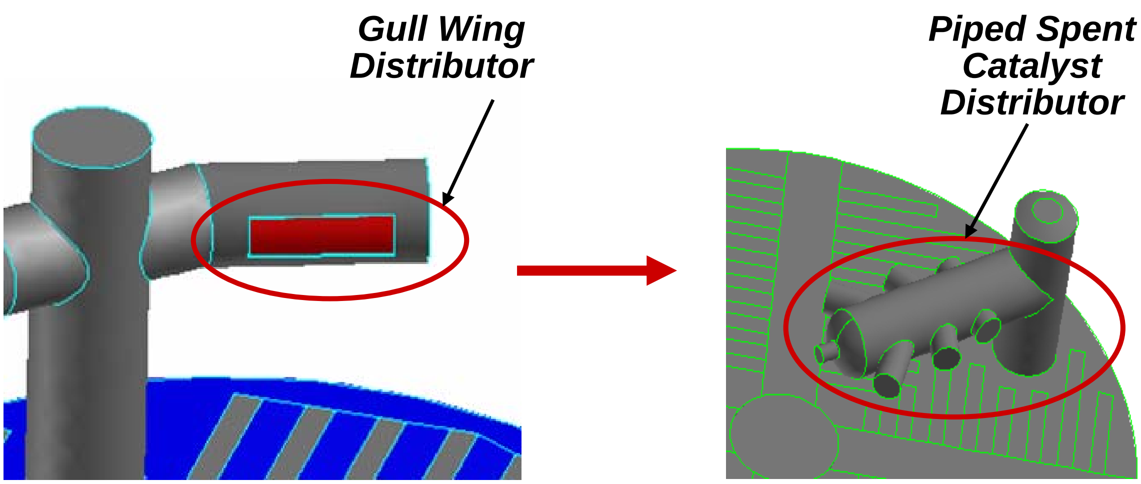


SOLUTION

The typical spent catalyst distributor installed in a bubbling bed regenerator of this vintage was the gull wing design with an external lift riser. A schematic of this distributor is shown in Figure 12. Air maldistribution in this type of regenerator design results from two sources. First, the external riser lift air discharges vertically out of the disengager, resulting in an oxygen rich environment in the dilute phase. Second, high localized catalyst density and resultant hydraulic head causing preferential flow of combustion air to the opposite side of the regenerator.

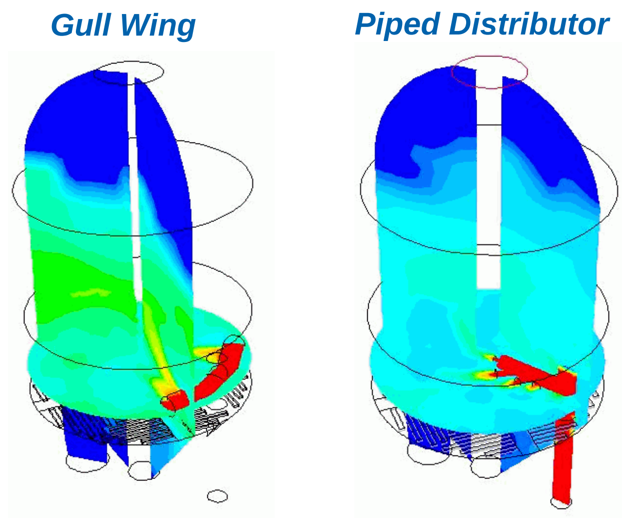
To achieve a more even catalyst density and uniform coke distribution, the piped spent catalyst distributor was developed; see Figure 12. The piped distributor was designed to radially distribute both the lift air and spent catalyst across the regenerator bed through a set of side arms. The size and orientation of the distributor arms were designed in an iterative process with CFD modeling to ensure as even catalyst and air distribution as possible within the back pressure limitations of the existing lift air blower.

Figure 12
Gull Wing and Piped Spent Catalyst Distributor



CFD models of the gull wing distributor and the piped spent catalyst distributor were created to predict the catalyst distribution, gas flow paths and bed density profiles in the bubbling bed regenerator. With the gull wing distributor, the catalyst was concentrated in the center of the bed. With the piped spent catalyst distributor, the catalyst distribution was much more uniform throughout the bed; see Figure 13.

Figure 13
CFD Model of the Catalyst Densities in a Regenerator with Gull Wing and Piped Spent Catalyst Distributors

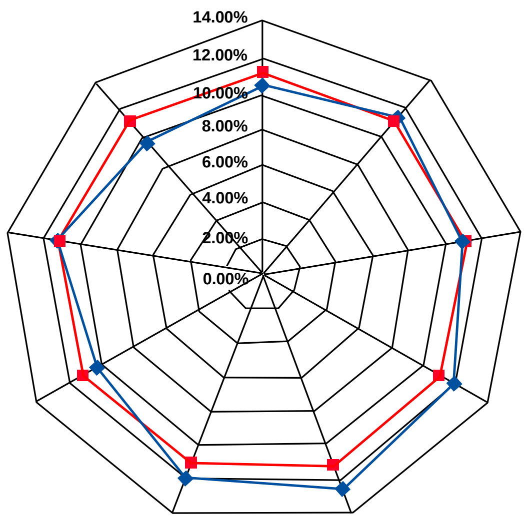


RESULTS

The piped spent catalyst distributor was commissioned in December 2006. Post-revamp tracer tests were conducted on the regenerator to evaluate the results of the design. The actual catalyst distribution is very close to the ideal distribution; see Figure 14.

Operational data also indicates a significant improvement in the regenerator performance. The dilute phase temperature differential was reduced from 100°F pre-revamp to about 15°F following the implementation of the pipe spent catalyst distributor. As a result, the refiner was able to lower the excess oxygen level in the flue gas from a pre-revamp minimum of 2 mol% to a post-revamp 1 mol%, enabling a higher capacity through existing assets and saving on utility consumption.

Figure 14:
Catalyst Tracer Results for Bubbling Bed Regenerator with Piped Spent Catalyst Distributor



UOP RxCat™ Technology and the ΔCoke Challenge

As improved equipment technology and catalyst offerings have resulted in progressive decreases in ΔCoke, many refiners have continued to de-bottleneck unit constraints within the capacity of existing major equipment, often with the constraint of not replacing main vessels or large rotating equipment, i.e., main air blower (MAB), wet gas compressor (WGC), regenerator shell, reactor shell, stripper shell, and catalyst circulation standpipes. Maintaining this philosophy through several technology upgrades can result in several operational and reliability concerns.

1. Excessive catalyst loading to regenerator cyclones
   - Cyclone erosion, fines generation
2. High catalyst circulation and catalyst flux
   - Insufficient regenerator & stripper residence time
   - Hydraulic instability or limitation in the catalyst standpipes
3. Excessive catalyst fines to the flue gas system
   - Increased particulate matter (PM) emissions

Improvements in FCC technology to achieve lower ΔCoke operations not only present the concerns listed above, but also cause refiners to face several dilemmas between "wants" and often conflicting "also wants"; see Table 1. Optimum product selectivities, conversion, and throughput are traditionally opposite to lower coke yield, optimum coke combustion, and retaining existing equipment.

Table 1
Conflicting "Wants"

"WANTS"		***"ALSO WANTS"***
Optimum Product Selectivities	***BUT***	***Sufficient regenerator temperature for*** **• Improved coke burn kinetics**
Higher Conversion	***BUT***	***Lower coke yield for*** **• Improved selectivity and** **• Lower CO_2**
Less Dry Gas	***BUT***	***Sufficient regenerated catalyst temperature for*** **• Improved coke burn kinetics**
Higher Throughput	***BUT***	***Retain existing equipment – Min CAPEX*** **• MAB, WGC, standpipes**

COMBINED TECHNOLOGY EFFECTS

Figure 15 shows the expected benefits to be obtained from a step-wise improvement in FCC reactor technology. The individual steps include:

1) Replaced elevated Premix distributor with elevated Optimix feed distribution system
2) Replaced reactor stripper with an AF stripper technology
3) Replaced a tee RTD with a VSS RTD

With each progression, the refiner gains the yield and selectivity benefits inherent of increased catalyst-to-oil and lower ΔCoke. The combined technology improvements result in a 23% increase in catalyst circulation and a regenerator dense-bed temperature reduction to 1260°F. The technology benefits are summarized in Table 2.

Figure 15
Technology Upgrade Effects

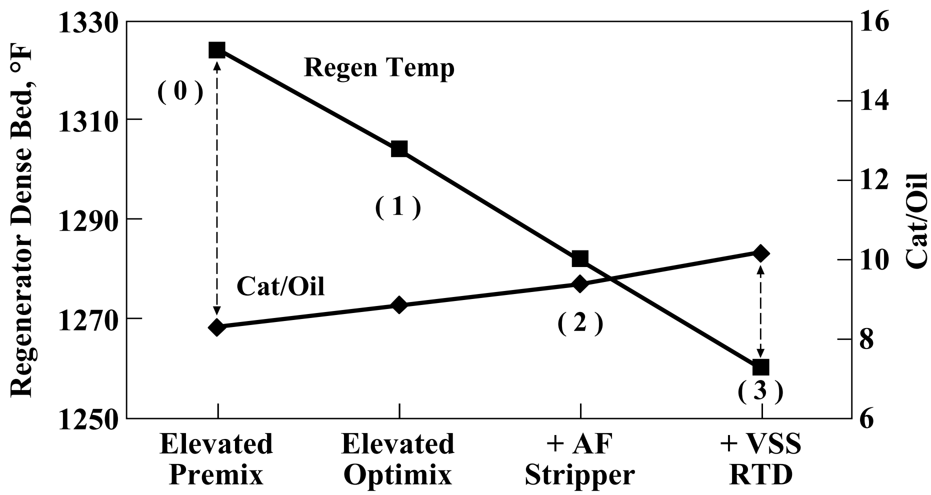


Table 2
Technology Upgrade Effects

	Base Case Premix Feed Distributor (Point 0)	*Plus Vss (Point 3)*
Cat-to-Oil	**8.27**	**10.14**
Regen Temp, °F	**1324**	**1260**
Conversion, lv% (90% at 380 °F)	**Base**	**+0.7**
Gasoline, lv% (90% at 380 °F)	**Base**	**+1.8**
Coke, Wt%	**5.6**	**5.6**
Δ Coke	**0.68**	**0.55**

As hydraulic limits are reached in the catalyst circulation between the reactor and regenerator, relieving one aspect of a hydraulic constraint through a slide valve or standpipe modification can be tempting. However, not paying attention to the overall design can simply result in the relocation of the constraint and the introduction of greater risk to the system reliability. With the on-set of clean fuels initiatives, these issues can be further strained by increasing the percentage of hydrotreated feed to the unit and further decreasing the ΔCoke and regenerator temperature. Refiners moving towards more hydrotreated feeds are often placed in the position of opting for less coke selective catalyst, firing the air heater, or firing torch oil to add heat to the regenerator. The use of less coke selective catalyst (more coke produced) negates yield and selectivity benefits previously gained from equipment upgrades. Firing the direct fired air heater for long durations can lead to erosion and failure of the air distributor as the distributor jets are pushed beyond design exit velocities. These high exit velocities can also lead to excessive catalyst fines generation. Firing torch oil to keep the regenerator hot essentially burns high value feedstock as fuel, while at the same time damaging the catalyst activity. The burning of any fuel in the regenerator apart from coke on the circulating catalyst inventory is an economic loss.

While the above issues present problems that the refiner must overcome, they also present some excellent operational, financial, and environmental opportunities.

THE RXCAT SOLUTION

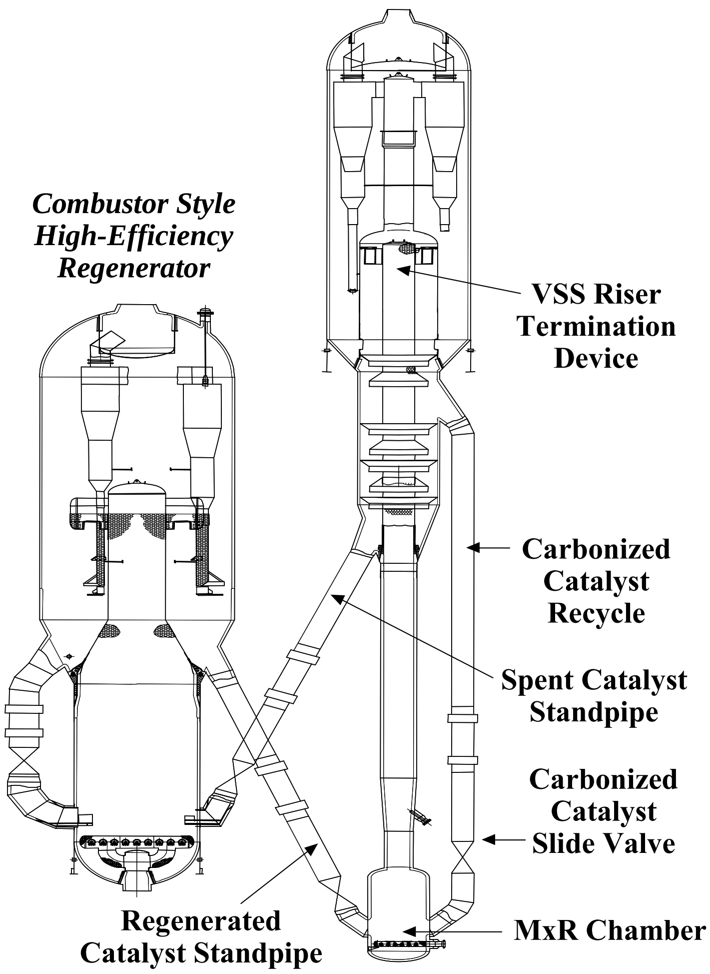
The problems of low ΔCoke operations (low regenerator temperature) have created an opportunity that UOP has uniquely addressed. Traditionally the catalyst from the bottom of the reactor stripper has commonly been referred to as “spent”. However, modern catalyst systems can accumulate appreciable quantities of coke and still maintain a significant amount of activity. UOP has adopted the term “carbonized” to describe this catalyst. The activity characteristics of carbonized catalyst are not only usable, but in certain cases preferred. Coke deposition preferentially attenuates the strongest catalytic sites providing for more selective cracking with carbonized catalyst. To take advantage of the selectivity benefits of conditioned catalyst, UOP developed RxCat technology.

In a traditional FCC unit, increasing the catalyst-to-oil ratio to increase conversion also increases the coke yield and catalyst circulation to the regenerator. RxCat technology provides the ability to increase both conversion and selectivity by recycling a portion of the carbonized catalyst back to the base of the reactor riser (Figure 16). The carbonized catalyst circulated from the stripper back to the base of the riser is effectively at the same temperature as the reactor. Since the recycle catalyst adds no heat to the system, the recycle is heat-balance neutral. For the first time, the catalyst circulation up the riser can be varied independently from the catalyst circulation rate to the regenerator and is de-coupled form the unit heat balance.

With RxCat technology, a portion of the stripped catalyst (~1000°F) is directed through the recycle catalyst standpipe to the UOP MxR™ chamber where it is combined with the hot regenerated catalyst (~1300°F). The lower contact temperature between the combined catalyst and raw oil feed results in higher product selectivity with less dry gas and coke production, and a substantial increase in conversion due to the higher riser catalyst-to-oil ratio. Similar to a conventional FCC unit, the balance of the carbonized catalyst that is not recycled travels through the stripper to the regenerator where the coke is burned off before it returns to the base of the riser. The catalyst flowing to the regenerator carries a higher coke content, which in turn raises the regenerator temperature and enables the easing of constraints in the system.

Figure 16

RxCat Technology



The ability to control the catalyst flow up the riser independently of the heat-balance adds increased flexibility to the FCC unit to more easily handle changes in feed quality and shifting product slates. This aspect of the technology is particularly useful in units that periodically switch from gasoline to olefin or distillate mode, throughout the year. In a conventional FCC unit a shift in operating mode is accomplished by a change in reactor temperature and a change in the rate or activity of the catalyst make-up. With RxCat technology, a change in catalyst activity in the riser can be accomplished by merely changing the amount of carbonized-catalyst recycle and as such, the change from gasoline mode to/from olefin mode can be rapid. This application has an even greater impact for refiners that use LPG olefins additives, i.e., ZSM-5, and have traditionally had to shift their catalyst inventory over several weeks to reap the full financial benefits of a change in product slate.

As of February 2010, four RxCat designs have been commissioned and are operating successfully. Four more units are now in design and five more are currently under construction.

Integration of RxCat technology provides numerous benefits in both revamp and new unit applications, providing the refiner with the ability to accomplish many of the following:

- Increased conversion
- Increased gasoline yield
- Decreased dry gas yield
- Increased propylene yield with additive use
- Reduced ZSM-5 additive consumption
- Decreased coke yield at constant conversion
- Increased regenerator dense bed temperature
- Increased regenerator residence time
- Lower regenerated and spent catalyst standpipe flux
- Lower regenerator emissions

Two of the largest benefits listed above are described briefly below.

Increased conversion - The substantial increase in riser catalyst-to-oil ratio results in a significant increase in conversion. At a 1:1 blend of carbonized to regenerated catalyst, the catalyst-to-oil ratio in the riser will typically increase 3 to 4 numbers. At a constant reactor temperature and catalyst activity, conversion can be increased 3 to 5 lv%. Alternatively, the large increase in the catalyst-to-oil ratio with its corresponding increase in conversion allows the reactor temperature (and hence thermal cracking) to be reduced while still maintaining or exceeding the original conversion level. Depending on the severity of the operation and the catalyst quality, most of this conversion would be directed towards increased gasoline yield.

Reduced ZSM-5 consumption – With the RxCat operation, the regenerator temperature increases, and reduces the regenerated catalyst flow to the riser by approximately 20%. However, the catalyst-to-oil ratio in the riser is 2X base. If the starting catalyst-to-oil ratio was 10, operating RxCat at a 1:1 ratio would result in a regenerated catalyst-to-oil in the riser of 8, with a carbonized catalyst-to-oil in the riser of 8, for a net cat-to-oil of 16. The coke accumulation on ZSM-5 is essentially zero in FCC operations, resulting in 100% performance of the ZSM-5 particles in the riser. As a result, the refiner can operate with less ZSM-5 content in inventory for the same C_3=, C_4= production by the ratio of 10/16 or 62.5% of the inventory required without a RxCat operation. With the premium price commanded by ZSM-5 additives, this translates into substantial savings for the refiner.

In addition to the yield and selectivity benefits, RxCat technology can be used to effectively de-bottleneck unit constraints. Approximately half of the catalyst that would traditionally circulate from the reactor to the regenerator is recycled to the base of the riser. As such, the catalyst circulation through the spent and regenerated catalyst standpipes is actually less than the “base case” operations before any technology upgrades were initiated. As opposed to a purely mechanical modification which utilizes CAPEX (new reactor, stripper, standpipes, etc.) for only capacity benefits, RxCat technology pays back with both increased throughput and product yields.

The expected benefits for the previously presented case study with the implementation of RxCat technology is shown below in Figure 17 and Table 3.

Figure 17
Effect of RxCat Technology on Unit Performance

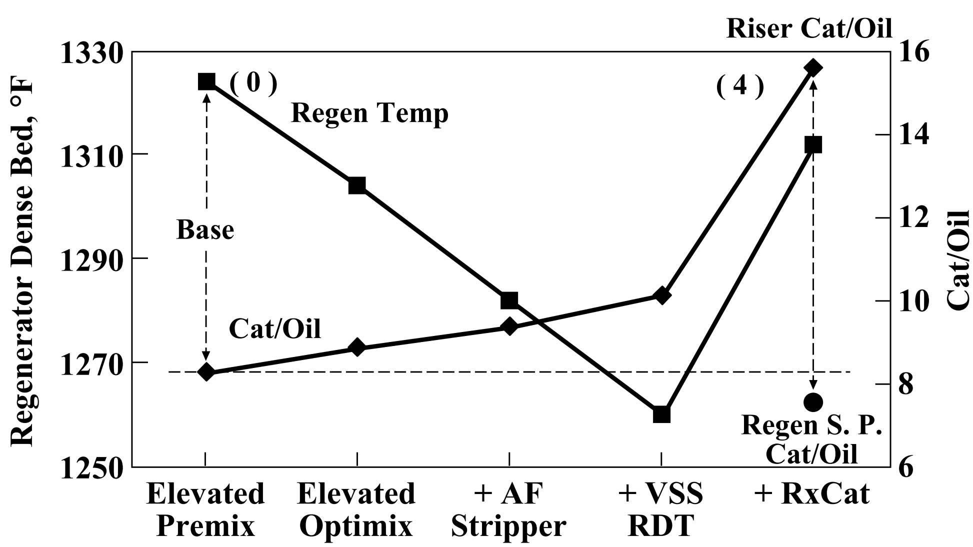


Table 3

Effects of RxCat Technology on Unit Performance

	Base Case Premix Feed Distributor (Point 0)	***Cumulative to RxCat Technology (Point 4)***	
		Riser	***Regen. Standpipe***
Cat-to-Oil	**8.27**	**15.6**	**7.8**
Regen Temp, °F	**1324**		**1312**
Conversion, lv% (90% at 380 °F)	**Base**		**+3.8**
Gasoline, lv% (90% at 380 °F)	**Base**		**+4.9**
Coke, Wt%	**5.6**		**5.4**
Δ Coke	**0.68**	**0.35**	**0.70**

The ability of RxCat technology to improve conversion and selectivity provides the refiner with a tool to achieve improved yield targets with less coke make. The reduced coke make translates to reduced air blower demand as well as a reduction in CO_2 emissions.

Catalyst consumption rates are also very competitive, if not better than typical FCC Units. For one operating RxCat Unit, catalyst consumption was 0.14 lb fresh catalyst per barrel of feed processed. A second RxCat operation has demonstrated approximately 35% lower catalyst consumption than a comparative unit operated by the same refiner without RxCat technology.

Despite the overwhelming success of the RxCat technology, the MxR chamber feature of the configuration has proven challenging in some revamp applications due to the inability to physically fit the chamber within the existing structure, and in some cases, within the timeframe of a turnaround. To address this issue, UOP is in the process of finalizing a modification to the RxCat technology that will eliminate the MxR chamber and enable installation on most FCC units.

SUMMARY

Although Fluid Catalytic Cracking technology is over 65 years old, there is still much to learn and improve, particularly as refiners maximize throughput on existing assets and move from fuels production to higher value products. Advanced diagnostic and design tools are accelerating the development and creation of state-of-the-art technology. This paper showcased three of these innovations that emerged through the use of such sophisticated tools.

CFD modeling, combined with radioactive tomography and commercial data analysis enabled the development of the dual radius feed distributors, and effectively shattered the paradigms on large riser design, extending well beyond previously published operating envelopes. The use of these tools, as well as radioactive tracing and physical inspection reports, allowed for the elephant trunk combustor arm disengager emergence, which is applicable to UOP combustor style regenerators of all sizes. CFD modeling, tomography and commercial data analysis also allowed for the successful development and implementation of the piped spent catalyst distributor, which reduced the excess oxygen level and decreased NOx emissions for bubbling bed regenerators.

RxCat has been proven in four operating units, and offers a cost effective solution for delta coke challenged customers, and lower operating expenses through reduced ZSM-5 consumption for refiners targeting propylene production.

Through the combined approach of using and validating innovative tools, UOP is improving existing FCC designs and moving an aged technology towards true growth opportunities.

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UOP LLC
25 East Algonquin Road
Des Plaines, IL 60017-5017
Tel: 847.391.2000
www.uop.com

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