

Upgrade FCC performance

New ceramic feed distributor offers ultimate erosion protection

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Fluid catalytic cracking (FCC) technology has been a part of the petroleum industry since the 1940s. 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.

Through the development and commercialization of world-scale FCC units, technical discoveries have emerged that provide opportunities for improvements across all units, independent of size. Using sophisticated engineering tools, such as computational fluid dynamic (CFD) modeling combined with radioactive tracer and tomography, will streamline physical inspection reports and commercial yield analysis. The article highlights advancements in regenerator technology for higher capacity through existing assets, emissions reduction and feed distribution systems for large-diameter risers.

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 a particular FCC unit has an inner diameter (ID) of 6.6 ft at the point of feed injection, which expands to 9 ft 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 test this hypothesis, a CFD model of the riser was created to analyze the fluid dynamics of the system. 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 CFD results, a tomographic analysis (gamma scan) of the riser was completed. The scan results confirmed the CFD model prediction as illustrated in Fig. 1.

Radioactive tracer work was also completed on the 9-ft ID riser. Irradiated Krypton-79 gas was injected into the riser base. Detectors were positioned along the riser length 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. An early peak followed by a secondary peak which was skewed a high degree is shown in Fig. 2.

A mathematical evaluation was performed to determine what type of continuous stir tank reactor (CSTR) response would be needed to emulate the measured data. To accurately reproduce the field data plot, a composite plot modeled 100, 40 and 15 CSTR responses (Fig. 2).

Unit performance, CFD modeling, tracer and tomography tests, and mathematical analysis all indicated the same pathology—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 low conversion and high dry gas and coke make. One solution to this problem would be to install two, smaller diameter risers to match more conventional FCC sizes. However, installing dual

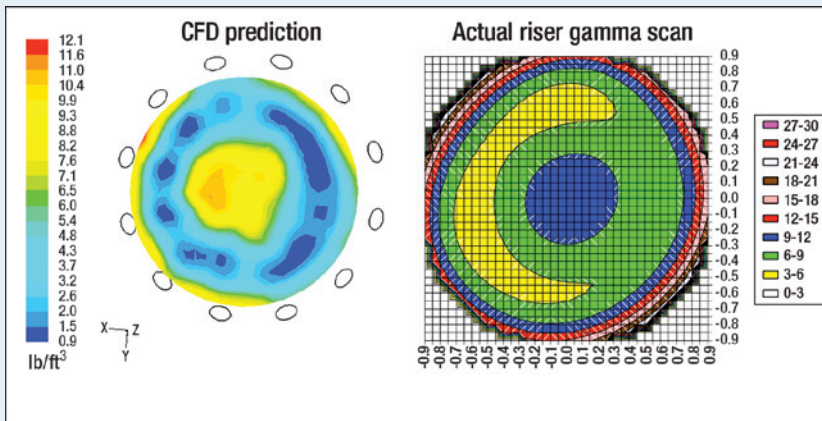


FIG. 1 CFD prediction and gamma scan of 6.6-ft riser.

risers, even with new construction, is substantially more expensive. For an FCC unit of 200,000 barrels per stream day (bpsd), the estimated cost difference between a single, large-radius riser and a pair of smaller risers has a cost estimated at \$60 million. A substantially lower cost solution with an implementation of dual-radius feed distributors was developed (Fig. 3). This design ensures optimal feed distribution across the entire riser, while avoiding adjacent spray impact that could cause undesirable spray interference.

Another CFD model that incorporates the dual-radius feed distributors was created. Fig. 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 shows the high-density core of the catalyst; the CFD model with the dual radius feed distributors indicates that the catalyst's dense core is effectively eliminated.

The dual-radius feed distributors were installed on a FCC unit designed with an 8-ft-diameter riser at the point of feed injection. The unit was commissioned in May 2009. Results indicate that dry gas yield and conversion and gasoline selectivity were within expectations. The riser's gamma scans indicate that the catalyst's high density core was effectively eliminated. The catalyst density profile of the riser at approximately 1 pipe diameter above the point of

dual radius feed injection, indicates that core annular flow has been achieved with an evenly distributed catalyst density profile (Fig. 5). Additional tomography scans were completed at varying feed ratios to optimize distribution of oil and steam across the riser.

Erosion of the inner feed distributors was a client concern. This was mitigated by using ceramic feed distributors. Ceramic offers the ultimate in erosion protection, and feed distributors with ceramic tips can 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 function in this harsh environment, FCC feed distributors have historically been fabricated from various erosion-resistant materials. While these materials are 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 erosion and brittle fracture can occur when relatively cold oil and/or steam are rapidly introduced to the system in which the tips are hot from circulating catalyst.

These issues were addressed in many ways with a distribution system. Following proper operating procedures will avoid thermal shock and brittle fracture. However, erosion is more a function of operating environment as opposed to improper operation.

Designs. Advanced design feed distributors include three primary designs: standard, weld overlay and ceramic. The standard design—the new distributor for most FCC applications—balances the erosion issue and the possibility of cracking due to thermal shock. The tip incorporates a more erosion-resistant metal alloy, changing the geometry and reducing stress concentrations. Incorporating orifice extensions extends the flashing hydrocarbon feed further away from the metal tip. Additional protection can be provided by applying a very hard diffusion coating over the cobalt-based (Co-based) alloy.

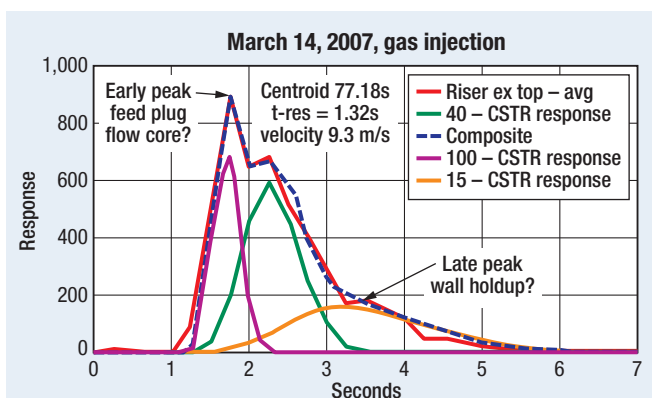


FIG. 2 Mathematical composite.

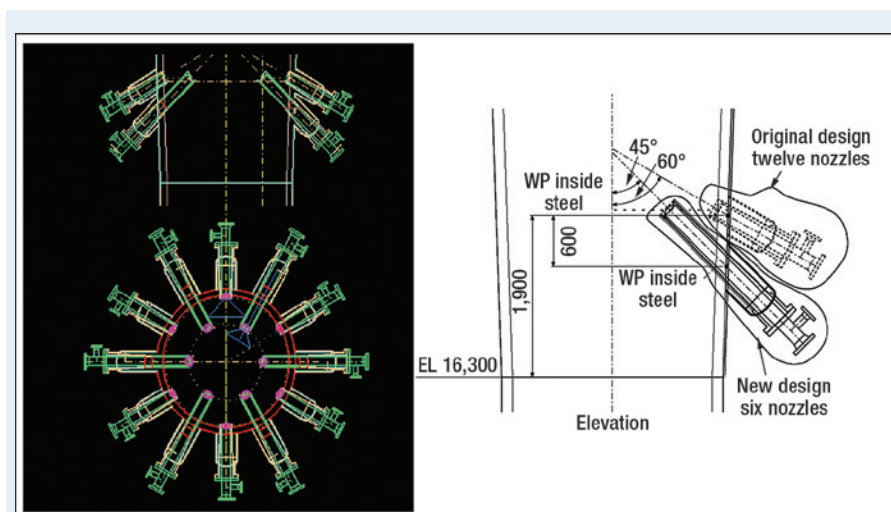


FIG. 3 Schematic of dual-radius feed distributors.

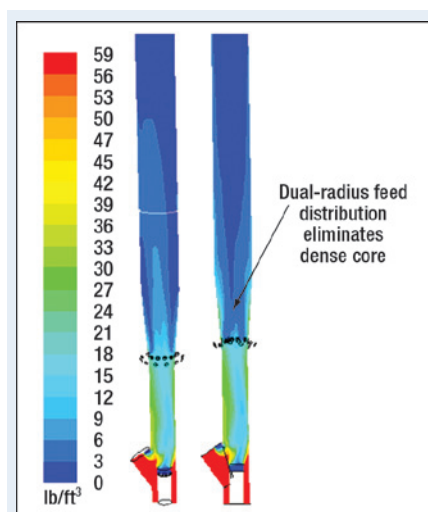


FIG. 4 CFD models of the riser catalyst profiles with and without dual-radius feed distributors.

The weld overlay design is applied to resolve chronic problems with wet steam and installations that 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 distributor tip. While a very hard diffusion coating is used to provide additional protection against erosion, the primary design goal is resistance to thermal shock, and, therefore, it 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. Determining the erosion

potential of FCC feed distributors is based on the physical properties of the feedstock. The ceramic design is used in applications where erosion is forecast 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 new ceramic tips are no more susceptible to thermal shock than traditional fabrications with co-based alloys. Fig. 6 shows three new tip designs, as well as older versions.

Ceramic tips—design challenges. Ceramic materials are widely accepted and proven to be more resistant to erosion than metallic materials. The characteristics that impart erosion resistance also tend to make these materials more brittle. Successful application of ceramics in FCC feed injection required that two technical challenges be overcome: 1) selecting a suitable ceramic material that can be fabricated into the required geometry and 2) developing a means to connect 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-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. Quench testing was used to help select the proper ceramic material, and it confirmed that the final material was no more susceptible to brittle fracture than previous FCC feed distributor metallic tips.

The large differences in thermal expansion coefficients between the materials provided the next challenge—a means of attaching the ceramic tip to the metallic base assembly. The attachment should 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 FCC unit shutdown. Creative engineering, 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 new distributors in a commercial application.

Ceramic tips—a commercial experience. As the design details for the new ceramic tip and connection were finalized, an opportunity presented itself in which two ceramic tips could

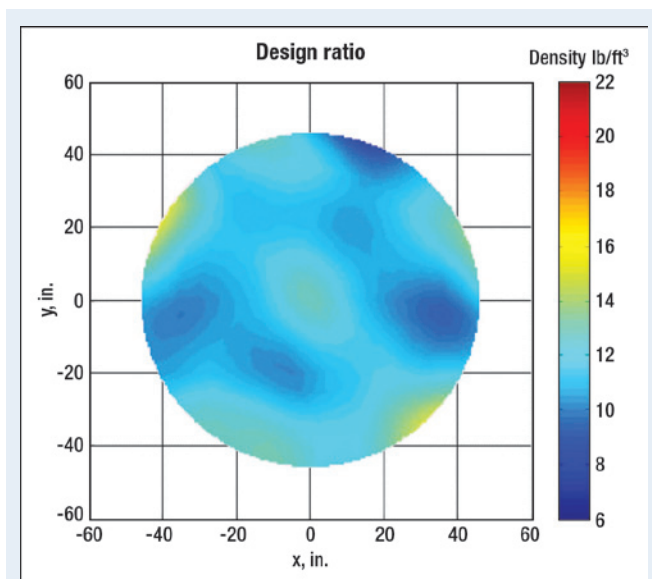


FIG. 5 Gamma scan of 8-ft ID riser with dual-radius feed distributors.

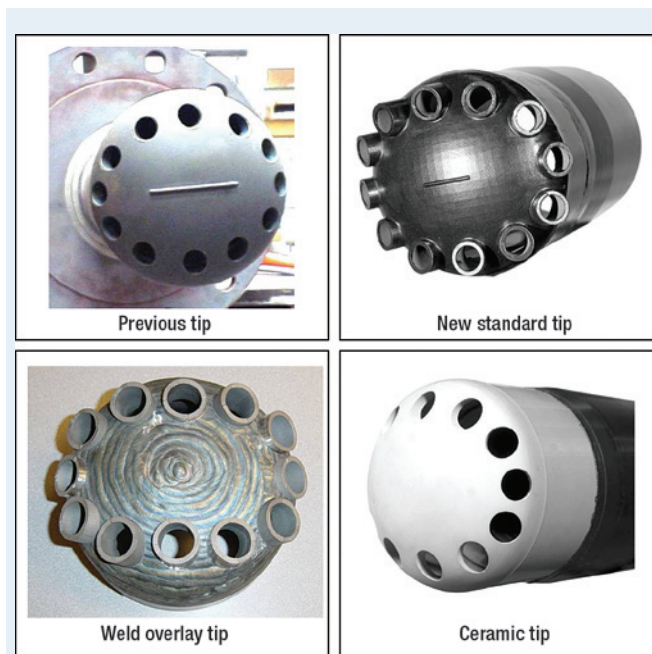


FIG. 6 FCC feed distributor tip designs.

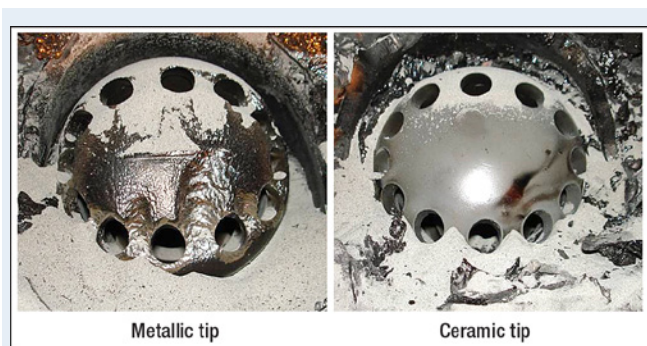


FIG. 7 Metallic and ceramic feed distributor tips after 18 months in operation.

be installed in the same reactor riser at the same time as metallic tips, providing an ideal side-by-side commercial test.¹ 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. In April 2007, ceramic tips were commissioned in a commercial FCC reactor riser.

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

The viability and benefit of using ceramic tips for the feed distributor were 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.

Since January 2010, FCC ceramic feed 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 it continues to perform well with two additional project shipments pending. Ceramic distributors are currently recommended and supplied as the premiere offering to improve reliability in installations with aggressive distributor tip erosion.

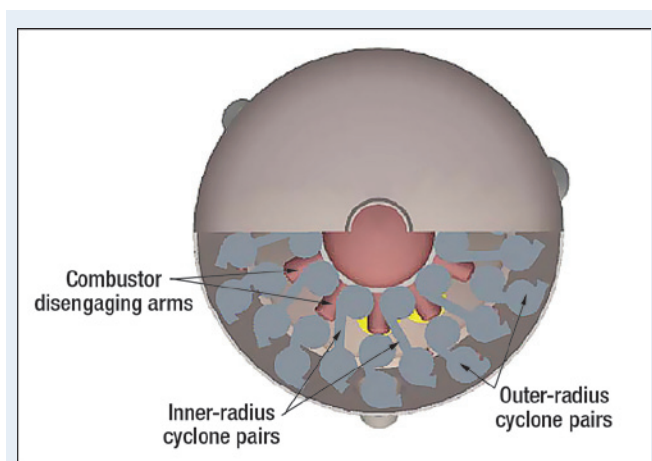


FIG. 8 Dual-radius cyclone system in regenerator.

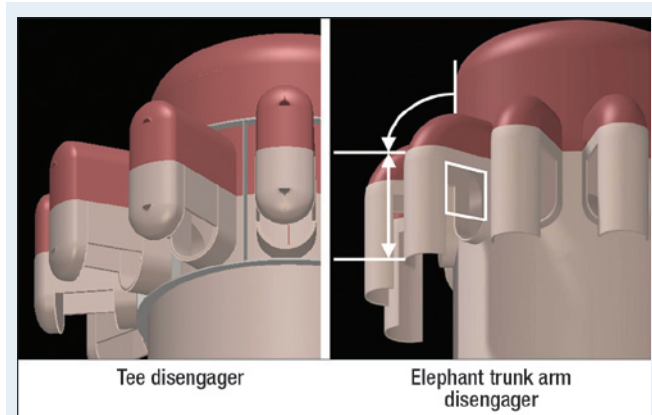


FIG. 9 Tee and elephant trunk arm disengage.

Elephant trunk 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 occurred on a large 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 an existing asset.

The inside of the upper regenerator has two major pieces of equipment: cyclones and a combustor disengager. The combustor disengager provides the first-stage inertial separation of catalyst from the combustion products, and the cyclones provide the final separation. Layout of this particular regenerator is unique in that the cyclone pairs are configured on two different radii (Fig. 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.

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 (Fig. 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. This 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 in. apart. However, the preferential flow was readily apparent upon internal unit inspections at the turnaround six years after commissioning. A slight change to the base design had a profound impact on the equipment performance.

Solution. The solution developed was a variation on what is called the elephant trunk disengager (Fig. 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

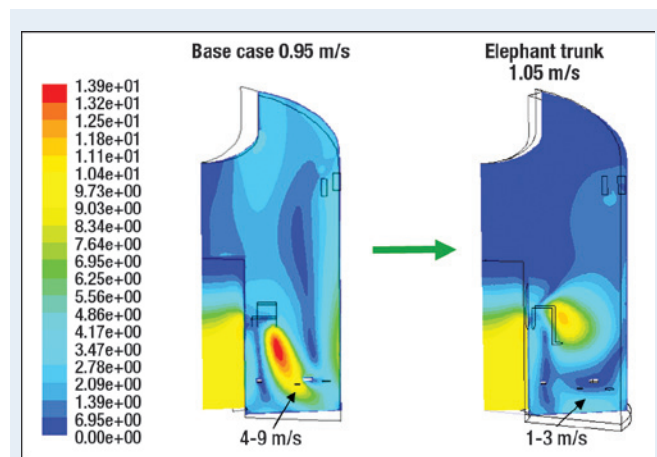


FIG. 10 CFD model of the gas profiles in the upper regenerator with tee and elephant trunk arm disengagers.

were achieved. The disengager arm was curved to lower the impact transition, reduce catalyst attrition and improve lining reliability. The shroud was extended to direct the catalyst more into the catalyst bed, but was limited in length so as not to provide excessive separation efficiency that would lead to increased afterburn and high dilute phase temperatures. The outlet area was optimized to ensure that the combustion gases bleed off horizontally with minimal cross-wind at cyclone dipleg terminations (Fig. 9).

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 (Fig. 10).

With the original design, 10 out of 11 inner cyclones holed through after six years of operation. With the elephant trunk disengage installation, 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 reduce maintenance costs and realize greater onstream 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 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 determine the proper boundary conditions for the models, multiple radioactive tracer tests were completed on regenerators with the tee disengager and 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

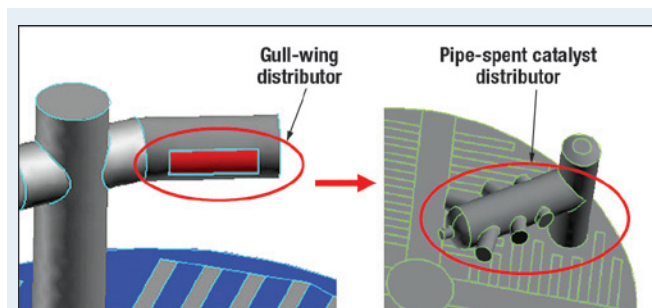


FIG. 12 Gull-wing and piped spent-catalyst distributor.

of the elephant trunk disengager confirmed a greater amount of gas dispersion, eliminating regions of high gas velocity, and effectively using regenerator volume.

The first commercial combustor riser elephant trunk disengager was commissioned in 2009. Initial results have been 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%—substantially improving regenerator performance. The unit design and operation resulted in extremely low delta coke operation and a regenerator average dense-bed temperature as low as 1,198°F. Even with this low regenerator temperature operating at maximum throughput, the average afterburn is only 8°F. This is a step-change advancement in regenerator combustion performance and it supports that the modeled increase in flue-gas residence time was achieved.²

The elephant trunk disengager was developed 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, by using these sophisticated tools, other benefits were discovered that are applicable to all sized units. Eliminating the high-velocity regions reduces 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 NO_x emissions. Now, 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. Engineering tools and associated skills used to solve the previously discussed problems for 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 used 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 instrumentation is placed in relation

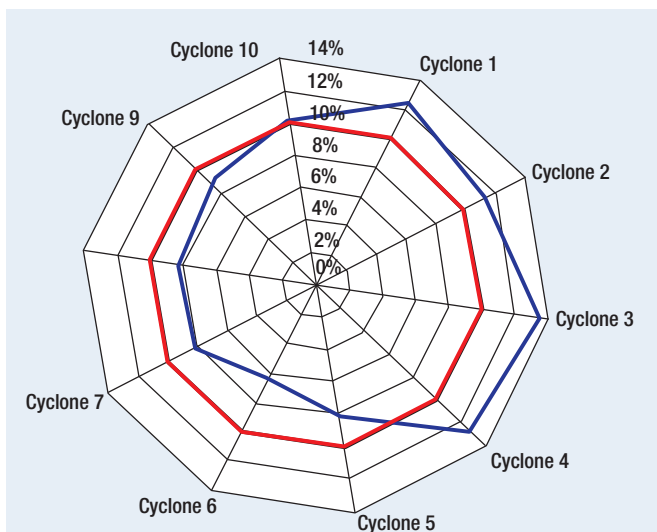


FIG. 11 Catalyst tracer results for a bubbling bed regenerator with a gull-wing design.

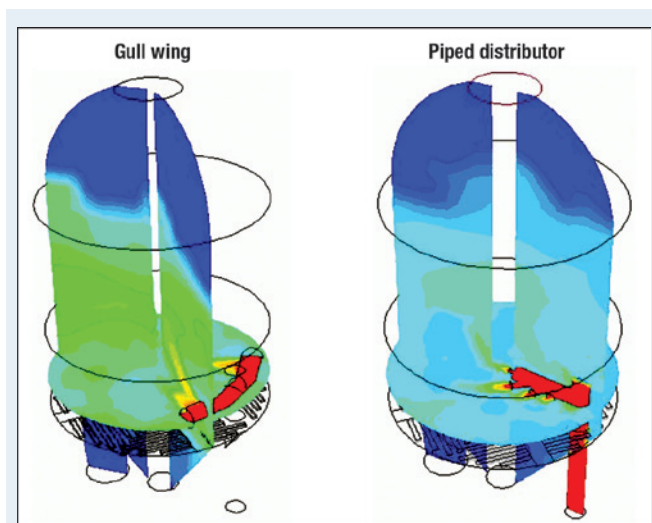


FIG. 13 CFD model of the catalyst densities in a regenerator with gull-wing and piped spent-catalyst distributors.

to the spent-catalyst inlet.

To 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 (Fig. 11).

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. Fig. 12 is a schematic of the distributor. 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 caused a 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 (Fig. 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 much even catalyst and air distribution as possible within the back-pressure limitations of the existing lift air blower.

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 bed center. With the piped spent catalyst distributor, the catalyst distribution was much more uniform throughout the bed (Fig. 13).

Results. The piped spent-catalyst distributor was commissioned in December 2006. Post-revamp tracer tests were conducted on the regenerator. The actual catalyst distribution is very close to the ideal distribution as illustrated in Fig. 14.

Operational data also indicate 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 piped 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. **HP**

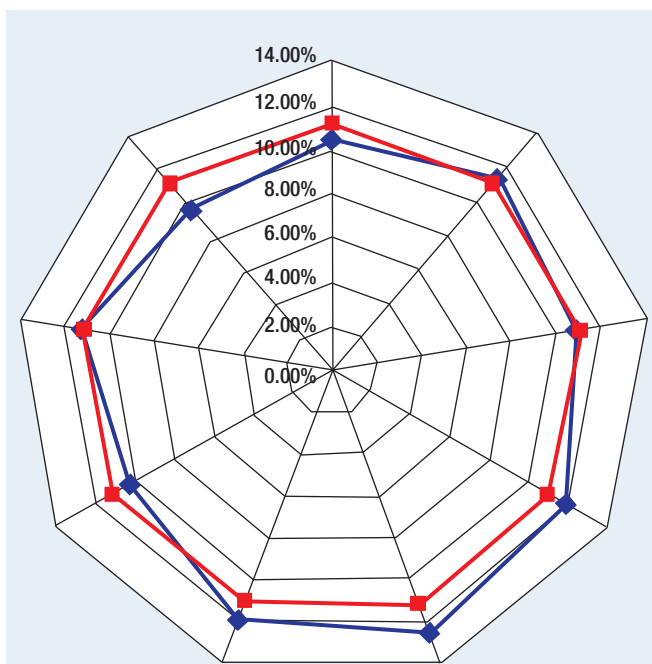


FIG. 14 Catalyst tracer results for bubbling-bed regenerator with piped spent-catalyst distributor.

A new catalyst regenerator technology was developed to improve Δ coke operations. Since improved equipment technology and catalyst offerings have resulted in progressive decreases in Δ coke, refiners have continued to debottleneck unit constraints within the capacity of existing major equipment. Usually with the constraint of not replacing main vessels or large rotating equipment, i.e., main air blowers (MABs), wet gas compressors (WGCs), regenerator shells, reactor shells, stripper shells and catalyst circulation standpipes. Maintaining this philosophy through several technology upgrades can result in several operational and reliability concerns:

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

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

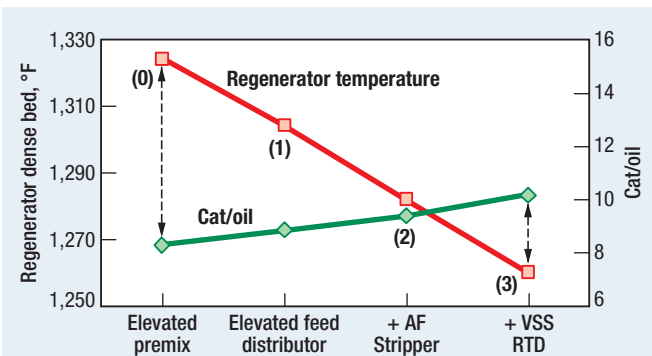


FIG. 15 Technology upgrade effects.

Combined technology effects. Fig. 15 illustrates the expected benefits to be obtained from a step-wise improvement in FCC reactor technology. The individual steps include:

- Replacing an elevated distributor with elevated feed distribution system
- Replacing a reactor stripper with an advanced fluidization stripper technology
- Replacing a tee riser termination device (RTD) with a vortex separation (VSS) RTD.

With each progression, the refiner gains the yield and selectivity benefits inherent of increased catalyst-to-oil and lower Δ coke. The combined technology improvements resulted in a 23% increase in catalyst circulation and a regenerator dense-bed temperature reduction to 1,260°F. The technology benefits are summarized in Table 2.

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, introducing greater risk to the system reliability. With the onset of clean fuels initiatives, these issues can be further strained by increasing the percentage of hydrotreated feed to the unit and further decreasing the Δ coke and regenerator temperature.

Refiners moving toward 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. Using a 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 these issues present problems that the refiner must overcome, they also present some excellent operational, financial and environmental opportunities.

New technology recycles spent catalyst. The problems of low Δ coke operations (low regenerator temperature) have created an opportunity that was 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. The term “carbonized” was adopted to describe this catalyst. The activity characteristics of carbonized catalyst are not only usable, but are, in certain cases, preferred. Coke deposition preferentially attenuates the strongest catalytic sites, providing for more selective cracking with carbonized catalyst.

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. The new 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 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 decoupled from the unit heat balance.

With new technology, a portion of the stripped catalyst (~1,000°F) is directed through the recycle catalyst standpipe to the chamber where it is combined with the hot regenerated catalyst (~1,300°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

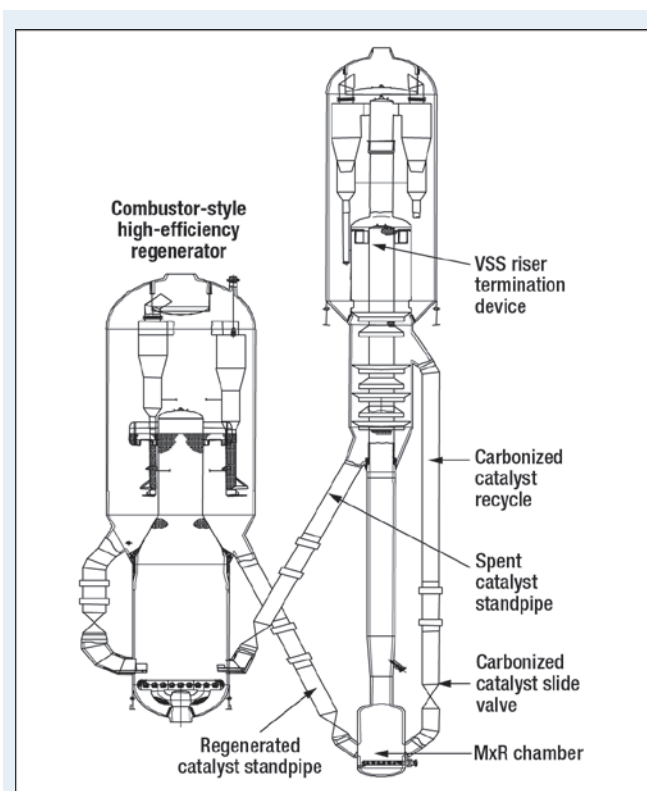


FIG. 16 Recycling spent catalyst technology.

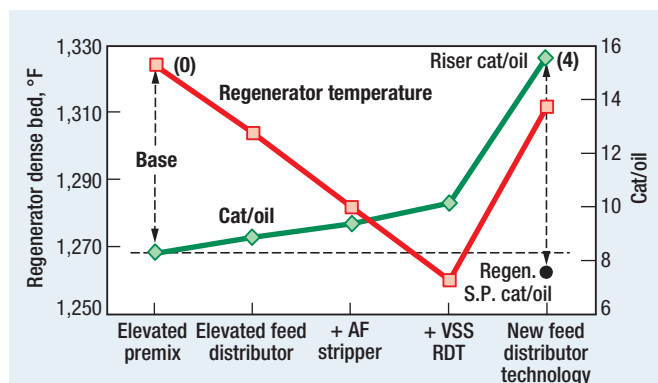


FIG. 17 Effect of new technology on unit performance.

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.

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 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 makeup. With new technology, a change in catalyst activity in the riser can be accomplished by merely changing the amount of carbonized-catalyst recycle. **Result:** The change from gasoline mode to/from olefin mode can be rapid. This application has an even greater impact for refiners that use liquefied-petroleum-gas olefin additives, i.e., ZSM-5, and refiners 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 new technology designs have been commissioned and are operating successfully. Four more units are now in design, and five more are currently under construction. Integrating the new technology provides numerous benefits in both revamp and new unit applications, providing the refiner with the ability to accomplish 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.

The expected benefits for the presented case study with the implementation of the new technology is shown in Fig. 17 and Table 3.

The ability of this new 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 CO₂ emissions.

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 • Lower CO₂
Less dry gas	But Sufficient regenerated catalyst temperature for: • Improved coke burn kinetics
Higher throughput	But Retain existing equipment—Min. CAPEX: • MAB, WGC, standpipes

TABLE 2. Technology upgrade effects

	Base case premix feed distributor (point 0)	Plus VSS (point 3)
Cat-to-oil	8.27	10.14
Regenerator temperature, °F	1,324	1,260
Conversion, lv% (90% at 380°F)	Base	+0.7
Gasoline, lv% (90% at 380°F)	Base	+1.8
Coke, wt%	5.6	5.6
Δcoke	0.68	0.55

TABLE 3. Effects of new technology on unit performance

	Base case premix feed distributor (point 0)	Cumulative to new fad distribution technology (point 4)	
		Riser	Regenerator standpipe
Cat-to-oil	8.27	15.6	7.8
Regenerator temperature, °F	1,324	—	1,312
Conversion, lv% (90% at 380°F)	Base	—	+3.8
Gasoline, lv% (90% at 380°F)	Base	—	+4.9
Coke, wt%	5.6	—	5.4
Δcoke	0.68	0.35	0.70

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

Summary. Although FCC technology is over 65 years old, there is still much to learn and improve upon 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 article showcased three of these innovations that have emerged by using 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. Using these tools, along with radioactive tracing and physical inspection reports, led to the development of the

elephant trunk combustor arm disengage, which is applicable to 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 NO_x emissions for bubbling bed regenerators. **HP**

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