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UOP FCC INNOVATIONS DEVELOPED USING SOPHISTICATED ENGINEERING TOOLS

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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, new technological innovations can be delivered 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.

DUAL RADIUS FEED DISTRIBUTORS

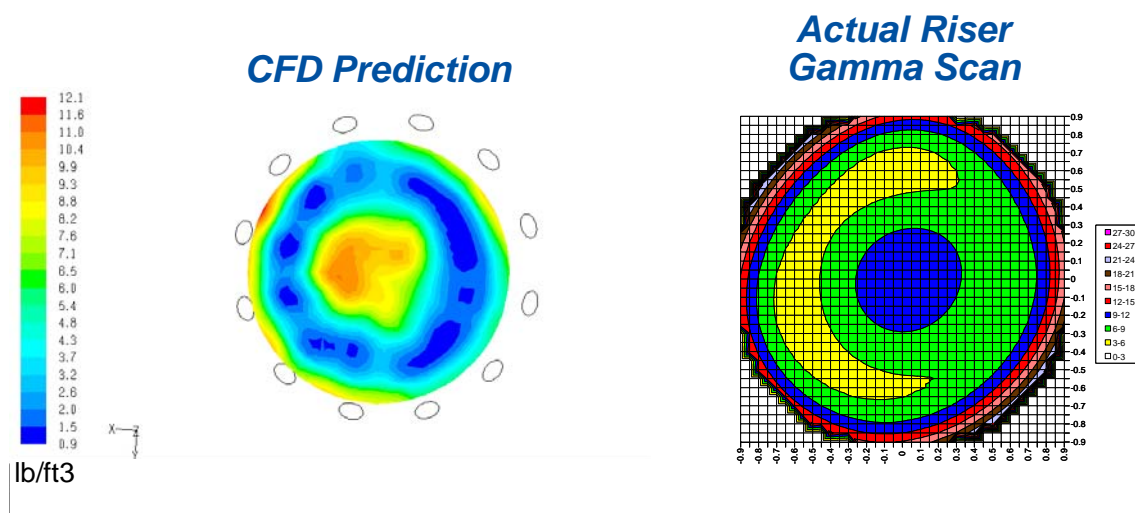
As refiners look to capitalize on economies of scale, design throughputs of FCC units have reached record levels. At this scale, opportunities have emerged from the background noise of the data to improve FCC technology. Through pushing multiple constraints to design limits, yields and conversion deviated 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 2 meters (6.6 feet) at the point of feed injection, which expands to 2.7 meters (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 CFD model of the riser was created to analyze the fluid dynamics of the system. The results of the model supported the theory 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.

Figure 1. CFD Prediction and Gamma Scan of 2 meter (6.6 foot) ID Riser

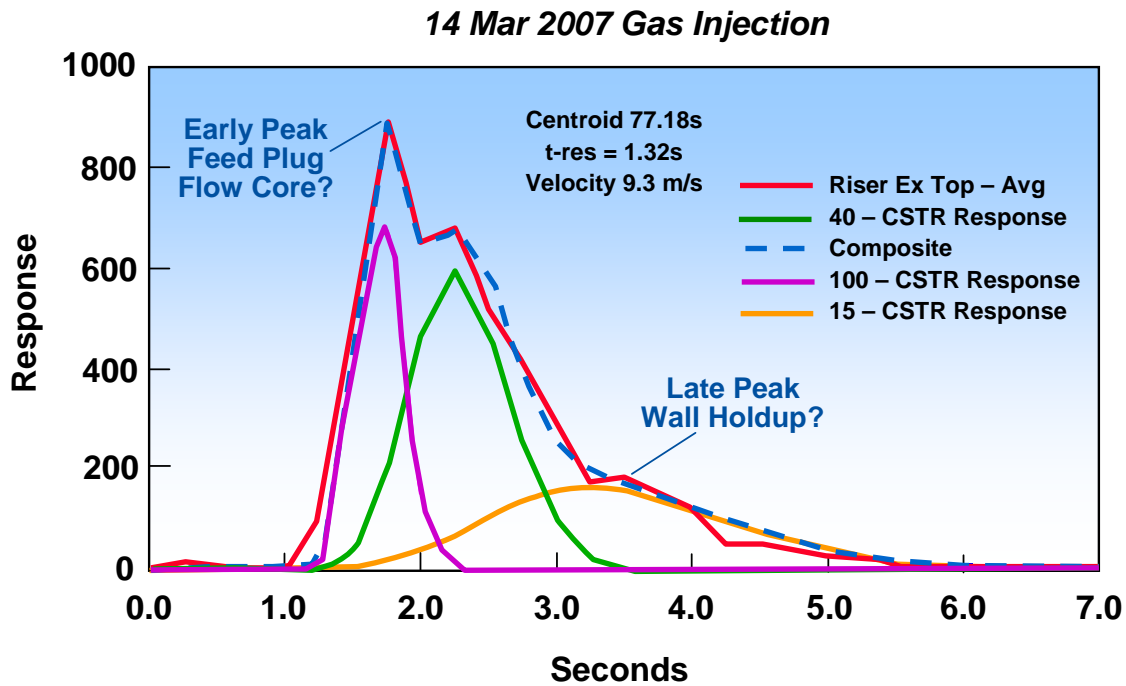


Radioactive tracer work was also completed on the 2 meter (6.6 foot) ID riser. Irradiated Krypton-79 gas was injected into the riser base. Detectors were positioned along the riser length and reactor to measure the tracer as it moved through the system. The results indicated that the time of flight of the krypton gas from one detector to another did not provide a sharp response peak. Rather, there was an early peak followed by a secondary peak and a high degree of skewness (Fig. 2).

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

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

Figure 2. Mathematical Composite



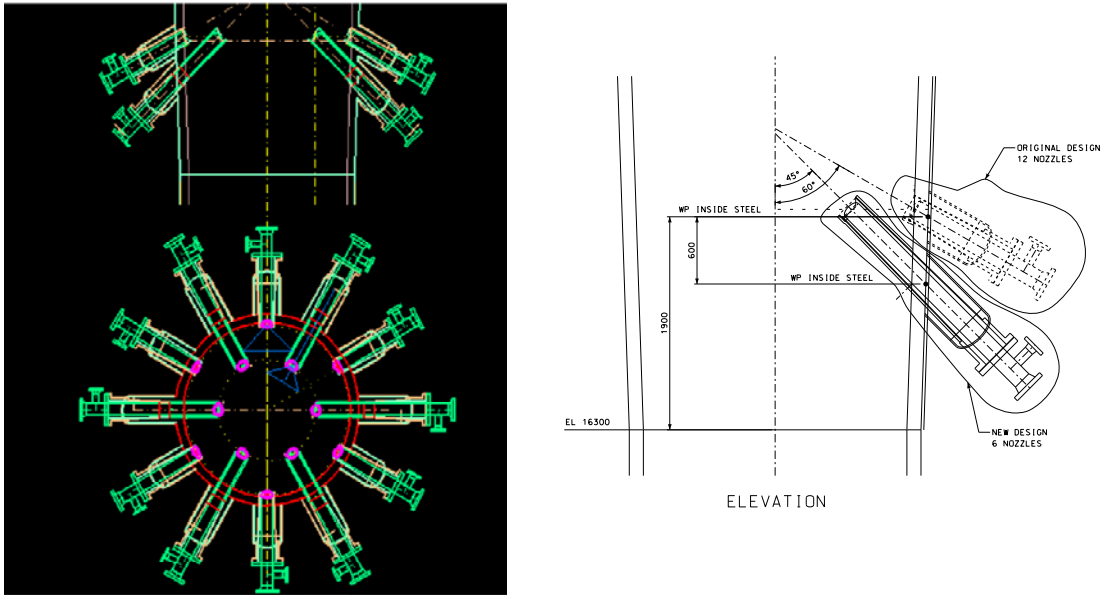
density annulus which caused low conversion and high dry gas and coke make. One solution to this problem would be to install two, smaller diameter risers to match more conventional FCC sizes. However, installing dual risers, even with a new construction is substantially more expensive. For an FCC Unit of 200,000 barrels per stream day (BPSD), the estimated cost difference between a single, large-radius riser and a pair of smaller risers was estimated to cost \$60 million, in 1998 US Dollars.

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

Another CFD model that now incorporated 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 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.

The dual radius feed distributors were installed on an FCC Unit designed with a 2.4 meter (8 foot) diameter riser. The unit was commissioned in May 2009. Results indicate that dry gas yield, conversion and gasoline selectivity are all within expectations. The riser's gamma scans

Figure 3. Dual Radius Feed Distributors Schematic



indicate that the high density core of catalyst 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 a very evenly distributed catalyst density profile (Fig. 5). Additional tomography scans were completed at varying feed ratios, to optimize the distribution of oil and steam across the riser.

SPENT CATALYST DISTRIBUTOR

PROBLEM

The Engineering tools and 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 56°C (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.

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

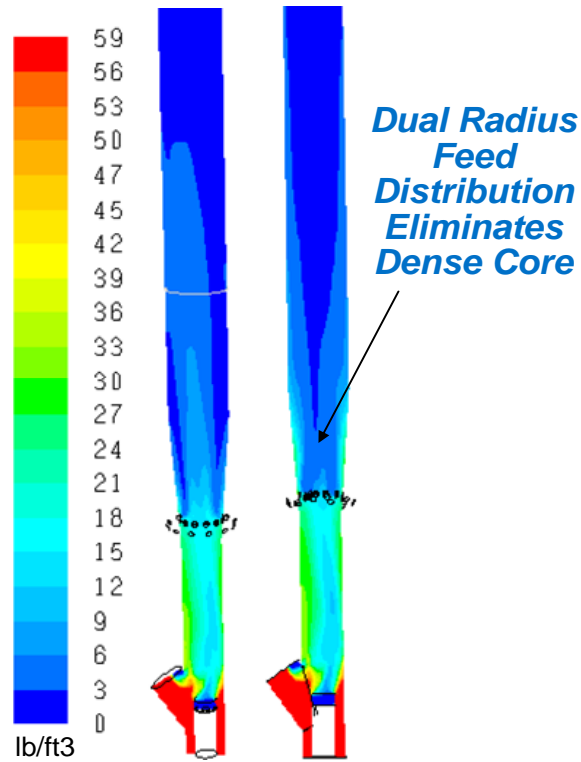
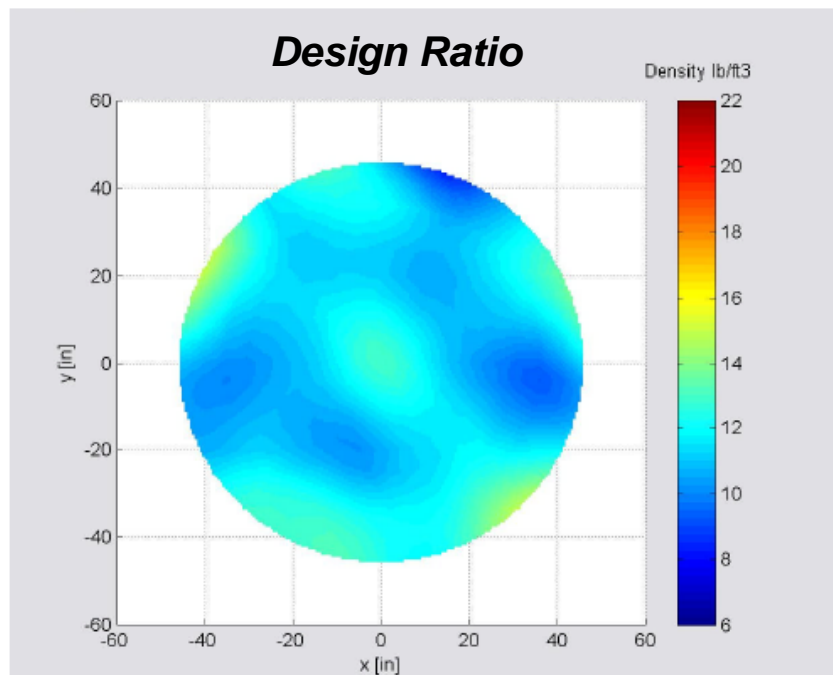
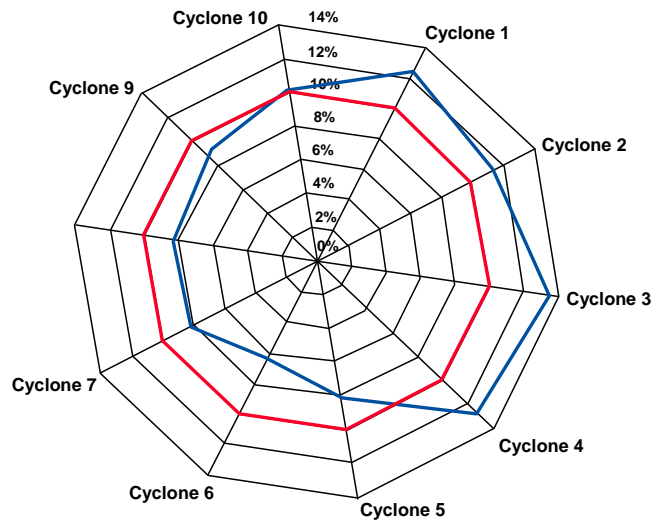


Figure 5. Gamma Scan of 2.4 meter (8 Foot) ID Riser with Dual Radius Feed Distributors



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. 6).

Figure 6. Catalyst Tracer Results for Bubbling Bed Regenerator with Gull Wing Design



SOLUTION

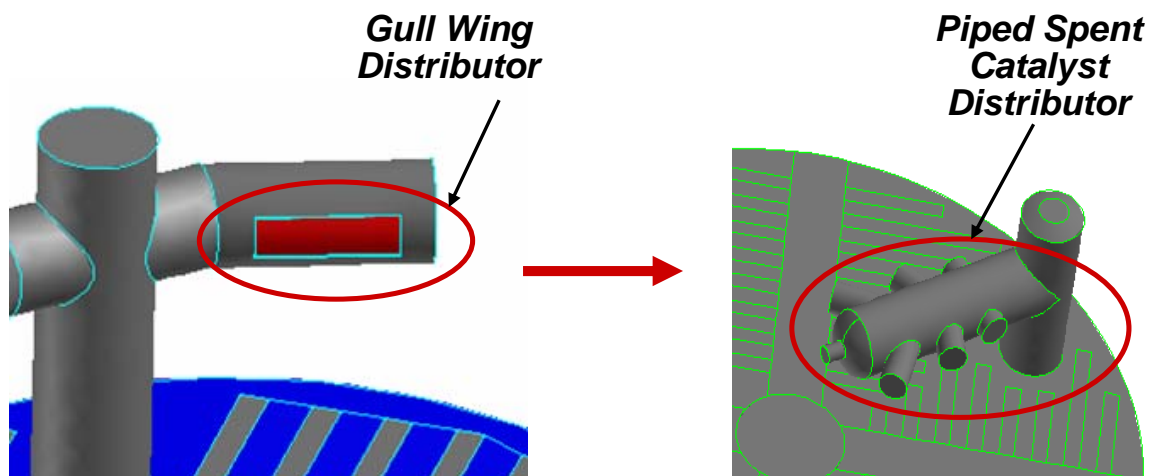
The typical spent catalyst distributor installed in a bubbling bed regenerator of this vintage was the gull wing design with an external lift riser. A schematic of this distributor is shown in Fig. 7. Air maldistribution in this type of regenerator design results from two sources. First, the external riser lift air discharges vertically out of the disengager, resulting in an oxygen rich environment in the dilute phase. Second, the high localized catalyst density and resultant hydraulic head causes 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. 7). 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.

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 (Fig. 8).

Figure 7. 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 (Fig. 9).

Operational data also indicates a significant improvement in the regenerator performance. The dilute phase temperature differential was reduced from 56°C (100°F) pre-revamp to about 8°C (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 8. CFD Model of the Catalyst Densities in a Regenerator with Gull Wing and Piped Spent Catalyst Distributors

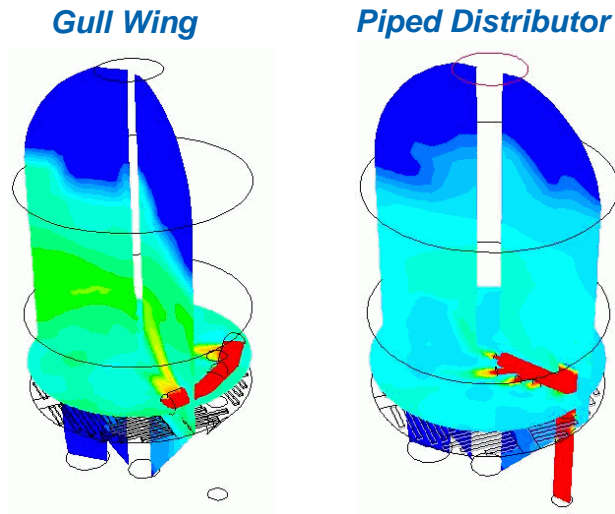
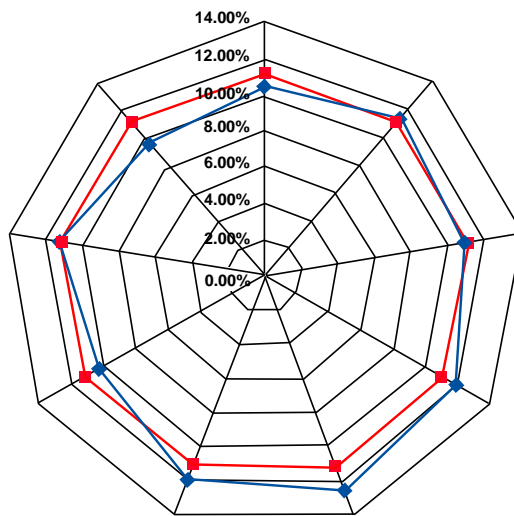


Figure 9. Catalyst Tracer Results for Bubbling Bed Regenerator with Piped Spent Catalyst Distributor



NOTATION

t-res residence time