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INTRODUCTION

Oil and gas refiners have run into some new and difficult challenges in recent years. Among them are the requirements for large capital expenditures and increased hydrogen usage for low sulfur fuels that are mandated by new environmental standards. Gasoline shortages caused by the hurricane damage in the United States Gulf Coast region has prompted news reports highlighting increased profit margins for refineries. Typically these margin increases are represented in absolute terms on a per gallon basis, and are not normalized by the cost of crude oil, which must be paid by the refiner. Although the price of gasoline has increased significantly, there is continued downward price pressure on petroleum products that are used in the chemical industry, because consumers and distributors have been able to keep consumer product prices low. Therefore, minimizing unplanned down-time while keeping operational and utility costs at a minimum is critical to business.

An additional challenge to refineries is the new set of environmental regulations that requires plants to reduce air pollution emissions. For example, the State Implementation Plan (SIP) for reducing NOx emissions in the Houston/Galveston area in Texas requires costly equipment retrofits and upgrades to conform to standards.
Following a tragic refinery explosion in 2005, operators have been raising safety awareness at their plants. The deaths and injuries from incidents like this one underscore the point that equipment failures are intolerable when they result in both human and financial loss.

All of these challenges mean that refinery operators must have a heightened awareness of safety, emissions, and cost reduction issues such as improving unit and refinery reliability, reducing refinery losses, and conserving energy. This white paper provides several examples showing how three-dimensional simulation software is being used in refineries to increase unit operation efficiency and improve reliability. The results have shown that engineers who use these tools to simulate the process in the virtual realm before building or modifying a unit see substantial savings in time and money, making their operation more profitable and safer.

**FCC RISERS**

Fluidized Catalytic Cracking (FCC) units are used to convert higher molecular weight crude distillates into lighter hydrocarbons that have more market value, such as gasoline, diesel, and fuel oil. The purpose of the riser is to force the high molecular weight feed into contact with catalyst particles for a desired period of time in order to crack the hydrocarbon chains into smaller molecules. The physical processes in these units are extremely complex, and it can be difficult to understand why performance is lower than expected. Often, performance problems are related to flow and thermal distribution of catalyst particles and feed. One such problem unit is depicted in this example, which was simulated by Fluent Inc. and KBC Advanced Technologies, Inc.

Figure 1 a) shows the geometry of the base of a riser that was underperforming. The engineering goal is to maximize contact between the feed (entering through the vertical standpipe holes) and the catalyst (entering from the angled standpipe) over the 36 meter height of the riser, so that an optimum amount of hydrocarbon cracking occurs.

Figure 1 b) depicts contours of catalyst volume fraction on several planes above the feed inlet, revealing regions of fully packed catalyst (red), and indicating very little mixing of catalyst and feed. Eventually, the catalyst concentrates on the side of the riser opposite the catalyst standpipe.

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These results make it clear that there is significant room for improvement regarding the mixing of feed and catalyst, that will likely lead to improved performance, thus increasing output and profits substantially. The next step in this project is anticipated to be an investigation of the impact of the feed inlet configuration.

**FCC COMPONENTS**

Maintaining the proper flow distribution in FCC components can have an enormous impact on operating costs. The regenerator, which burns the coke off of used catalyst prior to re-use, is a prime example. The blower in this unit is designed to draw air in and supply it to the regenerator internal manifold. Several years ago, the blower at a Mobil refinery was operating below 90% efficiency, which was significantly lower than that of other similar units, limiting the overall FCC performance. A flow simulation was performed to search for flow distribution problems in the line from the ambient air inlet to the blower intake port. As is visible from the velocity magnitude contours in Figure 2, the flow was strongly skewed by an unexpected interaction between two bends and the valve wafer in its normal open position. The mal-distribution of the flow at the blower face reduced efficiency. It was found that by adjusting the valve wafer’s position, the flow distribution could be significantly improved, sidestepping the need for more expensive modifications. It was estimated that the resulting incremental capacity benefit exceeded $6 million per year, all due to the insight gained from simulation.

**CATALYTIC REACTORS**

Standard flowsheet models can do a sufficient job of including catalytic reactor units within refineries when there is a long history or a clear understanding of performance over a wide parameter range. Flow distribution through the catalyst, however, can play an important role in the unit’s performance. In most cases, an even velocity distribution over the unit leads to optimal operation.

One refinery wanted to increase throughput and operating severity of a fixed bed reactor unit by increasing reactor catalyst loading without incurring a significant capital expenditure. This required reducing the headspace above the catalyst bed. To ensure the higher pressure drop through the catalyst bed would not cause bed channeling, the engineers decided to design improved inlet distributor and outlet collector systems.
KBC Advanced Technologies and Fluent Inc. simulated both reactors in order to assess the performance of the new bed relative to the old. Figure 3 shows the velocity magnitude on the center plane within each catalyst bed. In the revamped case, catalyst loading was doubled. While this new bed contains a small high velocity region near the outlet, the overall catalyst contacting is better, indicating a successful design of the extended bed reactor, which will increase unit capacity at a higher operating severity, enhancing the refinery’s bottom line.

EROSION

Some indication of erosion’s incurred cost can be ascertained from a rupture event caused by erosion and corrosion in the UK in 2001. While no deaths were caused by the accident, the owner was fined £895,000, in addition to bearing the cost of replacing the process equipment.

In refineries, erosion is most often caused by the impact of catalyst particles, sometimes inadvertently carried over from FCC units to the flue gas. Three-dimensional simulation can be used both to troubleshoot existing plant components that are subject to eroding environments and to minimize erosion rates in new equipment where erosion is a concern. The motion of fluid and entrained solids can be simulated through a part or unit by using a virtual erosion model that will calculate local erosion rate as a function of particle impact angle and velocity. Additionally, the simulated eroding part geometry can deform over time to take into account the shape change and ensuing changes in particle impact and erosion rate. Figure 4 shows contours of local erosion rate in a pipe with two 90 degree bends both initially, and after 5 ½ years of operation. The final internal shape of the pipe and the local total erosion is calculated. Once this information is known, baffles and/or bend angle reductions can be considered and simulated to quantitatively determine the benefits of any modifications.

FURNACE OPTIMIZATION

Furnaces are common in refineries, both for generating steam, and for thermal cracking operations. One of the major challenges facing operators is minimizing emissions from furnaces, while at the same time maintaining temperatures at levels that optimize the process.

Ethylene cracking is one example where this problem is particularly vexing. In planning to install staged low-NOx burners in one of their ethylene cracking facilities, ABB Lummus Global suspected that the flames would impinge directly on the process tubes, resulting in overly high temperatures and coking in the tubes. To confirm this suspicion, they modeled the entire furnace, including flow and reaction in process tubes, in order to get accurate tube temperatures.

Figure 5 shows temperature contours in the cracking furnace for several different scenarios. The first graphic in the figure depicts temperatures for one cross-sectional plane during operation under the original design parameters. The process tubes in the center are then predominantly heated by radiation from the walls. In b), the original burners are replaced with low NOx burners, which are operating under the same firing conditions. It is clear from the color contours
that the flames impinge on the process tubes near the lower end of the furnace. Using flow simulation, ABB Lummus experimented with floor placement and wall firing angles of the burners, and ultimately came up with the solution shown in c), where the flames no longer impinge directly on the process tubes in the center of the furnace. This new configuration is now in use and performing as predicted at the plant. The only other alternative for arriving at this solution would have been lengthy and costly physical tests and prototypes.

**SUMMARY**

Refineries are under ever-increasing pressure to minimize costs, safety risks, downtime, and emissions while maximizing performance. Frequently, the solution of fluid flow problems can lead to significantly enhanced unit performance and reliability, thereby improving the operation's profit margin while drastically eliminating the human risk factors.