

AVOID NASTY SURPRISES

Surprises are not always a good thing, especially during plant turnarounds. **Peter Blaser, Peter Loezos, and Bryan Tomsula, CPFD Software, USA**, highlight how simulations can be a critical turnaround risk reduction tool.

Turnarounds represent a unique opportunity to improve operations for a unit which runs 24/7 for years on end. But, if the post-turnaround behaviour is not as expected, the consequences remain for years as well. Reducing turnaround risk is critical for successful turnaround planning.

Refinery simulations

Simulation is an effective turnaround risk reduction tool. Simulations are used to identify the root cause of underperformance, ensuring that any planned changes have maximum impact. They are then used to perform virtual testing of potential modifications, to verify benefits while avoiding unexpected adverse effects. Lastly, simulations provide additional insights into unit performance, and often highlight other opportunities for optimisation.

Simulation, by itself, does not ensure a successful turnaround. Rather, the distribution of outcomes predicted mimic the distribution of outcomes from actual turnarounds: the turnaround could be wildly

successful, or have an average impact with some surprises, or it could make things worse. But, by testing the effects of turnaround changes in a virtual environment, simulation is used to reduce the probability of the poor or marginal outcomes, and increase the likelihood of successful, uneventful turnarounds with stable start-up and smooth operations.

This article explores the various potential outcomes through industrial case studies taken from North American refineries. Many types of simulations are useful for refinery application. For consistency, the examples in this article are all taken from multiphase computational fluid dynamics (CFD) simulations of fluidised catalytic cracking units (FCCUs), but the concepts are equally applicable to other types of simulation.¹

Positive outcomes confirmed

A US Gulf Coast refiner desired to improve operations for a full-burn FCC regenerator which regularly experienced about 50°F of afterburn despite the use

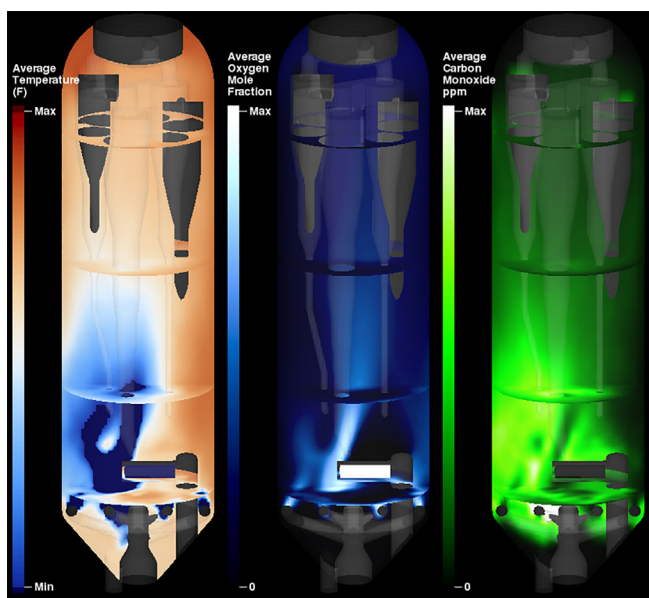


Figure 1. Temperature and gas composition in an FCC regenerator.

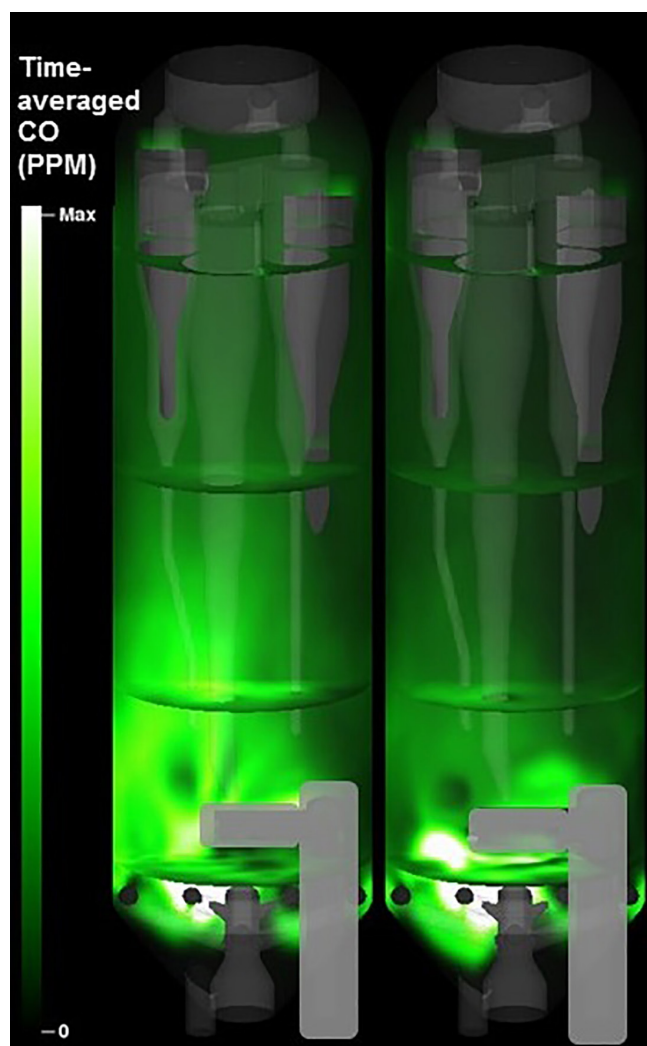


Figure 2. Virtual testing verified decrease in CO leading to reduced afterburn (spent catalyst distributor details intentionally obscured).

of a combustion promotor additive and air rates increased to the main air blower constraint.² The resultant high superficial velocities accelerated refractory erosion, causing hot spots on the outer shell which required cooling near the end of the operational cycle.

Simulation was used to assess the 3D, transient gas-catalyst hydrodynamics inside the regenerator, including thermal behaviour and combustion reactions. Figure 1 shows temperature on the left and reveals a cooler zone spanning nearly one half of the regenerator cross-section. This cooler region was confirmed via comparison with dense-phase temperature indicators on the unit. The CFD simulation confirmed the root cause to be the forward momentum of the spent catalyst upon exit of the distributor.

Oxygen (O_2) is shown in the centre of Figure 1. The air used to pneumatically convey the spent catalyst up the lift riser resulted in a stream of O_2 strong enough to penetrate the top of the dense bed. Carbon monoxide (CO) is shown on the right of Figure 1, with poor CO combustion evident in the cooler half of the regenerator. This CO persisted into the dilute phase where it reacted with the O_2 resulting in the observed afterburn.

Clearly, improvements to the spent catalyst distributor design were needed. Virtual testing was used to verify the expected efficacy of the new design as shown in Figure 2. The new design, on the right of the figure, showed that better mixing would result in a significant reduction of CO exiting the dense phase without any indication of adverse effects.

The new spent catalyst distributor was installed during the turnaround without incident. Following start-up, the afterburn was nearly eliminated and all emissions were within the refiner's regulatory constraints. These outcomes were achieved even after the refiner reduced air requirements and eliminated the use of combustion promotor.

Additional insights obtained

Sometimes changes go as expected, and simulation is a great way to confirm the positive outcome prior to turnaround. Effective solutions are not always so straightforward.

A US Gulf Coast refiner had recently completed a turnaround where it made significant modifications to the riser termination device (RTD), stripper and standpipe sections of its FCCU. Among multiple revamp objectives, modifications to the stripper and standpipe were intended to increase the pressure build across the stripper bed, reduce stripping steam rates and increase the pressure build in the spent catalyst standpipe. Although the revamp was generally successful, standpipe performance fell short of expectations. At the same time, the equilibrium catalyst (Ecat) particle size distribution was relatively coarse with a low fines content due to high catalyst losses from the regenerator cyclones.

Post-turnaround, the refiner experienced erratic catalyst flow and pressure build in the spent catalyst standpipe. The root cause of this was thought to be

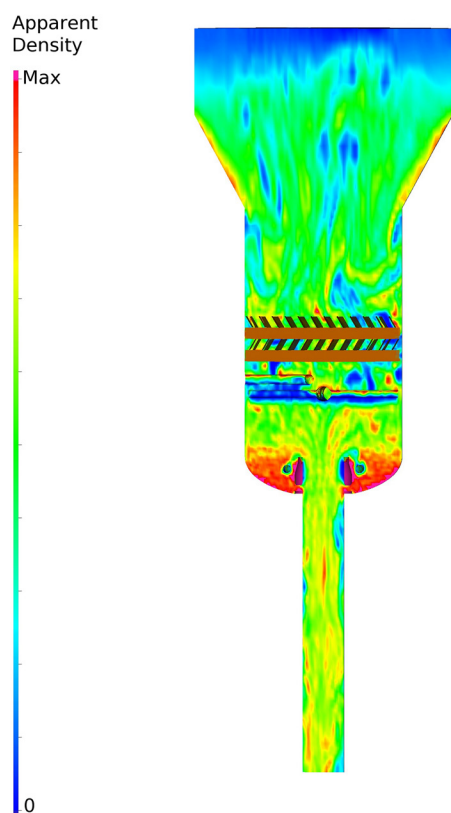


Figure 3. Density profile for the baseline PSD with 4% fines.

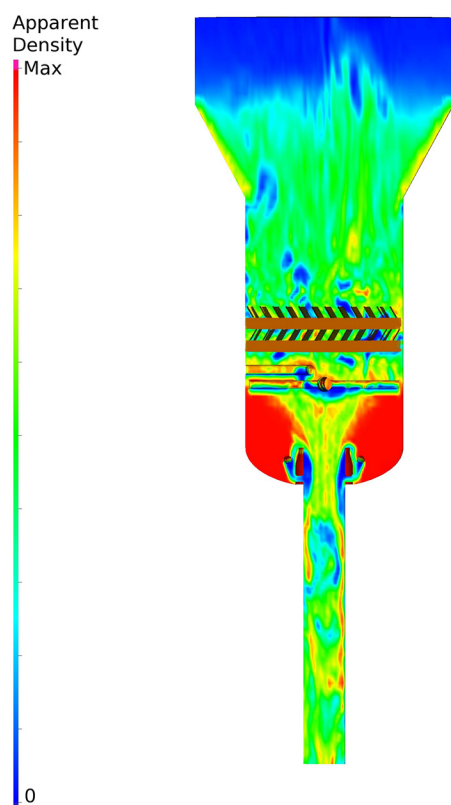


Figure 4. Density profile for the coarse catalyst PSD. Notice the pronounced de-fluidised zones in the elliptical head.

related to the stripper/standpipe transition where de-fluidised catalyst was building up at the bottom of the stripper and periodically slumping into the standpipe entrance. To address this inconsistent flow, high rates of fluffing steam were added to break up the de-fluidised catalyst and allow for smoother flow into the standpipe. Increasing the fluffing steam rates did result in stable catalyst flow, but at the expense of very low pressure build in the standpipe and low pressure differential across the spent catalyst plug valve.

Based on this outcome, a natural question to ask is whether the circulation constraints and lower than expected pressure build in the standpipe were a result of the design changes implemented during turnaround, or was the root cause associated more with the coarse Ecat?

To address these questions, simulations were performed for the post-revamp configuration of the stripper/standpipe section of the FCCU. A base case simulation was performed using a typical Ecat particle size distribution having an average particle size (APS) of 80 μm and fines content of approximately 4%. The base case was compared directly to a simulation performed with the identical geometry and process conditions, except the actual Ecat particle size distribution (PSD) and associated properties were implemented.

As a first step, a sample of Ecat was supplied by the refiner and simple fluidisation/de-fluidisation experiments were performed. Similar experiments were performed on a sample of Ecat having a typical PSD (80 μm and 4% fines). From these experiments, parameters related to the solid phase stress were extracted and inputted into CFD model. These parameters directly influence the window of stable expansion and de-fluidisation time of the catalyst, critical properties for modelling dense phase flows such as those present in the stripper and standpipe.

The catalyst density profile (corresponding to particle volume fraction) for a 2D cross-section of the stripper and upper standpipe is presented in Figure 3 for the base case. From these simulations, smooth and consistent catalyst flow was observed from the bottom of the stripper upon entry into the standpipe at target catalyst circulation, stripping and fluffing steam rates. The resultant pressure build in the standpipe was near optimal, achieving catalyst densities of approximately 35 lbs./ft³.

A similar catalyst density profile is shown in Figure 4 for simulations performed with the actual Ecat supplied by the refiner. The figure clearly indicates pronounced de-fluidised zones at the base of the stripper with an uneven catalyst density in the upper standpipe. These large de-fluidised zones are a direct result of the relatively rapid de-fluidisation time and narrow window of stable expansion for the actual Ecat system. The simulation further demonstrates periodic breakage or slumping of the catalyst from the de-fluidised zone into the catalyst standpipe, resulting in erratic flow and pressure build consistent with observations made by the refinery.

A final simulation was performed using the refinery Ecat where the fluffing steam was increased in an attempt to break up the de-fluidised catalyst around the standpipe entry. Consistent with refinery experience, the

increased stripping steam was successful in partially breaking up the de-fluidised catalyst and stabilising flow, but significant amounts of vapour were entrained down the standpipe. Lower pressure build in the standpipe was a direct result of the entrained vapour, where catalyst density profiles are shown in Figure 5.

These simulations demonstrate that while the stripper/standpipe design implemented during the turnaround was robust for a typical Ecat, the same design had significant shortcomings when applied to a coarse Ecat system. As a result, design modifications including changes to the location and geometry of the fluffing steam ring and further extension of the standpipe into the stripper are under evaluation. In parallel, the refinery is attempting to address the root cause of fines losses through the regenerator cyclones. This study underscores the importance of properly accounting for Ecat properties which must be seriously considered as part of any stripper or standpipe design/modification.

Negative outcomes avoided

While gaining insights through simulation is very helpful, risk reduction is most powerful when a negative outcome is avoided. The April 2019 issue of *Hydrocarbon Engineering* highlights such a case where a refiner found that nitrogen oxide (NO_x), CO and particulate emissions from their regenerator increased significantly following

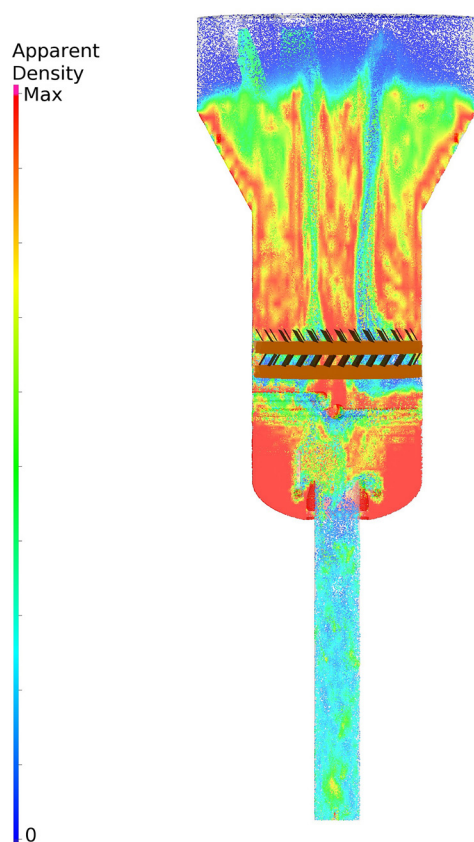



Figure 5. Density profile for the coarse catalyst PSD with roughly 3x the amount of fluffing steam. Stable circulation is observed at the cost of lower standpipe density.

the replacement of a combustion air distributor and cyclones during a turnaround.³ After start-up, NO_x emissions exceeded the permitted 365 day rolling average by approximately 10% while CO emissions nearly doubled. The article explains how a CFD study was used to identify various factors contributing to the problem and how simulation was used to provide the refiner with alternatives to mitigate the issue in support of a subsequent shutdown.

This problem, however, could have been avoided in the first place. Today, mature simulation technologies exist which can minimise the probability of these types of adverse outcomes.

Reducing risk for your next turnaround

Simulation, when used well, can be a critical turnaround risk reduction tool. Turnaround opportunities can be optimised by keeping the following in mind:

- Begin with baseline models of current operations. All examples in this article answer comparative questions. Does afterburn decrease? Will catalyst circulation be more stable? Will emissions be impacted? Are there other downside risks? To best answer these questions begin by modelling current or historical operations.
- Start early and be proactive. Turnarounds are, by definition, not a surprise. Regardless of whether the operational cycle is short or long, once a turnaround is complete the clock is counting down to the next one. Make the most of that time by putting proactive baseline models in place. If the model is needed sooner (e.g. post-audit analysis, inform operational decision-making, shutdown support, etc.), it will be ready when needed. By starting early, the model can be built, avoiding times of urgency.
- Include all stakeholders. Turnarounds are complex operations which require coordination between many internal and external parties. Perhaps the refinery is part of a larger group with a central engineering centre. Maybe technology licensors or third-party consultants are being used. Be sure to include these when planning together with hardware vendors, catalyst suppliers, and others. Simulation is an effective and objective way to evaluate and communicate with all parties.
- Take virtual risks. While this is an article about risk reduction, simulation allows virtual testing of changes to be performed, enabling the exploration of more significant changes than would otherwise be tolerated. Consider new technologies, explore new ideas, and take those risks – but do so in a virtual environment while reducing actual risk to the refinery. 

References

1. All CFD results shown were created using Barracuda Virtual Reactor® from CPFD Software.
2. FLETCHER, R., CLARK, S., PARKER, J., and BLASER, P., 'Identifying the Root Cause of Afterburn in Fluidized Catalytic Crackers', AFPM Annual Meeting, (2016), AM-16-15.
3. BLASER, P., and BARUA, R., 'Digitally Transforming Refineries', *Hydrocarbon Engineering*, Vol. 24, No. 4, (April, 2019), pp. 17 – 23.