Simulation, Turnarounds, and FCC Operational Cycles

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Simulation of FCCUs

Simulation goals
- Look inside FCCU
- Identify root cause of underperformance
- Learn from current and historical operations
- Virtual testing of proposed changes

Impact of simulation
- Increase likelihood of success
- Reduced risk of negative consequences during operation
- Reduce risk of unplanned shutdown

Simulation results in this presentation are from Barracuda Virtual Reactor®
When to Use Simulation?

**Established Baseline**
- Proactive modeling efforts
- Enables quick response for other simulation efforts

**Turnaround Planning**
- In support of next planned turnaround
- Enough time to make more significant changes

**Post-Audit**
- Used to understand unexpected performance changes
- Can lead to planning for next planned turnaround

**Unplanned Shutdown**
- Used to support decisions that must be made quickly
- Not enough time to make significant changes
Simulation During Turnaround Planning

Example courtesy of a North American refiner

- Afterburn, CO promoter, MAB limitations
- Thermal asymmetry, O2 bypassing, high CO

Source: R. Fletcher, AFPM AM-16-15
Regenerator Maldistribution

Changes tested before turnaround
• New spent catalyst distributor design

Outcome
• Emissions within specs
• Afterburn nearly eliminated
• Reduced air requirements
• Eliminated CO promotor use

Source: R. Fletcher, AFPM AM-16-15
Simulation during Post-Audit

Example Courtesy of Viva Energy Refining Pty Ltd (Geelong, Australia)

2011 changes
- Increased afterburn / flue gas temp spikes
- Panel operator intervention
- Reduced throughput

Baseline models of historical operations created prior to 2016 turnaround

<table>
<thead>
<tr>
<th>Design</th>
<th>2011 Changes*</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCID</td>
<td>New design</td>
</tr>
<tr>
<td>Cat cooler</td>
<td>Hoppers removed</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Operational</th>
<th>2011 Changes*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Catalyst circulation</td>
<td>+ 4.4%</td>
</tr>
<tr>
<td>Air rate</td>
<td>+14.7%</td>
</tr>
<tr>
<td>SCID aeration</td>
<td>Major changes</td>
</tr>
<tr>
<td>Cat cooler</td>
<td>Minor changes</td>
</tr>
</tbody>
</table>

* Changes relative to pre-2011 baseline configuration and operating conditions

Source: P. Blaser, ARTC 2018
Simulation of Historical Operations

Source: P. Blaser, ARTC 2018
Increased Maldistribution

Spent cat < 10 seconds residence time shown

Percent reaching east side < 10 seconds
  • Pre-2011: 21.3%
  • 2011-2016: 10.7%

Maldistribution of air and catalyst increased significantly following the 2011 turnaround

Source: P. Blaser, ARTC 2018
Effects of Maldistribution

Maldistribution of gas entering cyclones

- The increased maldistribution of spent catalyst results in non-uniformity of gas composition at the cyclone inlet elevation

O2 breakthrough

- Both simulation and operational data show the increase in O2 breakthrough
- Transient CO and O2 levels result in the observed afterburn and flue gas temperature spikes

Source: P. Blaser, ARTC 2018
2016 Turnaround and Outcome

2016 Turnaround

• Simulation indicated the planned changes would be beneficial
• The changes were implemented during the 2016 turnaround

Outcome

• 12 months of operational data were compared for the operational periods immediately before and after the 2016 turnaround
• Average afterburn 5°C lower
• Number of panel interventions reduced 75%
• Max daily average throughput 4% higher

Source: P. Blaser, ARTC 2018
Simulation During Unplanned Shutdowns

Example courtesy of a North American Refiner

• Changes made in late 2015 had unexpected problems

FCC exceeded emissions constraints:

• NOx: 10% over 365 day rolling average
• CO: 43% over 365 day rolling average
• Particulate emissions: frequent high loss episodes
• Significant afterburn

Radioactive tracer study performed

• Significant maldistribution
• Potential damage

Source: R. Fletcher, AFPM CCS 2016
Formation of Team and Initial Finding

Shutdown scheduled to repair expected damage

The simulation predicted significant gas channeling (without air grid damage)

• The spent catalyst distributor exacerbates the maldistribution

6 weeks before shutdown: Team formed to propose options if no damage was found

• Refinery engineers, corporate staff, cyclone vendor, two independent consultants, simulation expertise

Source: R. Fletcher, AFPM CCS 2016
What Could be Modified if No Damage Found?

During shutdown could alter:

- Air grid orientation
- Dipleg discharge direction
- Shortening secondary dipleg lengths

Source: R. Fletcher, AFPM CCS 2016
Mixing and Channeling

No case addresses root cause

Can incremental improvements be obtained?

- Regions with highest time-averaged gas bypass shown
- Cases 2 and 3 dissipate gas jets at a lower elevation

Source: R. Fletcher, AFPM CCS 2016
Thermal and Gas Composition Profiles

Simulations showed

• Regenerator temperature profiles dominated by maldistribution
• High O2 reaching dilute phase
• Afterburn due to O2 and CO mixing in the dilute phase
• Cases 2 and 3 show better mixing and less maldistribution

Source: R. Fletcher, AFPM CCS 2016
Outcome

During shutdown

- The air grid wasn’t broken
- Simulation gave the refiner confidence to implement the change
- The refiner opted for Case 2 with the secondary dipleg heights shortened by 1.5 ft

Post-shutdown:

- NOx & CO maintained below 365 day rolling average
  - Dropped significantly after start-up
  - Air rate optimization performed and NOx additive used
- Catalyst losses: complete elimination of the catalyst loss events

Source: R. Fletcher, AFPM CCS 2016
Simulation as a Proactive Tool: Established Baseline Model

Enables fast response for any situation
• Unplanned shutdown
• Post-audit
• Turnaround planning

Usually step 1 for all other use cases
• “How was it running before?”
• “Why did this change occur?”
• “What if we change this hardware?”
Conclusions

Simulations can be used in all stages of the FCC turnaround cycle
  • Different time constraints depending on situation
  • Different limitations on possible solutions

Having an established baseline model is critical
  • Enables fastest possible response time in all situations
Acknowledgements and References

Turnaround Planning Example

• Ray Fletcher, Sam Clark, and Peter Blaser, AM-16-15: “Identifying the Root Cause of Afterburn in Fluidized Catalytic Crackers”.


Post-Audit Example


  http://artc.wraconferences.com/

Unplanned Shutdown Example

• Ray Fletcher, Peter Blaser, John Pendergrass, and Ken Peccatiello, CAT-16-17: “The Experience of a Team of Experts to Resolve Severe FCC Regenerator Maldistribution”.

  https://www2.afpm.org/forms/store/ProductFormPublic/cat-16-17-the-experience-of-a-team-of-experts-to-resolve-severe-fcc-regenerator-maldistribution

  http://cpfd-software.com/resources/webinars/2017-ertc-presentation-resolving-severe-regenerator-maldistribution