Who is Astron?

- Delivering solutions to the refining industry since 1995
- Founded by Atulya Saraf & Rajul Rastogi
  - Chemical engineers, previous FCC design experience at Stone & Webster
  - Specializes in web applications for technical service needs
- Formed Refining Consulting Division in January 2008
  - CJ Farley brought in to lead consulting effort
    - More than 20 years FCC experience in operations, design/technical services, and catalyst manufacturing
The Reliability Challenge and Meeting Your Run Length

- Demands for process personnel's times have gone up dramatically in last 20 years
  - Management of change
  - Process Hazards Analysis
  - Environmental reporting
  - Lack of process engineers in refining
  - Process engineers are also younger on average
- Success for refiners is not usually measured by ‘only’ making 1 % more gasoline
- Instead, it’s...
  - Maintaining or reducing emissions,
  - Improving unit uptime or availability,
  - Operating within the plan,
  - AND making 1 % more gasoline

How Refiners Have Managed Reliability

- Reliable operation meets production targets, run lengths, and allows proactive management and planning of unit turnarounds
- How do you accomplish reliability with an already overstressed workforce?
  - When proactive management has been practiced, most organizations have been outsourcing, by...
    - Hiring contract employees (could be a centrally located cost center employee, not a locally based refinery based operation)
    - Leveraging catalyst suppliers or E&C providers
What Helps Create “Good” Reliability Metrics

- Two key behaviors identified to date:
  - Avoiding short term outages that have a chance to develop into something more serious
  - Monitoring unit condition routinely to head off problems before or as they develop (i.e., health checks)
  - Not taking the unit outside a reasonable operating envelope and understanding what those limits are

Feed Rates and Run Lengths (to show breadth of survey only)
Downtime vs. Current Run Length

The Astron Advantage Industry Expertise • Web Solutions • Tech Service Applications

What brings the FCC down? Not always what starts a turnaround

Major rotating equipment includes wet gas compressor, air blower, and expander (if present)

Major rotating equipment is ~ 50% air blower related, 33% expander, ~ 17% wet gas compressor

Data from ~ 15% of the refining industry presented (~ 65 units)
Major Rotating Equipment

- Includes air blower, wet gas compressor, and expander
  - Air blower results surprising
- Industry loss data still dominated economically by rotating equipment failures
  - Not a high incident rate, but LONG downtimes when they do take place (check valve failures still on list from ~ 20 years ago)

Concerns Reported by Units Heading into Turnarounds

- Over half concerned about refractory
- No concerns from units on major rotating equipment
- Adds to more than 100% as several refiners made multiple selections
The Long Term Problem with “Short” Outages

▪ “Simple” FCC outages develop lingering problems 10-15% of the time.
  ▪ Plugging distributors, rotating equipment damage, refractory or coke spalling are common examples

▪ Each time you cycle the unit, there are many chances to create this lingering problem
▪ The BEST operations and maintenance teams will eventually suffer a failure given enough chances.

FCC Health Checks and Unit Monitoring

▪ What is a health check?
  • Test run that looks at:
    − Yields
    − Equipment performance
    − Looks for unit trouble that has occurred or might be developing

▪ How often should you do?
  • More frequently is better
  • Must have historical view – what has changed?

▪ Why should you do it?
  • Lot of work, you will break a sweat
  • Important to predict future unit performance & can mean the difference in meeting your operating plan & budget
Performance Test Run Frequency

- ~ 70% once a week or more frequently
- ~ 20% every 6 months or less frequently

Health Check Topics

- Shutdown causes give a good idea of what should be checked
  - Cyclones & Catalyst material balance
  - Major distributor performance
    - Feed nozzles, air grid, stripping steam at a minimum
  - Major rotating equipment performance
- Also look at yields & how they compare to expected and historical
Catalyst material balance important
- Know additions, withdrawals, and losses
- Go one step further, calculate differential particle balance

Monitor:
- Pressure drops
- Dipleg levels
- Inlet & outlet velocities
- Calculated efficiencies
  - Total losses per side vs loadings
  - 99.997 % or higher is target
Erosion at Top of Dipleg
Most Common Cyclone Failure

Typical Slurry or Scrubber Solids

Monitor over time – do peaks shift left or right, or get larger?
Calculate Differential Catalyst
Particle Size Generation Rates

Base case important when looking at potential unit problems

Major Rotating Equipment

- Air blower, wet gas compressor, and expander
  - Air blower results surprising in terms of outages outside the US
- At a minimum, look for trends in vibration
- Health checks should look at:
  - Flow vs discharge pressure, horsepower
    - Plot on design curve, look for changes over time
  - Look for changes in efficiency, might indicate fouling or erosion
Rotating Equipment Maintenance

- Major rotating equipment repairs can be costly & time consuming
- What is the preventative maintenance strategy?
- How do you control fouling & erosion?

Expander Erosion

- Erosion caused by large particles (> 10 microns)
- All expanders suffer from erosion
- Statistical run lengths are ‘short’ relative to rest of unit, but technology has improved dramatically over 20 years
Distributors

• Three main distributors of interest (feed, air, stripping steam)

• Feed Distributors
  ▪ High Vapor Outlet Velocities (100-250+ fps)
  ▪ Generally low attrition source

• Stripping Steam and Air Distributors
  ▪ High Vapor Outlet Velocities if partially plugged, poorly designed or operated at very high flow

• Many other distributors in the unit
  ▪ Half of the FCC design is distributor work

Distributor Performance

Checks Required

• Inlet Pressure
  − Should agree with Calculated based on expected pressure drop accounting for inlet pressure

• Inlet control valve position consistent with distributor flow? No changes over time that are unexplained?

• Outlet velocity
  − If flow rates are being pushed over time, outlet velocity can be high enough to be a concern

• Orifice velocity
Eroded Feed Nozzle Cap

Eroded Air Distributor Nozzle
Yields

- Yield shifts over time can indicate trouble
  - Conversion & coke selectivity shifts?
  - Distillation gaps?
  - Carbon levels on catalyst & distribution?
  - Volume gain?

- Feed monitoring can help
  - 10 years ago, popularity of HPLC has led to multiple theoretical potential conversion calcs, but that instrument is essentially non-existent today
  - Be careful not to over interpret value of theoretical conversion

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Know how coke is being made in your unit - overall coke yield set by enthalpy balance (KBC Profimatics FCC-SIM output)

<table>
<thead>
<tr>
<th>Profiles</th>
<th>Unit 1</th>
<th>Unit 2</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Gas Oil with high preheat</td>
<td>Resid with catalyst cooler</td>
</tr>
<tr>
<td>Coke</td>
<td>Wt %</td>
<td>Wt %</td>
</tr>
<tr>
<td>-Total</td>
<td>4.06</td>
<td>6.52</td>
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<tr>
<td>-Catalytic</td>
<td>59.45</td>
<td>20.78</td>
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<tr>
<td>-Feed Concarbon</td>
<td>4.24</td>
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<tr>
<td>-Metals</td>
<td>6.31</td>
<td>50.92</td>
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<tr>
<td>-Stripper</td>
<td>30.00</td>
<td>15.00</td>
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<tr>
<td>-Non-Vaporized Feed</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Conversion</td>
<td>Vol %</td>
<td></td>
</tr>
<tr>
<td></td>
<td>82.54</td>
<td>68.51</td>
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Lower catalytic coke yield is an indicator of being further away from maximum conversion, as determined by feed properties
Example of FCC Reliability Analysis – High Catalyst Loss from Regen upon Restart

Intermittent air grid plugging taking place
Results in restricted dipleg operation as well as high localized velocities

Example of Reliability Analysis – Catalyst Losses Elevated Mid-run

Reactor cyclone operation shown here for 3 weeks of operation
Critical flags were operating within minimum remaining dipleg on 2nd stage and decreasing pressure drop
Losses jumped by ~ 0.5 TPD
Analysis indicates partial bypassing of 1 second stage
Analysis of slurry solids confirmed, came AFTER the process work
Manage the Small Things

- Most major (the ones that make the news) incidents require 4 – 7 small issues to take place at the same time.
- Managing small issues as they manifest remove them from the equation in terms of creating large problems.
- Many times, the post-audit reveals improper preventative maintenance or monitoring took place.
- Be extremely careful on restarts – empirical observation (of hundreds of unit start ups) is that between 10 and 15 % of the time, a problem takes place during start-up that ultimately requires a unit outage to resolve.

FCC Reliable Run Length Management Conclusions

- 75 % of shutdowns driven by:
  - Rotating equipment failure
  - Distributor failure
  - Excessive catalyst loss
  - Catalyst circulation failure
- Approximately 1/5th of units do test runs every 6 months or less frequently.
- Minimize unexpected outages – there is no free start-up.
  - Unit troubles can linger 10 – 15 % of the time after each start-up.
  - Monitor unit health routinely and manage the ‘small’ issues to eliminate or mitigate large issues.
<table>
<thead>
<tr>
<th>Key Items?</th>
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<tbody>
<tr>
<td>Reactor termination/cyclone pressure drop, velocity, dipleg operation</td>
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<tr>
<td>Reactor vapor line pressure drop</td>
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<tr>
<td>Reactor/stripper bed height &amp; density</td>
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<tr>
<td>Stripper flux, residence time, net upward steam velocity</td>
</tr>
<tr>
<td>Stripping steam distributor(s) outlet velocity, orifice velocity, pressure drop</td>
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<tr>
<td>Spent standpipe flux, pressure build up, density</td>
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<tr>
<td>Spent slide valve position and delta P</td>
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<tr>
<td>Regen bed level/height and density</td>
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<tr>
<td>Regen cyclone pressure drop, velocities, dipleg operation</td>
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<tr>
<td>Air distributor outlet velocity, orifice velocity, pressure drop</td>
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<tr>
<td>Regen residence time &amp; afterburning monitoring</td>
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<td>Regen standpipe flux, pressure build, density</td>
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<td>Riser pressure drop</td>
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<td>Riser velocities (bottom, pickup, outlet)</td>
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<td>Feed injection monitoring (distribution/flows, delta P)</td>
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<td>Air blower performance monitoring (discharge pressure, flow, horsepower)</td>
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<tr>
<td>Wet Gas Compressor performance monitoring (discharge pressure, flow, horsepower)</td>
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<td>Expander (if present) monitoring</td>
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<td>Main column loadings &amp; fractionation efficiencies</td>
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<td>Heat transfer monitoring for main column PA, feed exchangers, flue gas circuit</td>
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<td>Delta coke monitoring</td>
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<td>Hydrogen &amp; dry gas monitoring</td>
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<td>Conversion and selectivity monitoring</td>
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<td>Trends of operation to pinpoint economic performance issues early</td>
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