TROUBLESHOOTING: LOOKING BEYOND THE OBVIOUS

INTRODUCTION

by: Michael Edwards June 2010

A definition of troubleshooter:

A skilled worker employed to locate trouble and make repairs in machinery and technical equipment (http://www.m-w.com/dictionary/TROUBLESHOOTER). Sounds simple. But it neglects to state that the underlying trouble is what needs to be located, not just the proximate one. Don't treat the symptom(s); find the cause(s). Don't find data to support your hypothesis; use all the available data to generate the hypothesis for the root cause. Computer model results do not trump data. See the preface to Norm's third edition on this topic for these and other maxims (and the rest of the book for practical expositions: Norman P. Lieberman, "Troubleshooting Process Operations," Third Edition, PennWell Books, 1991). I will go through some examples to show that the initial suspect often conceals the true villain. And sometimes you get lucky; going after the actual cause is always more effective, but it can also be cheaper than just medicating symptoms.

THE SCOPE OF EXAMPLES

Here are seven examples encountered over more than a decade, working in multiple countries and Fluid Catalytic Cracking units, detailing primary causes ranging from contamination, to process or mechanical mistakes, to instrument error. There are many more, in other process units as well, that could be mentioned, but this time let's stay with the FCC theme and stick with a bit shorter essay.

1. THE CAVITATING PUMP

The FCC main column pump for heavy naphtha sidedraw was cavitating during the winter. Lack of sufficient Net Positive Suction Head (NPSH) was suspected, and preliminary plans for a new low NPSH pump were in progress. But why in winter, and not in the warmer months? Typically, hotter temperatures aggravate pump cavitation. The first clue to the true cause was use of live steam in the HN stripper; low temperature strippers, e.g., in atmospheric towers, typically use indirect stripping with pumparound reboilers. Second clue was the fact that the steam was from the low pressure steam header, barely superheated. And the final was supplied by the operators' observation (see Chapter 30 of Lieberman for their importance in troubleshooting): steam was turned way down or even off in the winter because of product planning complaints on free water in the naphtha tankage.

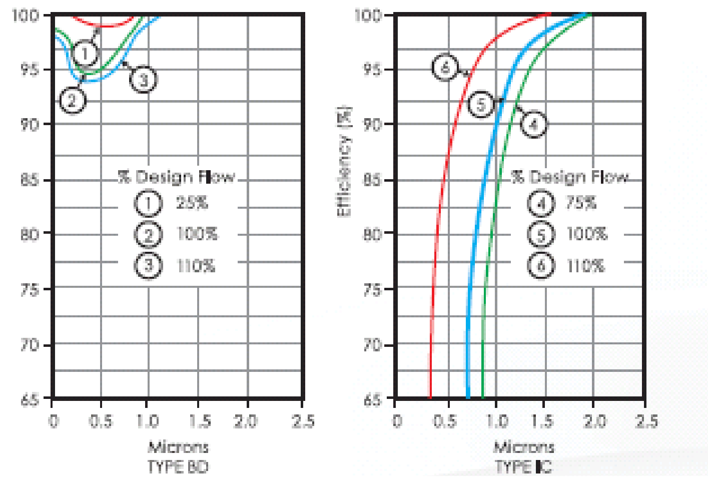
Providing a new pump with lower required NPSH would solve the proximate symptom of cavitation, removing the damage to the pump at a relatively high cost (especially if the existing spare were also to be replaced). But when we put the three clues together, there is a root cause to be found. Lower temperatures in winter result in lower HN draw temperature, more cooling of this naphtha in the pipe to the stripper, less LP steam superheat (if any), and more condensate carried with the HN to tankage. The cavitation ensued when the LP steam was greatly reduced (or shut) on planning's complaints and lighter vapors were dragged to the pump inlet. The water contamination is avoided in other applications where P/A reboiling is specified, but this would entail even more capital expense than new pumps. Here, the simple solution was also the cheap one: A metal flexhose from the (well superheated) medium pressure steam header was connected to the stripping steam inlet nozzle, with no other changes, and the cavitation was eliminated, without any entrained water to naphtha tankage.

2. THE BREAKING COMPRESSOR

For most FCC units, the wet gas compressor is centrifugal, but in this smaller refinery, a reciprocating (positive displacement) compressor handled the duty. At least when it was working, and not shut down to replace the piston rings, which was occurring too often since the last turnaround when the FCC unit was expanded in throughput. Liquid droplets were damaging the rings. Buying expensive high-grade metallurgy rings was under consideration. Checking the entry section of the compressor, using an endoscope through the "hand-hole" that was opened during a shutdown for repairs, I could see tracks of liquid condensate marked on the side of the section. Yet the knock-out pot in front of the compressor had also been recently modified, resized and demister packing installed for the feedrate expansion project. In fact, the demister had been resized conservatively, to handle even more than the anticipated maximum wet gas flow rate, and specified as "Impaction" style, to permit use of the low volume of packing allowed by the high velocity permitted (http://www.koch-ottoyork.com/downloads/ProductCatalog.pdf):

Table 4. Collection Mechanism and Efficiency

Type	Primary Collection Mechanism	Collection Efficiency: Particle Size (Microns)	Collection Efficiency: Efficiency* (%)	Element Pressure Drop mm W.G. (inches W.G.)	Bed Velocity m/sec (ft./min.)
BD	Brownian Diffusion	>3 <3	Essentially 100 Up to 99.95+	50 - 500 (2-20)	0.03 - 0.2 (5 - 40)
IC	Impaction Cylinder	>3	Essentially 100	100 - 250 (4 - 10)	1.3 - 1.8 (250 - 350)
		1 - 3	95 - 99+		
IP	Impaction Panel	1 - 3	85 - 97	125 - 180 (5 - 7)	2.03 - 2.54 (400 - 500)
		0.5 - 1	50 - 85		



Unfortunately, the "conservative" design meant that the KO pot was operating all the time below the design demister flow rate (and most of the time below the maximum rate for the expansion project). That translates to efficiencies of droplet collection at or below curve 4 above, which was particularly low with the finer droplets. Returning to the original project basis for design and switching to "Brownian Diffusion" style of demister pad, the surface area was greatly increased, but the efficiency was much improved, and almost completely insensitive to turndown flow rates. Higher collection efficiencies than the other style demister were achievable even above project max rates (compare curve 3 with curve 6). A general lesson can also be seen here: Conservative design does not always mean over-design, especially in such items as cyclones (efficiency drops rapidly below design rate) and exchangers in fouling service (low flow rates promote the very fouling feared in the first place).

3. THE SODIUM FROM NOWHERE

So once again the sodium level was climbing on our FCC e-cat, with predictable (and bad) effects on catalyst activity and unit performance. We had seen this in prior years, but the symptoms went away on their own, with little to do but maintain an aggressive makeup rate to counteract the impacts. Checking all the feed components (the usual suspect in sodium excursions) showed no evidence of excess sodium, the desalters and vacuum tower overflash were in order, there was no resid processing at the time, fresh catalyst sodium levels were in order, and would not have impacted catalyst activity anyway (high sodium on fresh catalyst hurts octane, but not activity). This time around, with a highly motivated and intense young FCC engineer, we went further – checking all steam sources to the FCC, looking for any potential recycle lines for possible leakage, and finally, checking even the main air blower discharge at drain points.

"How often have I said to you that when you have eliminated the impossible, whatever remains, however improbable, must be the truth?" "The Sign of the Four", 1890, Chap. 6, p111. http://en.wikiquote.org/wiki/Sherlock_Holmes

Did I mention it was a refinery adjacent a major river, next to a sea, in a cold climate? And the attacks corresponded to late Fall and early Winter, when the fogs and mists rolled in up-river to the refinery? Yep, there was salt in them there condensate drains in the MAB discharge piping. The heavy, dense mists were salt-laden, and pulled in to the MAB suction, depositing on the regenerator e-cat for up to several months each year when the weather patterns "allowed". No clean solution, but at least we could set our catalyst makeup strategy based on the weather-man's projections for the coming week.

4. WHERE IS THE AIR GOING

The air grid had been redesigned at the preceding turnaround, with a plugging pattern shaped to force more air flow in zones with high catalyst carbon loads, and less air to the remaining zones. As a swirl regenerator, catalyst entered tangentially at one side from the reactor, "swirled" around the circumference most of 330 degrees or so, then departed through a bath-tub exit into the regen catalyst standpipe. Most of the air was needed close to the entrance, much less later in the swirl. So, with high catalyst losses when the regenerator bed level was high, and high losses when the bed level was low, cyclones were obviously implicated. Project group was talking in the $4 million range for a complete changeout. Then the tracer people arrived, with radioactivity in hand (so to speak) for both the air flows and catalyst flows in the regenerator.

Turns out that when the bed was high, several secondary cyclones on one side of the regen were in defluidized bed and flooding, while with the others, their trickle valves were just covered by the dense bed. When the bed was low, the second set were uncovered and lost collection efficiency because of air leaking into the diplegs. The tracer studies showed that air from one side of the grid did not flow to the other side – local air and flue gas flow went straight to the cyclone inlets vertically above. Horizontal mixing of air and flue gas was non-existent. The bed density in the "high air rate" segment of the swirl was very low, in the "low air rate" segment, very high. The calculations for air grid plugging pattern assumed uniform bed density above the grid nozzles. However, when less air flowed in one segment, the higher resulting bed density then increased local back pressure on that segment's air nozzles, further restricting local air flow. The iterative calculations needed were not conducted. Taking into account the second-order impact of lower air rate on local bed density, recognizing that the vapors would not redistribute themselves (per the tracer work), the solution was simple – we marked the excess plugs in the next turnaround to be ground out, noted much more uniform bed densities on restart (and saved a few $mil).

5. WHO (OR WHAT) SHUT THE VALVE

Checking the various temperature indications for the FCC reactor, shortly after a turn-around where lots of new equipment and instruments had been installed, I hear the panel man shout out that the regenerated catalyst slide valve had just slammed shut. It was a new design at the time, separate hydraulic package locally mounted, very fast response time. Lots of discussion about slowing down the slide valve response time, speculation that a minor ΔP dip across the valve led the hair-trigger valve to slam shut. A couple of hours after restart, as Ollie and I discussed the sequence of events, I slowly went back through my actions. I had switched the TI panel instrument (a Doric LED read-out, if I remember correctly, with rotary selector switch between 5 or 6 inputs) to read various reactor temperatures unconnected to the reactor temperature controller, and then switched to the TIC (the TI actually controlling). Depending on setpoint, and the value on this TIC, the regen cat slide valve would open (to increase reactor temperature) or close (to decrease).

Repeating my actions, I noted that the value reported by the reactor TIC dropped immediately – and Ollie shouted again that the regen cat slide valve was slamming shut. This time he managed to get the slide valve on manual and recover before oil was pulled from the riser. The low TIC signal had forced the slide valve to open completely, ***then*** the valve ΔP dropped way below shutoff value, and only then the valve of course slammed shut. But why did the TIC signal drop like a rock when I switched the TI read-out to this instrument? Turned out the signal from the field was wired in parallel both to the slide valve controller, and to the read-out. When the panel selector picked the TIC, its signal was reduced by the parallel paths and reported only half its actual strength to the valve controller, which assumed this to be a reactor temperature well below the set point. No problem at all with the new valve. High tech solution? Not really. A label was engraved and glued to the panel adjacent to the TI selector switch, saying roughly: <u>Do not select the TIC with this switch!</u> [In mitigation – the refinery was planning a central control building, with full electronic instrumentation, DCS, etc. and knew the problem would be more elegantly resolved in the near future. And having shut down an FCC myself, this one in fact, for the first and so far only time during many years in the field, I was not going to raise the issue.]

6. THE SALTED PACKED COLUMN

The main column internals were almost completely replaced with structured packing during the prior turnaround. Very high capacity and robust against any plugging or blockage, but the naphtha side-draw went off spec & black. Along with the rapid jump in column pressure drop, these clear signals of plugging were last seen by me in a trayed main column where salt deposits had blocked liquid flow near the column top. Ammonium chloride can plug up trays relatively easily when column top temperature is low (below 120 °C at normal column pressure) and a bit of extra chloride is in the feed, since ammonia is always present in the column vapors. But packing was known to be very resistant to this. Saltation it was, and a normal on-line water wash removed the salt, with sampling of the water rundown showing high concentrations. Simple mass balancing was suggesting ***tons*** of salt, not the hundreds of pounds typical of salted tray problems seen in the past. With normal desalter operations in the crude unit, and anyway a relatively light VGO feed with no resid components, a meeting with the feed schedulers was in order. Long-story short, they had gotten a real "bargain" on two 10,000-barrel lots of VGO recently. The first batch had excellent properties (at least, those they measured) and had just been processed on the FCC prior to the saltation problems. They were from a firm specializing in cleaning hydrocarbon systems, and the retain sample showed 10,000 ppm Cl content – the VGO was the waste material from cleaning systems with chlorinated products. It had not been tested for Chloride since it was non-resid oil, and no-one connected the firm's business line with its implications for just why they would have cut-rate VGO for sale. The second lot of VGO was diverted from FCC feed tankage just in time.

7. THE COKED PACKED SECTION

Again a packed main column, only this time even the MCB wash zone was completely packed with grid. And when the column flooded, it turned out the grid was completely packed with coke. We are talking "jack-hammers-to-remove" packed; use of explosives was under discussion at one point. Calling out the tracer people, we found the entering reactor effluent traveled across the column diameter, then went up through the packing on the far side. The high velocity in this area pushed all liquid reflux and condensate out of the path, and the coke built up in this dry, hot region. It then spread out across the bed, as the high vapor rate was directed elsewhere by the mounting tonnage of coke. After removal of all the disk-and-donut trays in the bottom of the column, half-round pipes were installed below the grid packing, in the theory that these pipes would impede the vapor flow and spread it uniformly across the bottom of the grid. The pipes were mounted across the diameter, spaced a couple feet apart both horizontally and vertically, and oriented with the open side directly facing the inlet pipe. Given the vertical alignment of the pipes, they served only as slight turbulence inducers, and did not spread the flow. A quick fix was needed, since the shutdown occurred mid-December just prior to the holiday season. We retained the half-round pipes, but rotated them upwards at about 30 degrees to vertical, and replaced the grid with Raschig-rings that were available on-site (the rings could handle the hydraulics, but were only a rough repair since they would be highly susceptible to mal-distribution and coking). The tracer folks found the rotated pipes did adequately redistribute the vapor flow across the diameter, though there still was low vapor, high liquid traffic at the side walls. But it was enough to restart by Christmas and live. A better solution would have been reinstalling the bottom-most 2 or 3 trays for proper vapor distribution; sadly the refinery was shuttered before a permanent fix could be installed.

CONCLUSION

The intriguing part of working with FCC units is that you can still be surprised by the next problem coming down the pike. There are the typical problems:

- Some “smart” engineer, ***not*** on the FCC unit, decides to send poorer quality feed to the FCC without full consideration of the impacts (see Lieberman pp159-160 for what happened, though he himself was not picked up as the cause and counted that as a give-me in his engineering life)

- An operations manager decides to “save” lots of money by sharply curtailing catalyst makeup rate (remember, it is called Fluid ***Catalytic*** Cracking for a reason, not thermal cracking)

- Stripping steam flows to both sides of the reactor annular stripper without using independent flow controllers, but does not perform (since steam flows mostly to the lower pressure side near the catalyst exit, easily fixed with separate control valves) - And then the unit “optimizer” sees he can “save” lots of money by reducing stripping steam rate at the same time, since it is not doing much anyway

- A reactor secondary cyclone dipleg plugs, with coke or defluidized catalyst, (fixed by known procedures without shutdown and entry for repair)

Been there, done (or better said, un-done) many of these. But the examples detailed above represent some adventures a bit out of the ordinary, even by FCC standards. And FCC continues to excite, and remain a bit out of the ordinary in refinery work.