

Correcting Design Errors Can Prevent Coking in Main Fractionators

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Coking in petroleum refinery main fractionators causes unscheduled shutdowns and significant production losses (**Photo 1**). High temperatures and excessive residence time are the primary causes of coking in these units – which include crude and lube vacuum columns, fluid catalytic cracking (FCC) and delayed coker main fractionators, and visbreaker and hydrocracker vacuum columns.

Coking, however, is not inevitable. It is a function of the process and equipment design and operating errors. If the equipment is not designed properly, the unit will coke, regardless of how it is operated.

As operating severities of refinery primary fractionators increase to improve economics, the incidence of coking also increases. If the consequences of more severe operation are ignored, the units will coke up and have to be shutdown or very poor product quality must be accepted.

But higher distillate yields can be achieved through better design practices, and unit reliability can be improved while meeting higher distillate recoveries.

Packing

Poorly designed vacuum columns can produce heavy vacuum gas oil (HVGO) products containing more than 20 ppmw metals or 2,000 ppmw asphaltenes. Main fractionator designs that work at low temperature, high overflash, low conversion, and high recycle simply do not work when the unit is operated at higher temperature or lower liquid rates.

The use of packing in refinery main fractionators at low liquid rates is common (**Photo 2**). Using packing in the desuperheating section of an FCC main fractionator has process, efficiency, and mechanical advantages over shed or disc-and-donut trays. But while packing has the advantage of inherently low hold-up or res-

idence time, it is less forgiving of poor liquid and vapor distribution. Engineers must customize equipment design to the specifics of each system.

Process simulator features, such as packing efficiency correlations, do not address the realities of packed column revamps. Low packing efficiency and coking are caused by improper liquid and vapor distribution, poor collector tray design, and incorrect flash zone internals design.

Several packed column case studies are presented in this article which details the causes of several unit outages. Understanding what causes coking allows the revamp engineer to properly design the equipment and avoid unplanned shutdowns.

Coking

Coke formation in petroleum refinery packed columns is caused by several



Photo 1. Coked Packing



Photo 2. Clean Packing

Causes of Coking

- Inadequate vapor distribution-localized "dry-out"
- Ultralow localized liquid rate-high residence time
- High residue entrainment
- Inadequate liquid mixing – thermal and composition gradients
- High oil residence time on collector trays.

Table 1.

design errors, including those shown in **Table 1**.

The steady state or ideal temperatures at any elevation in a column are controlled by the unit operation and can be accurately calculated by the process simulation model. Oil composition and pressure set average bulk temperatures, however localized temperatures are controlled by equipment design. Main fractionator internals design considerations dramatically influence both residence time and localized temperature. Coke formation is a consequence of high localized temperature and oil residence time.

Coking can be reduced or eliminated, but ignoring important design issues is not the solution. For instance, revamping low-recycle delayed cokers to control heavy coker gas oil (HCGO) quality has been done successfully. But a standard design that works well at 10 – 20% recycle will not operate reliably at 4% recycle. Using only a spray chamber to meet the low recycle rate does not address the low efficiency and relatively poor HCGO quality that result.

Packing can be used as an alternative to a spray chamber in a delayed coker wash section. However, all critical vapor and liquid distribution, and collector tray design criteria must be addressed. Packing has very low intrinsic residence time compared

to other fractionating devices used in these services such as bubble-cap, sieve, shed, disc-and-donut, or turbo-grid trays. All these devices including packing will coke if designed incorrectly. Yet, packing is the only viable solution when the liquid rate is very low and the product quality must be controlled. Though the use of spray chambers is common in delayed cokers, product quality generally suffers due to poor efficiency.

Vapor Maldistribution

Refinery main fractionators wash section operation is characterized by very low liquid/vapor ratios. Liquid rate is very low and vapor rate is high. Ideally the liquid rate leaving the wash section (overflow) should be kept to a minimum. Overflow is the quantity of vapor returned to the flash zone as liquid. Decreasing overflow raises distillate yield, whether on a delayed coker, atmospheric crude, crude vacuum or visbreaker vacuum column. But in practice, minimizing overflow is difficult because several process and equipment design variables influence the overflow rate. Furthermore when operating at low overflow the amount of recoverable gas oil often is relatively small. Hence, the economic benefit of recovery does not justify the high risk of coking. Nonetheless many times, wash oil flow rate is reduced below the minimum needed to avoid localized coke formation.

A large portion of the liquid distributed to the wash section is vaporized. If the vapor feed is poorly distributed, then some cross-sectional areas of the packing will have higher vapor rate that vaporizes even more of the distributed liquid. Thus, portions of the packed bed actually dry out and the residence time becomes excessive. Therefore, poor vapor distribution strongly

influences coking through its effect on localized liquid residence time. High residence time, even at lower temperature, can result in coke formation.

Process simulators help the design engineer calculate overall column performance. For example, coke drum temperature, drum vapor-line quench, and recycle all contribute to the cal-

culated temperature in the wash zone. But liquid and vapor distribution ultimately control local temperatures. These localized temperature variations, albeit non-ideal, are the reality. The larger these variations the more likely premature coking will occur. But steady-state computer simulations do not identify localized conditions. This requires field troubleshooting tools such as vessel radial skin-temperature measurements. They will show poor vapor and liquid distribution that occurs in these services.

Ultralow Liquid Rate

Computer calculations show the highest temperature and lowest liquid rate are in the bottom of the wash bed. Nonetheless, coking in vacuum columns usually starts in the middle of the wash bed, not at the bottom. While the temperature is lower in the middle of the bed than at the bottom; the liquid rate is lowest in the middle of the bed not the bottom. This is true because the bottom of the packing is partially wetted from entrainment; therefore, the liquid rate at the bottom of the packed bed is relatively high.

Furthermore, many units are designed with wash oil flow rates less than half the amount needed to prevent coking. Thus, high oil residence time and temperature initiates coking in the middle of the packed bed.

Inadequate Mixing

Grid packing has been used successfully numerous times since it was first installed in 1965. These packed FCC slurry PA sections operate at relatively high liquid rates of 8-25 gpm/ft² tower cross-sectional area. The feed to the column is superheated vapor 960-1,040°F. and the feed velocity enters at 125-180 ft/sec. Typically the slurry section has no vapor distributor because most types will cause the middle of the packed bed to coke rapidly.

Liquid distributed to the slurry section consists of two streams: the cold pumparound return and the liquid leaving the wash section. Wash section liquid is hot and has a much lower endpoint than the slurry pumparound, therefore, most of it vaporizes. Slurry PA liquid is subcooled by 150-200°F. If these two liquid streams are not adequately mixed prior to distributing, then sections of the packing get hot and will have lower liquid rate. Lower liquid rates cause excessive oil residence

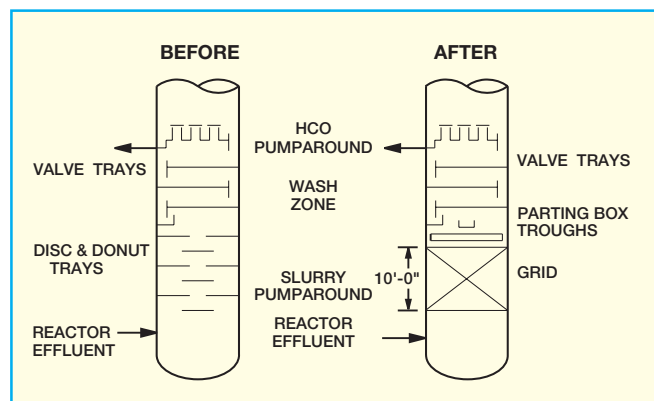


Figure 1 FCC Slurry Pumparound Revamp

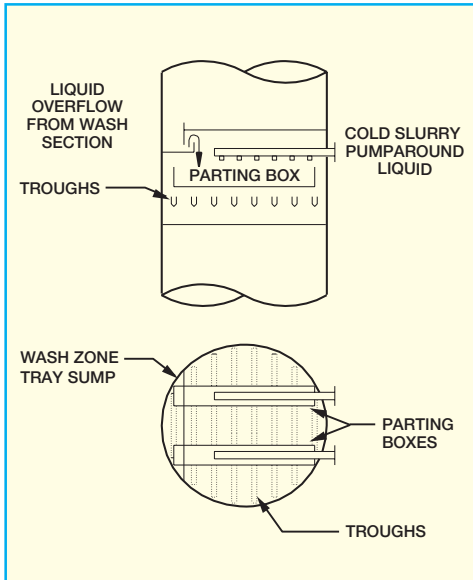


Figure 2. Packed Column Internals

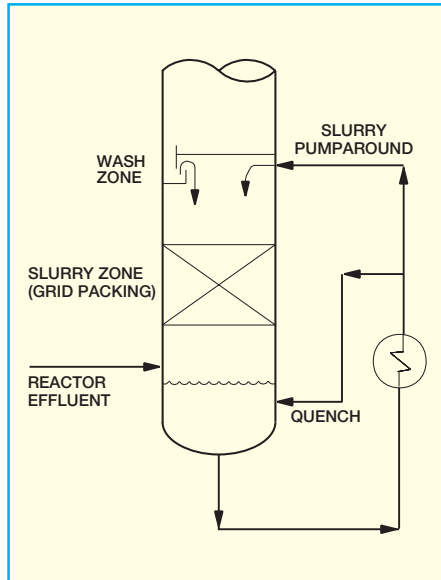


Figure 3. FCC Desuperheating Section

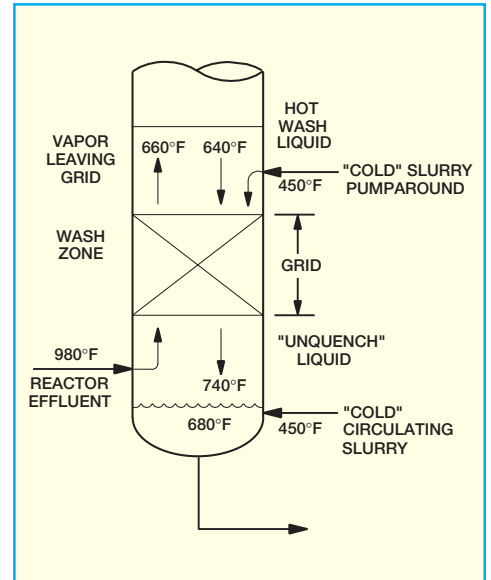


Figure 4. Desuperheating Section Temp.

time and very high temperature, thereby, initiating coke formation.

High Entertainment

Visbreaker and H-oil[®] vacuum column feeds are thermally unstable. The degree of instability is a function of the unit conversion. The design of the flash and wash zones in these columns must be correct or unit run lengths will be very short. These systems require good vapor/liquid disengagement in the flash zone, good vapor distribution, and reliable liquid distribution.

Case #1: FCC Slurry PA Section Coking

The disc-and-donut trays of a 95,000 Bpd FCC main fractionator (Photo 3) were replaced with grid to improve the efficiency of the pumparound section (Figure 1). The objective was to decrease the light cycle oil (LCO) content of the decant oil product leaving the bottom of the column.

The revamped column ran well for about 3 months, and then the pressure drop across the packing began to increase. The cause was thought to be the depth of the grid bed. Like many troubleshooting solutions it was solved in the office and not the field. The initial solution was to reduce the packed bed height. This was solely based on calculations of the heat transfer coefficient. The calculated main column unquenched bottom temperature was 875°F. In this case, the engineer failed to take into account vapor/liquid equilibrium. In fact, because the liquid rates are so high

in this service, packed bed depth has little influence on the rate of coking.

The decant product initial boiling point corresponding to 875°F. bottom temperature would be over 800°F. The actual decant oil product had an initial boiling point of less than 450 °F. While slurry PA section bed depth does influence product composition by changing bed efficiency, temperature changes of only +/- 10°F are possible. Unless the LCO product endpoint was increased to 900°F., it would be impossible to have an 875°F. unquenched temperature.

Decant oil product composition and column pressure determines unquenched temperature. Decant oil product composition is related to the column's heat and mass balance, and fractionation efficiency, not to the heat transfer coefficient of the packing. Thus, liquid temperature leaving the Slurry PA section packing is controlled by the decant oil product composition, not the heat transfer calculation.

Once the packing began to coke liquid hold-up increased. Liquid hold-up would cause the pressure drop to gradually increase to about 3 psi, and then the liquid in the bed would dump, which rapidly decreased pressure drop. This upset the reactor-regenerator pressure balance and caused high liquid level in the bottom of the column.

Causes of Coking

FCC main fractionator slurry sections have relatively high liquid rates. Although the feed temperature to the column is typically

965°F or higher, if the packing has good liquid distribution and the feed velocity is below 150-170 ft/sec then the bed will not coke. However, poor slurry PA liquid distribution has caused high localized temperatures which initiate the coke formation. Additionally, the liquid distributor above a slurry PA bed must mix the hot wash liquid and the cold slurry PA to ensure all the packing is properly wetted.

In this design, the wash liquid was fed into the slurry PA liquid distributor from the one-pass trays, as shown in Figure 2.



Photo 3. Packed FCC Column

Figure 3 is a schematic of the bottom section of the fractionator. Cold slurry PA liquid was used to quench the main column liquid pool temperature to 700°F or less.

Liquid Distribution

Good liquid distribution is very important when using packing because the slurry zone operates at very high temperature. But the vapor entering contains catalyst fines and the liquid distributor must operate for 3-5 years without plugging. Therefore, the distributor must first be reliable, and then distribution quality should be addressed. Thus, slurry distributor design is a compromise. Commercial results over the past 15 years with the type of distributor used in this column had been very good. Yet, the packed bed still coked.

Poor Liquid Mixing

Failure to properly mix the wash liquid and the slurry PA caused high temperature and low liquid rates in parts of the packing. The wash oil and the slurry pumparound liquid TBP distillations for a typical FCC unit are shown in **Table 2**.

Wash and Slurry PA Distillation TBP Temperatures, °F		
Volume %	Slurry PA	Liquid leaving wash section
IBP	214	145
5	664	600
10	703	655
30	775	703
50	843	725
70	927	764
90	986	851

Table 2.

Wash oil is lighter than slurry pump-around, consequently, most of this stream vaporizes before it leaves the bottom of the packing. Moreover, it also is at its bubble-point temperature at approximately 640°F. (**Figure 4**), whereas, the slurry pumparound is sub cooled by 150-300°F. If the two liquid streams are not well mixed, then the bed can coke.

Coked Packing

The liquid distributor design preferentially fed the wash liquid to one section of the packing and the slurry pumparound liquid to another. Inspection of the packing

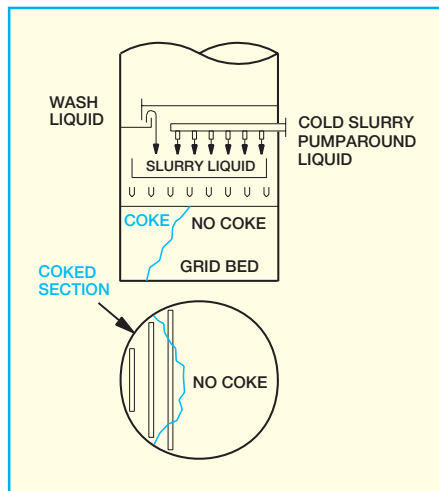


Figure 5. FCC Main Fractionator

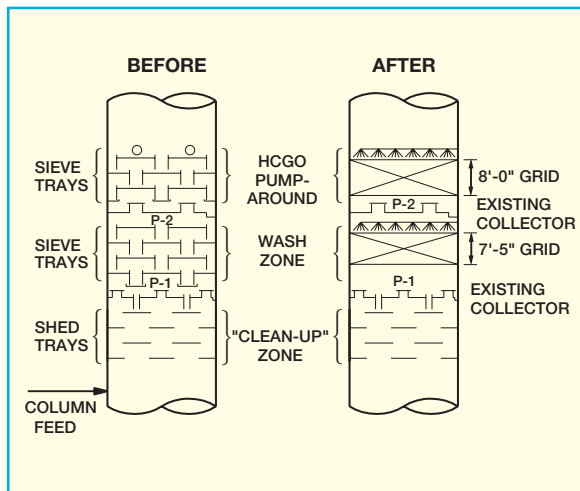


Figure 6. Delayed Coker Fractionator Revamp

showed localized coking only in the area where wash liquid was distributed. Thus, the bed coked because wash section liquid and the slurry pumparound were not mixed (**Figure 5**). While similar distributor designs have been used in many other FCCs, this one resulted in localized coke formation because the liquid rate leaving the wash section was very high due to column heat balance. Modifications to the liquid distributor improved mixing of the wash liquid and slurry pumparound and the unit has operated for many years without coking.

Case #2: Delayed Coker Wash Section

A delayed coker main fractionator (**Photo 4**) wash section was revamped from tray to packing to increase unit charge rate and reduce recycle rate. Four sieve trays were replaced with an 8-ft. bed of grid. However the packing began to coke after less than 6 months of operation. The packed bed pressure drop increased from 6 inches of water just after start up to over 32 inches after only 6-month period. **Figure 6** shows the column before and after the revamp. To reduce the initial revamp costs, the collector tray under the wash bed was not modified and the shed trays below the collector were not removed (**Photo 5**).

Once pressure drop increased above 18 inches the asphaltene content increased rapidly and coke fines were carried into the HCGO product. The coke fines plugged the down stream hydrotreater feed filter system and caused chronic operating problems. After just 6 months the column was shutdown and the grid replaced.

The four sieve trays were replaced to

reduce the recycle rate on the unit. Trays require at least 15% recycle or more to keep them wetted and, even at these rates, trays have coked due to high liquid residence time. Thus, grid was the only practical solution to operate at low recycle rate and maintain HCGO quality.



Photo 4. Packed Coker Column



Photo 5. Shed Trays

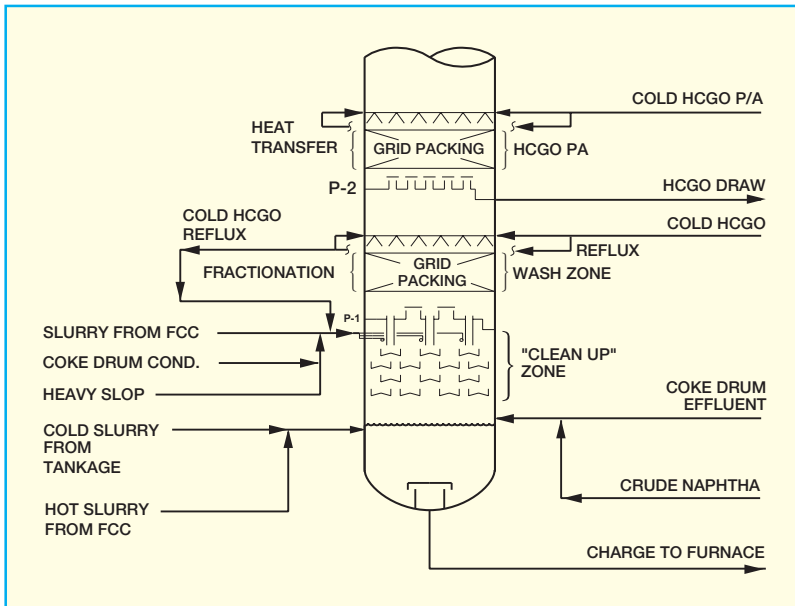


Figure 7. Delayed Coker Fractionator

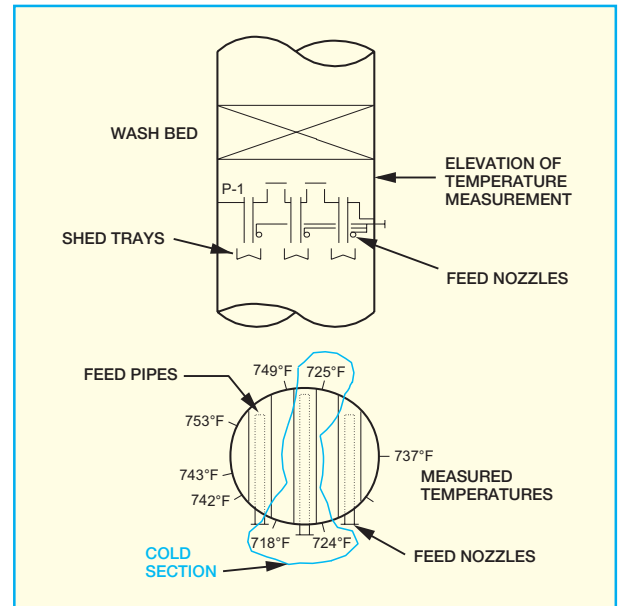


Figure 8. Coker Fractionator Radial Temperatures

Troubleshooting

During the first run, no field data was gathered to help identify the root cause of the problem. The grid bed was simply replaced in kind. During the second run, the bed pressure drop again began to increase. The cause of the problem was blamed on the packing. At this point, field troubleshooting efforts were launched to determine the actual cause of coking. During field tests, temperature and pressure surveys were conducted to see what was happening. Many times, office-based engineering approaches are used to troubleshoot, and operators are not consulted. Therefore, a critical source of information is ignored.

Equipment design is not the only source of most problems. Process flow schemes always interact with the equipment, and thus understanding both is necessary when troubleshooting. Process stream flows are shown in Figure 7.

Reviewing the flow scheme showed a fundamental flaw. Cold HCGO was fed to both the wash bed and to the shed trays below the wash bed. Thus, the liquid rate feeding the wash section packing was not being maximized. The cold HCGO flow to the wash bed was 9,000 b/d and to the shed trays was 5,000 b/d. The cold HCGO feeding the shed trays, in theory, cooled the rising vapor prior to it entering the wash section. Three separate 4-inch nozzles with internal pipes were used to distribute the cold HCGO onto the six-pass shed trays. However, feeding cold HCGO onto the sheds lowered the wash section

liquid rate for the targeted recycle rate. Thus, the process flow scheme did not make any sense.

Pressure Survey

Pressure drop is a measure of flow rate and/or restriction in any piping distribution system. The measured pressure drop across the wash zone spray header indicated that none of the spray nozzles were plugged (Photo 6) because the developed pressure drop was very close to the manufacturer's specified pressure drop. However the measured pressure across the shed tray feed pipes was 120 psi and the cold HCGO control valve was wide open. Also, two of the three feed lines were cold to the touch, thus there was no flow. The calculated pressure drop for one feed pipe was only 5 psi but the measured pressure drop was 120 psi.

The cold HCGO feed system was designed by the coker technology licensor to cool the hot drum vapor before it

entered the sieve trays. However, all 5,000 b/d were not being uniformly distributed, they were actually feeding only one section of the column. Using three 4-inch lines was fundamentally poor design practice. The calculated feed line velocity, assuming all three feed lines operated, was less than 1 ft/sec. Even if the header did not plug it would not provide good liquid distribution to the six pass sheds because it was not designed properly.

Temperature Survey

Measuring radial temperature profile is a good method to infer liquid and vapor distribution. The radial temperature survey below the packing had high to low temperature variation of 40°F. (Figure 8). Yet, the temperature drop across the wash section with uniform liquid and vapor distribution would be only 40°F. Furthermore, the wash zone liquid rate to the top of the packed bed was only 1.0 gpm/ft² when feeding 9,000 b/d of cold HCGO. Over half



Photo 6. Spray Header Testing



Photo 7. Collector Tray Coking

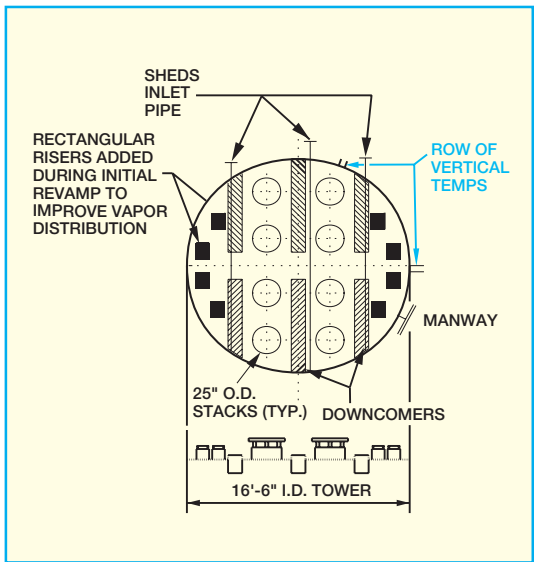


Figure 9. Coker Wash Section, Initial Revamp

of this liquid vaporizes, therefore, the liquid rate leaving the packing would be less than 0.5 gpm /ft² assuming perfect vapor and liquid distribution.

But what happens to local liquid rates if vapor is poorly distributed and the vapor temperature entering the packing is not uniform due to poorly designed shed tray cold HCGO feed system? The temperature survey proved that sections of the packing had higher temperature, thus lower liquid rate and higher oil liquid residence. Hence the packed bed coked.

Solution

Process and equipment changes were required to eliminate coke formation. Cold HCGO routed to the shed trays was eliminated; consequently all the cold HCGO was fed to the top of the wash section. Uniform liquid and vapor distribution and

higher wash oil flow dramatically reduced coking in the wash bed. Vapor distribution was poor because the collector tray design below the bed (Figure 9) did not uniformly distribute vapor. In addition, the collector tray below the packing had to distribute liquid to the six shed trays and it is very difficult to distribute a small amount of liquid internally.

In a packed bed, if vapor is poorly distributed it will cause sections of the packing to have lower liquid rates and higher oil residence time. Recommendations were to eliminate the cold HCGO to the shed trays (Figure 10), replace the collector tray to improve vapor distribution, and remove the sheds to eliminate

the multiple downcomers on the collector below the bed. The refiner implemented the first two but left the sheds in the column. Thus, the collector design still had multiple downcomers.

Shed trays in delayed coker main fractionators serve no useful purpose. They are a remnant of the era of high recycle and sieve tray wash sections. Most refiners have removed them because they constantly coke and often are mechanically damaged. Fundamentally shed tray design and operating principles dictate they operate well only at high liquid rates. Six-pass shed trays have very high weir length, hence they would require over 30% recycle to establish sufficient liquid level over the weir to provide good liquid distribution. Furthermore they would need to be perfectly level or distribution would still be poor. Delayed coker main fractionators

should never use shed trays because there is insufficient liquid flow rate to make them operate properly even when a picket fence weir is used.

After several more unscheduled shut-downs the sheds were removed. Removing the sheds allowed the collector tray design to be modified to a single downcomer and the coking on the collector tray was eliminated (Photo 7). The coking problem has not recurred.

Case #3:

Deep-cut, vacuum column (Photo 8) revamps are common today, but many units shut down to replace coked wash sections. Often these columns are shut down more than once because the cause of the problem is not determined.

Wash Zone Coking

Computer models are not calculating the wash oil flow rate correctly. The required wash oil flow rate is more than twice the design needed to avoid coking for most revamps. Coking (Figure 11) is caused by low wash oil flow rate to the top of the packing. Once the majority of the wash liquid vaporizes the quantity of liquid in the middle of the bed is so low that high liquid residence time occurs leading to coke formation.

Assuming the column vapor rate remains constant, once coke begins to form pressure drop increases. Initially a pressure drop increase of only 2 mm Hg indicates the onset of coking. But gas oil quality does not begin to deteriorate until the pressure drop increases by 4-5 mm Hg. At this point, contaminants will increase significantly and the product color will turn

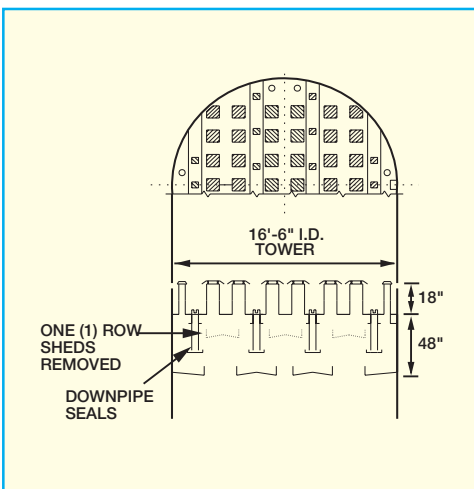


Figure 10. Improved Coker Wash Section



Photo 8. Vacuum Column

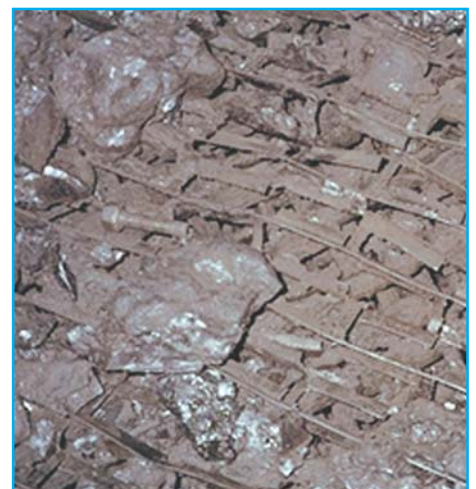


Photo 9. Coked Wash Zone

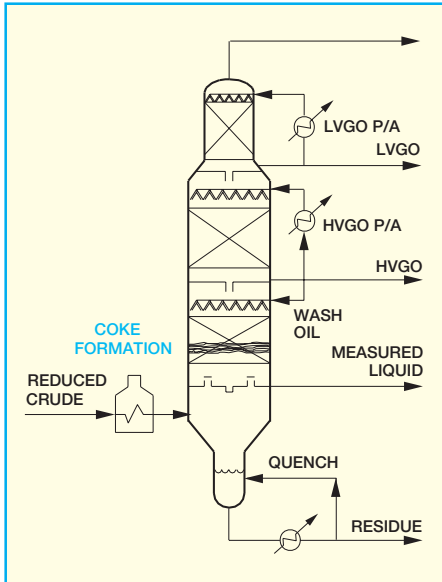


Figure 11. Crude Vacuum Washzone Coking

black. When the pressure drop increases to 8-10 mm Hg, gas oil quality will be very poor. Pressure drops as high as 80 mm Hg have been measured across vacuum columns wash sections (Photo 9).

Process simulation errors cause many wash section spray headers to be undersized, thus they cannot be operated at higher flow rates. Generally these headers are sized for 15-psi pressure drop at design conditions. As spray nozzle flow rate increases the pressure drop developed goes up and the droplet size leaving the nozzle decreases. Nozzle type will dictate the droplet size. Developed pressure drops greater than 10-15 psig will produce large

quantities of small droplets. As droplet size decreases the amount of liquid leaving the nozzle that is entrained by the vapor flow increases. Therefore, as wash oil flow rate increases the amount of entrained liquid increases and less liquid reaches the packing.

The wash oil spray header design flow rate must be correct, otherwise the bed will coke. Incorrect wash oil rate calculations result from poor feed characterization and incorrect flow sheet modeling. Design pressure drop for the wash oil header should be approximately 7 psi.

Typical process simulation models are structured assuming all the feed entering the vacuum column flash zone is in equilibrium. But this assumption is not correct because vapor and liquid in the transfer line (Photo 10) from the heater to the vacuum column are not in equilibrium. Transfer line phase separation generates superheated vapor and causes more of the wash oil to vaporize than is predicted by the typical process model structure.

Correct feed characterization and flow sheet modeling are essential to better estimate the wash oil flow rates. Assuming the wash oil spray header design is correct, operating at sufficient wash oil rate is essential to avoid coking.

Some refiners' control the wash oil flow rate based upon the metered flow rate (slop wax) from the collector tray below the wash section packing. However, the liquid on the collector tray below the wash section contains entrainment and overflash. The metered flow, however, is not

overflash. In fact, on many units, entrainment is more than 50% of the slop wax flow rate. Assuming all the slop wax is overflash will result in low wash oil rate flow and coking.

Controlling wash oil rate based on gas oil quality is also not a good idea. Good gas oil quality can be achieved with very low wash oil rates; however, the wash bed will eventually begin to coke because the liquid flow in the middle of the packed bed is too low to prevent coking.

Overflash Rate

Estimating the overflash and entrainment rates is necessary to control the wash rate. Samples of the liquid on the slop wax collector tray and residue should be analyzed for contaminants. Material balancing the flow rates and the contaminants will yield two equations and two unknowns from which an estimate of entrainment can be made. An example of such a contaminant balance is asphaltenes, which are non-volatile.

Microcarbon residue (MCR) is one of the easiest analytical tests, but MCR is a volatile contaminant just as vanadium and nickel. Therefore, an estimate must be made of the volatile content in the overflash. For typical crudes, not high vanadium crudes like Maya and Venezuelan crudes, assuming the overflash contains 10-15 times the HVGO product vanadium content will allow vanadium to be used for the contaminants balance.

Vacuum Tower

Both visbreakers and hydrocrackers convert vacuum residue to lighter components. A typical percent conversion based on 1,000°F and lighter products for visbreakers and hydrocrackers are 40% and 80%, respectively. To achieve maximum yield of clean liquid products, many refineries have installed vacuum towers to reprocess the thermally degraded tar. Two case histories illustrate the central problem



Photo 10. Vacuum Transfer Line



Photo 11. Sump Coking

Original Equipment Design Errors

- Nonoptimum design of vapor horn
- Oversized chimneys on slop wax collector tray
- Too high a residence time on the slop wax collector tray
- Too much wash oil liquid hitting the walls of the tower above the wash oil grid
- Too low wash oil rate during initial unit operation

Table 3.

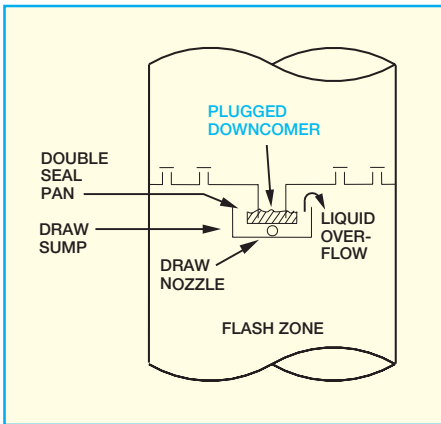


Figure 12. Hydrocracking Vacuum Column-Overflow Pan

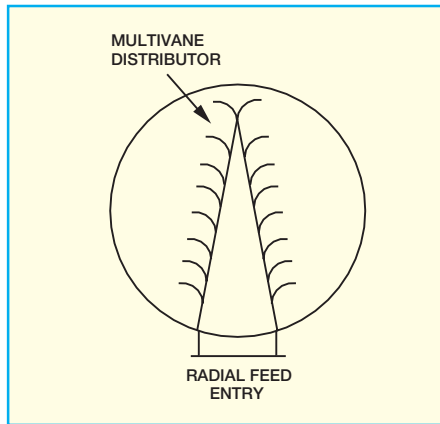


Figure 13. Hydrocracking Vacuum Column

with such vacuum towers: coke formation of the wash oil grid and collector tray below the grid.

Case #4:

A Gulf Coast unit had a long history of producing black distillates from the hydrocracking vacuum tower. Even though the flash zone C-factor was only 0.3 fps, the HGO contained 4 wt % Concarbon and the LGO had 1.5 wt % Concarbon. The HGO was so poor in quality that it was redistilled in the plant's virgin vacuum column.

When the column was opened, the wash-oil grid was coked to the consistency of concrete. The authors' analysis had previously indicated that the wash oil section design could be improved by correcting several design flaws (Table 3).

When the recommended modifications

were installed, the initial results were excellent. The HGO concarbon dropped to 0.4 wt %. However, after 3 months of operation, the wash oil grid pressure drop started to increase and the HGO Concarbon also began to increase.

Why? The overflow recycle pump had never been commissioned. While the overflow pan did have a provision for internal overflow, the authors had made mistakes (Table 4) in design (Figure 12). When the tower was shutdown, the wash oil grid was replaced. Since that time, the overflow pump has been run continuously and the HGO quality has remained excellent. The lesson from this incident is that a 100% reliable provision for internal overflow of overflow liquid is critical for vacuum towers processing thermally degraded feedstocks.

Case #5:

An overseas refinery constructed a new visbreaker vacuum column. The design was based on tower internal drawings from an operating visbreaker vacuum tower in a nearby plant. The new vacuum tower copied the radial feed-entry design, combination grid, and structured packing of the older unit.

When the new tower was commissioned, the HGO was black and contained 2 wt % Concarbon. Two months later, the unit was shut down because of a 25 mm Hg delta P through the wash oil grid, and three times the initial HGO concarbon (6 wt %).

The grid was removed and the wash oil nozzles were modified. Initial operations have produced a black HGO with 2 wt % Concarbon. It is the authors' opinion that the central problem with this design is the radial feed entry (Figure 13). These types

of entry promote resid entrainment and, as a consequence, wash section grid coking. The authors' recommendation is a tangential entry.

Unfortunately, the prototype used for this design also produced a black, high-Concarbon HGO. While using an existing unit as a basis for a new design may be acceptable, one should make sure that the unit being copied is actually meeting expectations. ■

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Small Design Errors—Large Consequences

- The slop wax collector draw-off sump had a high residence time before it would overflow.
- If the slop wax pump was running, the liquid level in the sump was low, and coking would be retarded.
- When the pump was not operating, the draw-off sump coked (Photo 11). With a virgin vacuum column, the temperature in the sump would not have resulted in a high rate of coke formation. But when processing thermally degraded feed, coking proceeds much more rapidly.
- Once the draw-off sump coked, flow to the overflow pan's internal overflow pipe was blocked.
- The slop wax began to overflow through the vapor chimneys, thus promoting entrainment of the slop wax into HGO product.
- The entrainment caused the wash oil grid to coke-off.

Table 4.



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