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De-entrainment and washing of flash-zone vapors in heavy oil fractionators

Extensive troubleshooting experience shows what methods are most successful

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The correct selection of wash-zone internals can aid in the operation of heavy oil fractionators. Mistakes in the process design and poor selection and installation of internals can greatly reduce the run length and quality of recovered gas oils from these towers.

The most effective way to increase the reliability and effectiveness of the wash-oil section is to properly address and solve the initial vapor distribution and de-entrainment of residual materials from the flash zone. For different towers, it is not the rote solution or the calculation ability of the personnel, but rather the design engineer's experience level that solves the operating problems. Towers are different and require different solutions depending on operations, feed supply, tower layout, etc. Through many revamps, we have proved that this is the most effective way to suppress wash-zone coking and plugging, regardless of grid or trays.

Background. In the past 10 years, there has been a great deal of progress in removing entrained residual components from flash-zone vapors. Hundreds of projects have been implemented, many were successful and others failed. These successes and disasters are judged on the basis of run-length improvement or ability to fractionate the heavy ends from the heavy oil distillate.

We have been directly involved in the design, operation, installation, inspection and troubleshooting of a large percentage of these projects. The following describes what we found to be successful and what has not worked as well. Our observations and related experiences are based on a large range of heavy oil services. In order of the number of units encountered, rated by the service of the tower, this article is based on:

- Virgin crude vacuum (fuels, asphalt and lube) columns
- Virgin crude columns

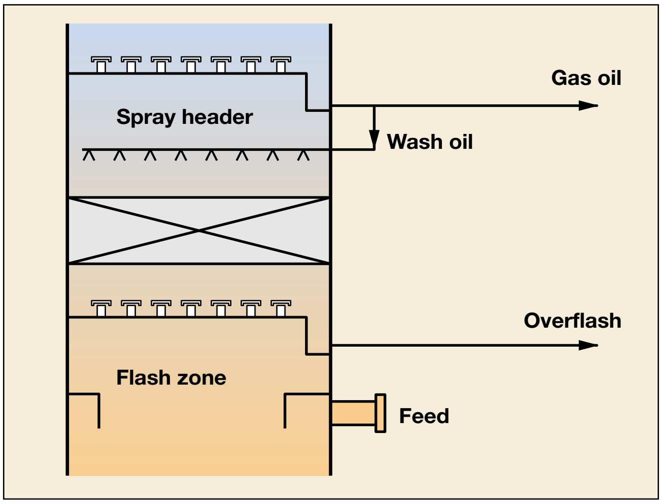

Fig. 1. Typical layout of a heavy oils tower.

- FCCU main fractionator slurry pumparounds
- Visbreaker vacuum flashers
- H-Oil vacuum towers
- H-Oil main fractionators
- Coker main fractionators
- Visbreaker fractionators
- Flexicoker main fractionators
- Recovered lube oil (waste oil recovery) vacuum tower.

The type of contacting devices used in the wash zones of these columns are:

- ▶ Dumped random packing
- ▶ Structured packing
- ▶ Grid packing
- ▶ Combinations of the above
- ▶ Trays, including valve, bubble cap and sieve
- ▶ Open spray chambers
- ▶ Side-to-side shower decks.

Causes of failure. Wash-zone failures are categorized into:

1. Wash-zone coking
2. Mechanical damage.

We will only focus on the causes of wash-zone coking, even though the second point can and has caused wash-zone failures.

Wash-zone internals coking can be extremely severe.

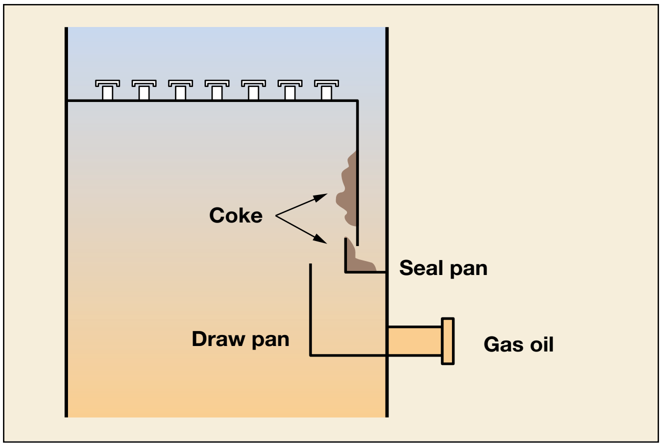

Fig. 2. Coked gas oil draw tray.

In one Gulf Coast virgin vacuum column, the tower exhibited such severe coking of the structured packing bed that it resembled a paved asphalt road. In another vacuum column, the tower was approximately 15-ft diameter, and the only free open area for vapor flow was reduced to a diameter of approximately 3 ft. The pressure drop of this tower, at 65% of design rate, was around 35 mmHg. A coker fractionator grid bed became sufficiently coked to the point that the wash oil drainage through the grid was essentially zero. In an H-Oil vacuum tower, the pressure drop due to wash-zone grid coking exceeded 50 mmHg.

When a wash oil bed cokes, the pressure drop increases (Fig. 1). This creates localized high vapor velocities as the coking "chokes off" some of the tower's open area. Since the bed does not coke evenly, high vapor velocities will promote high entrainment in these areas.

As the pressure drop increases due to high vapor velocity, the liquid retention time in the packing increases. On a simplified model, coking is a function of time and temperature. As the liquid hold-up and retention time increases, the coking tendency will increase. As coking increases, the pressure drop will increase across the wash-zone packing. Hence, the old adage "coke-makes-coke" is certainly applicable.

Temperature effects. For virgin atmospheric fractionators and vacuum columns, a flash-zone temperature of less than 690°F will almost guarantee that coking will not be a problem, even when the wash oil is zero and vapor velocities are high. Above 690°F, wash oil is needed to retard coking.

A flash-zone temperature of 780°F is considered to be extremely high from a wash oil coking perspective. We have designed several vacuum columns with flash-zone temperatures approaching 775°F without coking the wash bed. Run lengths of several of these columns have been up to five years.

For delayed coker fractionators, a flash-zone temperature of 760°F to 790°F is normal. For visbreaker vacuum flashers, a temperature of 730°F appears to be excessive, while 660°F appears to retard flash-zone coke formation.

H-Oil vacuum towers seem to coke more readily than visbreaker vacuum flashers at comparable flash-zone temperatures. We believe that this is due to the higher residual conversions of the H-Oil reactors, as compared to the visbreaker soaker units.

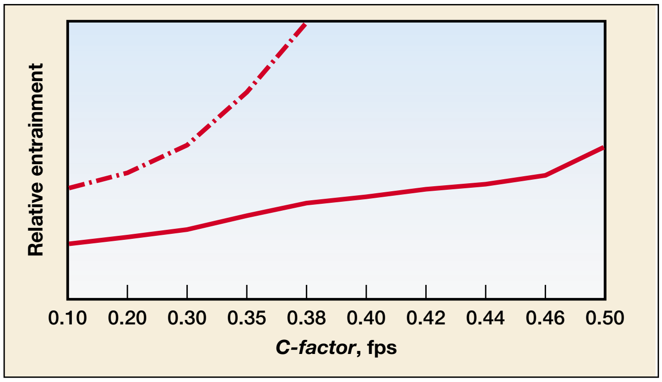

Fig. 3. Relative de-entrainment comparison.

Recovered lube oil vacuum towers form "polymeric" coke in the flash zone, regardless of flash-zone temperatures. Better process design and chemical treatment of the feed has reduced the occurrence of polymeric coking in this service. However, to date, this problem has not been totally eliminated.

For FCCU main fractionators, the reactor overhead temperature does not influence coke formation in the slurry pumparound. The main tendency to form coke in this service correlates with paraffinicity of the reactor feed (feed quality), leaking of fresh feed into the pumparound circuits and distribution quality to the slurry pumparound bed.

Entrainment (vapor) velocity. We use this factor to characterize the amount of entrainment to the wash-zone collector tray. We can correlate this velocity using the flash zone "C-factor:"

$$C - factor = V_s \sqrt{\frac{\rho_V}{\rho_L - \rho_V}} \tag{1}$$

where V_s = superficial vapor velocity based on tower cross-sectional area
ρ_V = vapor density
ρ_L = liquid density

Entrainment velocities seen in practice can range from 0.05 to 0.65 feet per second (fps). An entrainment velocity *C-factor* of 0.15 fps is considered to be low and will normally only be used in new tower designs where significant capacity increases are needed in the future. At this low *C-factor,* the wash-oil section packing or trays will be protected from entrainment coking due to low entrainment. This does not protect the refiner against coking caused by errors in process design.

An entrainment velocity approaching 0.65 fps is high and significant entrainment and re-entrainment of the wash oil is unavoidable. Most new units are typically designed for a *C-factor* of 0.30 to 0.35 fps, while many revamps are successfully and predictably executed at 0.45 fps. *C-factors* of 0.50 fps have been tested and observed to produce controllable entrainment rates due to excellent liquid and vapor distribution. *C-factors* above 0.50 to 0.65 fps are operable, but entrainment and coke formation is inevitable in operating these columns.

Wall coke. In H-Oil vacuum towers, visbreaker fractionators and vacuum flashers, wall coke is prevalent and frequently observed. This coke is thick (12 in. or more) and is frequently found below the gas oil draw pan (Fig. 2). This wall coke often falls from the wall onto the wash oil grid or vapor horn distributor. The significant feature of this wall coke is that it is forming on a vertical surface.

Coke forms 50% to 70% as fast on vertical surfaces as it does on horizontal surfaces. Thus, trying to retard the rate of coke formation by designing for self-draining surfaces, in these applications, is largely ineffective. At best, these design features may prolong the run-length of a tower by a relatively short time span.

The coke formation rate seems to be largely a function of the entrained residual components flowing past a surface, rather than surface orientation. Horizontal surfaces should be sloped. But if the surfaces are not wetted by wash oil, even a slope of 90° will not particularly influence the surface coke deposition rate. This has been observed in many shutdowns in these types of severe high-conversion towers.

Coke formation on vertical surfaces is usually a more urgent problem than coke formation on the topside of a horizontal surface. This is because coke forming on vertical surfaces eventually falls off and causes problems for the tower internals. For example, in one visbreaker fractionator, coke breaking off the outside of a downcomer restricted and prevented flow into the draw-off pan below (Fig. 2). This caused a premature unit shutdown.

Coker fractionators. When properly designed, the short grid bed in the coker fractionator's wash zone will produce less than 0.5 wt% conradson carbon (CCR) in the heavy gas oil. This type of gas oil quality was demonstrated with a flash-zone temperature of 770°F and an entrainment velocity of 0.4 fps. Run lengths of over three years on these units have been demonstrated in industry.

The same set of operating parameters would cause a visbreaker evaporator or visbreaker fractionator wash zone to coke in a few weeks or a month. Both coker and visbreaker flash-zone vapors are thermally cracked and contain thermally degraded entrained liquids. But why is there such disparity in their operations? Answer: vapor flowing into a delayed coker fractionator comes from a coke drum that is typically twice the fractionator's diameter. If the fractionator's entrainment velocity is 0.4 fps, then the coke drum's entrainment velocity would be 0.1 fps. Therefore, the amount of entrained liquid entering the coker fractionator is already low. We have observed that visbreaker fractionators operating at an entrainment velocity of 0.1 fps do not coke in the flash zone.

Vapor distribution. When discussing reasonable and obtainable entrainment velocities or *C-factors,* initial vapor distribution is the most important factor and must be considered. In one virgin vacuum column, we observed a *C-factor* of 0.5 fps without excessive entrainment. Another virgin vacuum column had terrible entrainment at a *C-factor* of 0.3 fps prior to revamp. We have revamped towers operating at 0.43 fps *C-factors* to address vapor distribution, and were able to push post-revamp capacities and lift to a *C-factor* of 0.46 fps with lower entrainment. More entrainment in the flash zone means more rapid coke formation, since the rate of flash-zone and wash-zone coking is proportional to entrainment rates.

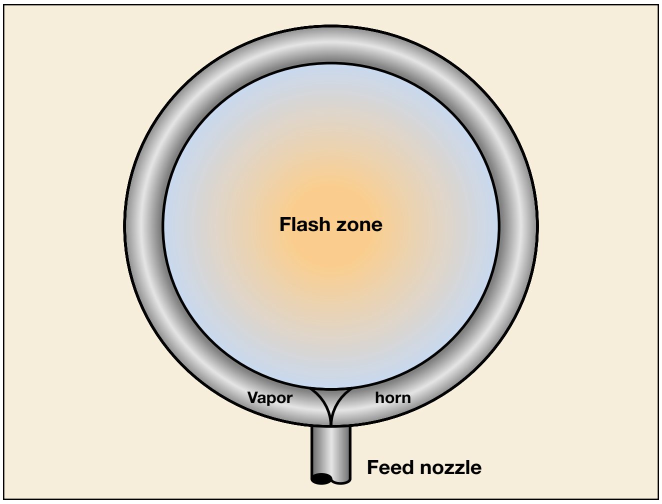

Fig. 4. Radial flow vapor horn schematic.

With over 200 industry applications in high-vapor-rate vacuum services, we have correlated expected entrainment vs. *C-factor* in Fig. 3. Compared to other flash-zone distribution devices on the market (dashed line), the vapor horn (solid line) has proven to be both an effective vapor distribution and de-entrainment device as its entrainment curve stays essentially flat until high *C-factors.* With other vapor distributors, the entrainment increases exponentially above a *C-factor* of 0.32 fps. The vapor horn has maintained very high de-entrainment capabilities at *C-factors* approaching 0.46 fps.

Successfully demonstrated factors that retard flash-zone entrainment are:

- Keeping the feed inlet nozzle top at least 5 ft below the overflash draw pan
- Designing dual inlets for large-diameter towers over 20 ft in diameter
- Minimizing the width of the vapor horn distributor
- Using internal "cut-off" baffles inside the horn
- Using internal "swirl vanes" to aid in vapor distribution
- Using radial entry and split-flow vapor horns (Fig. 4) for smaller-diameter towers rather than tangential entries
- Providing for emergency internal overflow pipe from the overflash pan
- Designing the overflash pan with many small chimneys to function as a vapor distributor with significant pressure drop.

The first item on this list is an excellent rule-of-thumb. In revamp after revamp, we have seen gas oil quality greatly improve by increasing the vertical height of the flash zone. In one revamp, we modified an older-style vapor horn using all of these guidelines in a virgin crude vacuum column operating on Venezuelan crude. The revamp results were excellent. The tower diameter was over 30 ft. The unit was plagued by poorer-than-expected gas oil quality that limited an increase in cutpoint. The vapor horn was modified, using the guidelines, and the heavy vacuum gas oil (HVGO) quality improved enough so that the refinery was able to increase cutpoint by 10°F to 15°F. Fig. 5 is a schematic of the vapor horn that was used. The cut-off vanes are not shown due to the view.

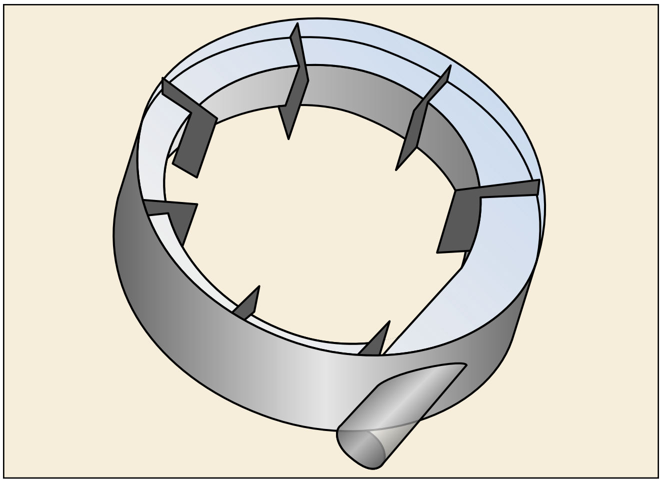

Fig. 5. Tangential vapor horn.

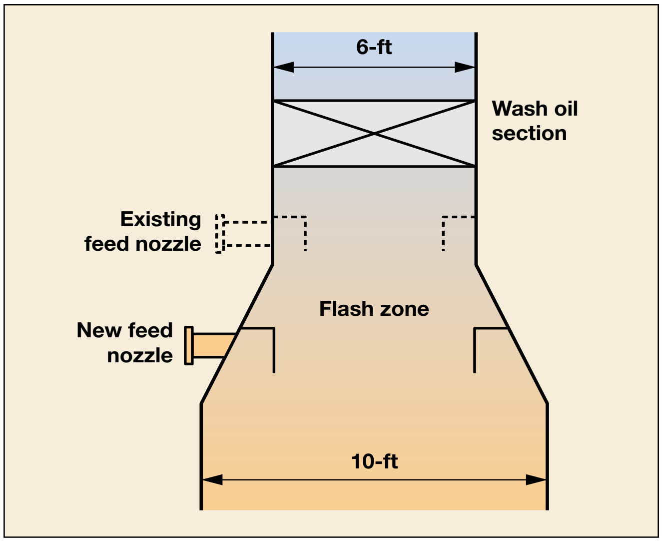

Fig. 6. Recovered lube oil vacuum column flash-zone revamp.

Open sprays vs. grid. Both valve and bubble cap trays have the ability to reduce entrainment levels by 65% to 75%. Grid and structured packing have an increased ability to reduce entrainment by 90%. De-entrainment will continue until the internal device cokes off. Then the entrainment levels will skyrocket, as previously discussed.

In several harsh services, including two H-Oil vacuum columns and visbreaker vacuum flashers, we converted the typical trayed or packed wash zones to open spray chambers. These are less likely to coke off than the internals in the same service.

At high *C-factors* (i.e., >0.3-fps entrainment velocity), results have been marginal and lower quality gas oil has been obtained, compared to predicted qualities. Our calculations show that 40% to 50% of the entrainment is suppressed by the open spray chamber at spray wash rates on the order of 0.5 gpm/ft^2. Using more, smaller nozzles and wash oil would help, of course. Unfortunately, this would increase the recycle and degrade cutpoint, which is not an option in residue conversion units. Using multiple levels of spray chambers does not seem to help.

Gravity is reliable—reducing the operating *C-factors* in these towers from 0.3 fps to 0.2 fps cuts the observed entrainment rates roughly in half, as measured by CCR concentrations in the heavy gas oil product.

Trays in wash oil service. Trays have a reliability problem for long run-length operations. Older-style bubble cap trays often perform reasonably well in severe coking services, provided that the cap's bottom has a substantial clearance above the tray deck. Also—just as critical—the vapor velocity underneath the cap must be small. All this will permit coke to build up on the tray deck before restricting vapor flow. However, at some point, high vapor pressure drop through the caps will force the vapor to flow up through the downcomers and will flood the trays. At this point, the heavy gas oil product quality will degrade even more severely than with the open spray chamber operations.

Valve trays appear to be the worst choice for wash oil trays. The valve lift may only be 0.5 in. Many times, moveable valves get stuck or the open area gets coked off. Only large volumes of wash oil permit the use of flutter-type valve trays in wash oil service. Fixed mini-valves have been used with limited success in these applications.

We have seen side-to-side shower decks used in visbreaker service with good results. The ends of each shower deck had a small rectangular box (approximately 6 in. deep) filled with expanded metal or sieve holes. The expanded metal and sieve holes redistribute the wash oil over the weir length of the shower decks. On inspection after 2-yr run lengths, these, too, were coked off due to the residence time of liquid in the box.

Packing in wash oil service. Rings or other random packings have been used with poor results in this service. They are prone to mechanical failure (crushing) and upset dislodgment (ring migration). Random packings are also subject to higher fouling and coking, because of greater liquid hold-up due to the nonuniform liquid flow patterns in the packing (i.e., random packing).

Heavy-duty grid, with minimum vertical height and the correct metallurgy, is often the best choice. Grid has an extremely low liquid hold-up as compared to structured packings or "structured grids." Don't be fooled into thinking that grid will not coke: it will coke, as other internals will, if the process design does not consider the minimum wash oil to the wash zone for proper wetting or proper and uniform vapor distribution.

Recovered lube oil vacuum column. We have worked extensively on a vacuum column in this service. Additives in the waste oil caused a polymerization reaction that plugged the wash oil grid, as shown in Fig. 6.

To solve the entrainment problem that was causing the coking, we lowered the feed nozzle into the "swedged" section of the tower. This effectively reduced the entrainment velocity at the feed nozzle elevation.

A result of this change was an increase in run length. By improving the vapor distribution and de-entrainment, the refiner increased run length six-fold, from one month to six months. We are working with this refiner on other solutions to increase the run length even further.

Flexicoker main fractionator. This tower is the same as a coker main fractionator, with the exception that its feed can possibly contain catalyst fines. Reactor effluent enters at the main fractionator's bottom as a superheated vapor stream.

This tower was revamped with grid and a "specialized vapor distributor" in 1995. The goals of the revamp were to increase the fractionation ability of the wash zone while using less wash oil than with the existing trays. The tower started operations in November 1995. By February 1996, the pressure drop in the wash zone had quadrupled. The fractionation plummeted and the heavy distillate quality could not be controlled.

After reviewing the tower, we noted that it had poor vapor distribution to the wash-oil grid. The "vapor distributor" was approximately 9 in. below the wash-oil grid. The inlet nozzle to the fractionator was 54-in. diameter. Inspection during a shutdown confirmed our belief that poor vapor distribution had caused this failure.

The solution included relocating the wash grid higher in the column and adding a proper vapor distribution tray. The refiner insisted that the "specialized vapor distributor" had to be maintained because it would take too much manpower to remove. The fixes for the tower were completed, and the tower has been operating for two years without incident.

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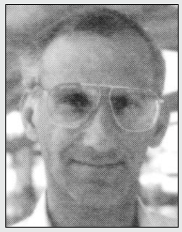

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