

Reliability vs recovery for delayed coking fractionators

When selecting tower internals, numerous choices are available for coker main fractionator configurations, each offering benefits and trade-offs. Some of these choices are discussed along with insight into the internals features that can be provided in any coker fractionator

Darius Remesat
Koch-Glitsch Canada

The increased processing, now and in the future, of lower quality, heavier, more sour, less stable crudes, together with the rise in demand for refined products, makes it necessary to upgrade as many of these crudes as possible to maximise refinery economics.

Delayed cokers have proven to be effective at decarbonising and demetallising heavy petroleum residues. This refining process can provide 20–40% of the downstream hydroprocessing feedstocks. In general, cokers producing fuel-quality by-product coke are operated to maximise liquids and minimise coke. Optimisation of the coker operation is crucial to any clean fuels programme. Having the delayed coker produce clean hydroprocessing feedstocks may compete with the need to improve coker operations to process heavier feedstocks and/or increase capacity. The economic and reliable operation of these units requires a review of feedstocks, including the properties of cracked feeds from delayed coking operations, and the right choice of internals.

The coker fractionator plays a key role in ensuring the unit delivers the products as desired and operates reliably for the required run length.¹

Main fractionator

A coker usually consists of one or two sets of coke drums and a main fractionator (Figure 1). The coker main fractionator separates the unstabilised naphtha and heavier products. Figure 2 illustrates a typical main fractionator configuration including pumparounds and side strippers. There are two main sections in the main fractionator: the wash zone and the fractionation zone.² The upper section of the column is the fractionation zone used for separating the main fractionator products, such as naphtha, kerosene, light gas oil (LGO) and heavy gas oil (HGO). The lower section of the column (below the HGO draw tray) is the wash zone. An additional sub-section, called the quench zone, can

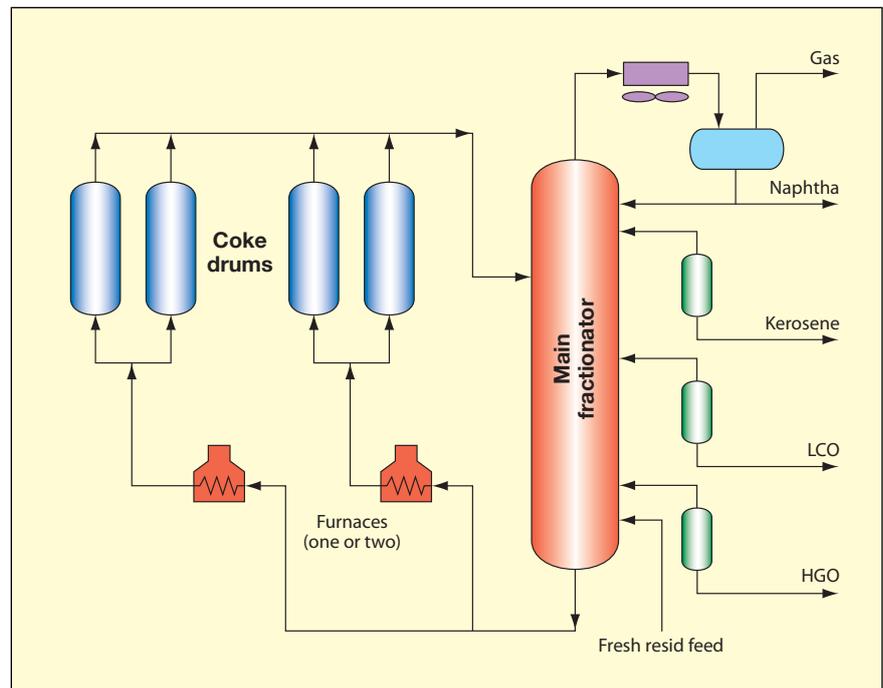


Figure 1 Simplified block flow diagram of coking process¹

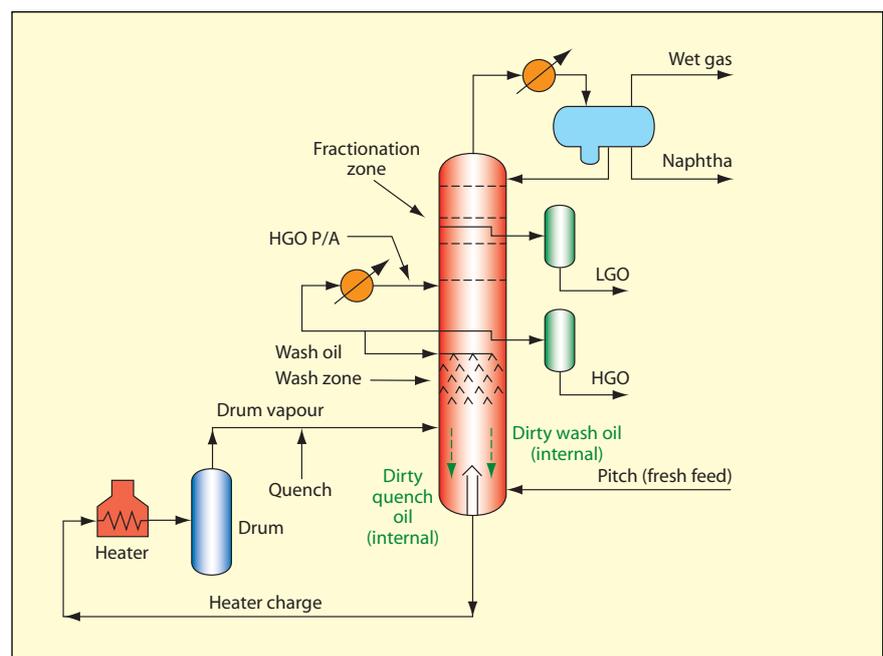


Figure 2 Coker main fractionator¹

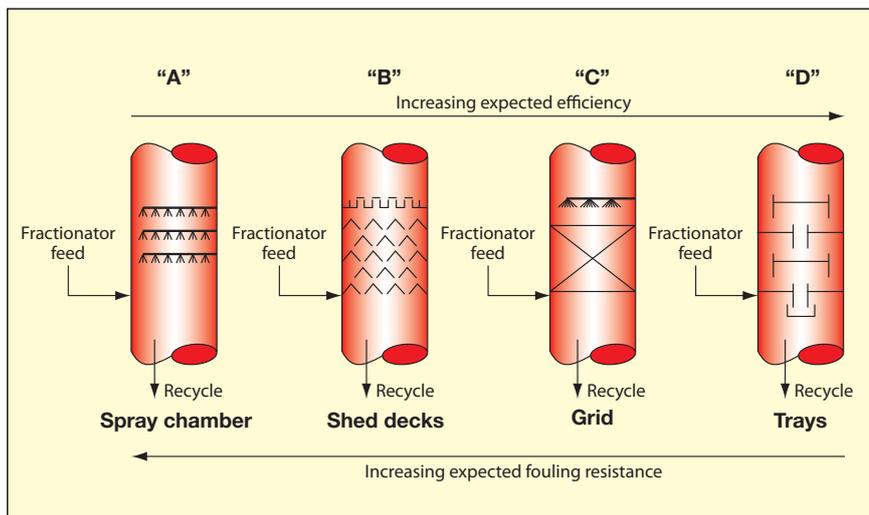


Figure 3 Wash zone designs options

be provided in the wash zone, to deal with high severity coke drum designs for very heavy, unstable crudes that generates a high proportion of coke fines. The quench zone protects the internals in the wash zone from the coke fines in the feed vapour.

Wash zone considerations

The wash zone has three objectives:

- To control the heavy tail of the HGO distillation
- To minimise entrained coke fines in the main fractionator products (mainly HGO)
- To optimise product yield by setting the recycle cut point.

The design of the wash zone requires trade-offs between HGO product quality, unit reliability, yields and unit throughput, and involves two basic choices: wash oil rate and fractionation hardware. High wash oil rates improve HGO product quality by removing more of the heavy tail and coke fines, and

improve column reliability by mitigating the tendency for coking. However, high wash oil rates reduce unit capacity, since the wash material ends up in the product bottoms and contributes to the recycle load on the heater charge.

The wash zone can have various configurations, with Figure 3 illustrating four typical arrangements. Higher wash zone efficiency is countered by reduced fouling resistance, with the spray chamber (Design A) considered the highest fouling-resistant and lowest efficiency configuration. There is minimum opportunity for coking, since this design provides a minimum surface area for coke particles to adhere to. Reliability is normally better than with the other designs, but the recovery of heavy coker gas oil (HCGO) is reduced. Design B, with shed decks, attempts to use a rudimentary separation device (eg, 10–20% tray efficiency per shed row) to gain efficiency while maintaining run length. As with Design B, Design C uses

a grid to improve wash zone separation efficiency.

Design D shows a traditional high-efficiency approach, with trays in the wash zone requiring a high recycle rate (typically maintained above 15% to prevent very short run lengths), and produces the best quality HCGO. This design has the lowest yield and is the most prone to coking. A quench zone is considered most often with trays due to the low reliability of the trays.

Data has been gathered and compiled from operating units for the various configurations used in the coker fractionator wash zone. Figure 4 takes this industrial feedback, plotting observed run lengths against average wash zone efficiency, measured as vanadium in the HGO product stream. Although there are many variables (type of crude [eg, contaminants, stability], coke drum operation and wash rates) that impact the efficiency and reliability of an operating unit, the data shown in Figure 4 provide some insight into each configuration. All the designs show both successes and failures.

The underlining message is that if the design objectives are clear and match the actual operation, a wash zone configuration can be successful. One design is not better than any other; they just address different design objectives. However, you should not necessarily settle for low wash zone efficiency to increase your chances of a desired run length. It appears that each design can create a desired run length, and there is a difference in efficiency among the offerings. Spray chambers and shed decks offer comparable performance, while grid and trays provide improved wash zone efficiency. The impact of wash oil flow rates needs to be factored into this assertion. Included in the data are cases where unconventional, unstable crudes (such as oil sands) have a grid in the wash zone and have provided favourable results. The operator's experience level, economic objective and risk/reward philosophy dictate which configuration is used and it is the design team's responsibility to maximise the economic objective.

Wash zone section designs depend on the recycle and HCGO quality targets. Increasing the liquid volume yield requires minimum recycle. Therefore, for high reliability, high yield, with minimum concern for product quality, spray chambers are used. However, as noted in Figure 4, they have very low efficiency and, once column vapour capacity (noted as C-factor) rises above 0.26–0.28 ft/s, entrainment of non-distillable material and coke fines into the HCGO increases.

For situations such as revamps, where improved HCGO product quality is desired and/or capacity increases are

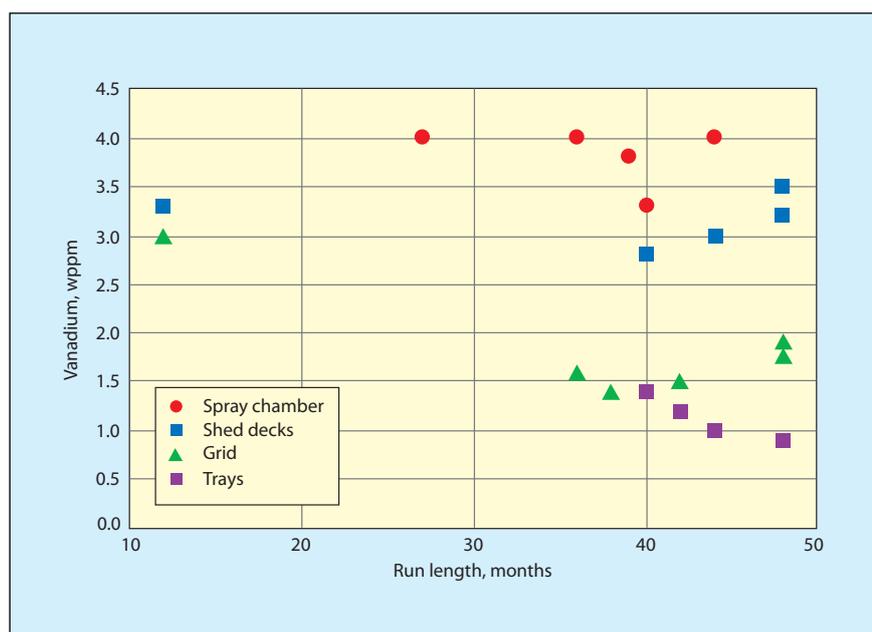


Figure 4 Performance comparison between wash zone styles: efficiency and run length

Publically available parameters associated with various grids/packing^{2,3}

Grid characteristic	Flexigrid 2	Thick SS packing/ pseudo-grid	Thin smooth sheet packing
Minimum thickness	16 ga or 1.58mm	16 ga or 1.58mm	Up to 0.5mm
Packing factor, fp (1/ft)	4	8–10	6–7
Pressure drop, wc/ft	0.054	0.15–0.176	0.200–0.2105

Table 1

needed, resulting in high C-factors, internals in the wash zone along with good vapour distribution need to be considered. The internals, collector trays and/or inlet feed devices must address the increased tendency to coke by introducing more obstructions in the column.

Improving wash zone performance

From the data in Figure 4, there is a big gap in performance between sheds and a grid in terms of fouling mitigation and efficiency. A grid and trays have comparable separation efficiency, with a grid providing increased resistance to fouling over the trays due to the open area advantage (and thus lower wash oil flow rates). A few items should be considered when deciding on the type of grid to use in the wash zone, if a grid is to be used at all.

Grid considerations

Inclusion of a grid in the wash zone spray chamber provides the following benefits:

- A medium for vapour and liquid to contact and transfer heat from phase to phase. This is much more efficient than just mixing the two streams in an empty tower, as in an empty spray chamber there is just the surface area of the droplets (which are going to have a wide size distribution). Each spray header provides heat transfer (approximately 1/2 HTU) in its direct

zone of influence. A grid extends that zone of influence and, by pooling the small droplets into larger ones and creating a curtain of liquid, the hot vapour is forced to pass through this liquid stream, providing additional heat and mass transfer

- Acts as a de-entrainment device for the rising vapour. The significance of this benefit depends on what the feed is like, whether it is in two phase (losing yield if you drag some liquid all the way up and out the tower) and/or feed vapour velocity

- Overall on-spec throughput is larger for a grid wash zone vs a spray header due to the benefits of improved heat and mass transfer and de-entrainment.

If a grid is chosen for the wash zone, the style of grid is crucial if the towers' reliability is to be maintained. The grid needs to supply the necessary opening area for fouling mitigation, while still providing enough contact area to obtain the separation benefits, and it must be robust enough to handle the severe operating conditions. Table 1 provides some publically available characteristics of grids offered for severe service operations. Thickness is shown as a typical indicator of durability (thickness equates to higher durability), packing factor (definition of grid's hydraulic capacity: lower packing factor equates to higher capacity) and pressure drop as a measure of fouling mitigation, and pressure drop as an indicator of capacity.

From the data shown in Table 1 and Figure 4, it can be summarised that to provide the necessary reliability while trying to improve separation, a plausible specification for a grid in a coker fractionator wash zone could be the following:

- Minimum thickness of 1.5mm
- Packing factor less than or equal to 4 (1/ft)
- Pressure drop of less than 0.076in wc/ft at design loads (<0.076in wc/ft)
- Not constructed from corrugated sheet metal.

Feed inlet device

Even though the feed velocity to the coker main fractionator can be very high, providing an inlet feed device in this severe service (suspended coke fines in vapour and at temperatures conducive to fouling/plugging) is not easily suggested. However, to realise any efficiency gains from including a grid in the wash zone, proper vapour (and also liquid) distribution needs to be addressed. As a general rule, as vapour velocity is decreased in the feed, the concern for vapour maldistribution in the column decreases. Possible options for improving wash zone vapour distribution (for reducing the inlet feed velocity) to deal with the highly fouling and erosive nature of the vapour flow is to:⁴

- Increase the feed nozzle size by removing some of the refractory
- Swaging up immediately upstream of the nozzle (no real benefits have been observed in other units)
- Install a vapour feed inlet device.

Conventional designs such as vapour horns, vane types and baffle plates have been proven not to work in this service, where coking and erosion are severe. Poorly designed distributors have coked to the point where vapour flow was obstructed, resulting in premature

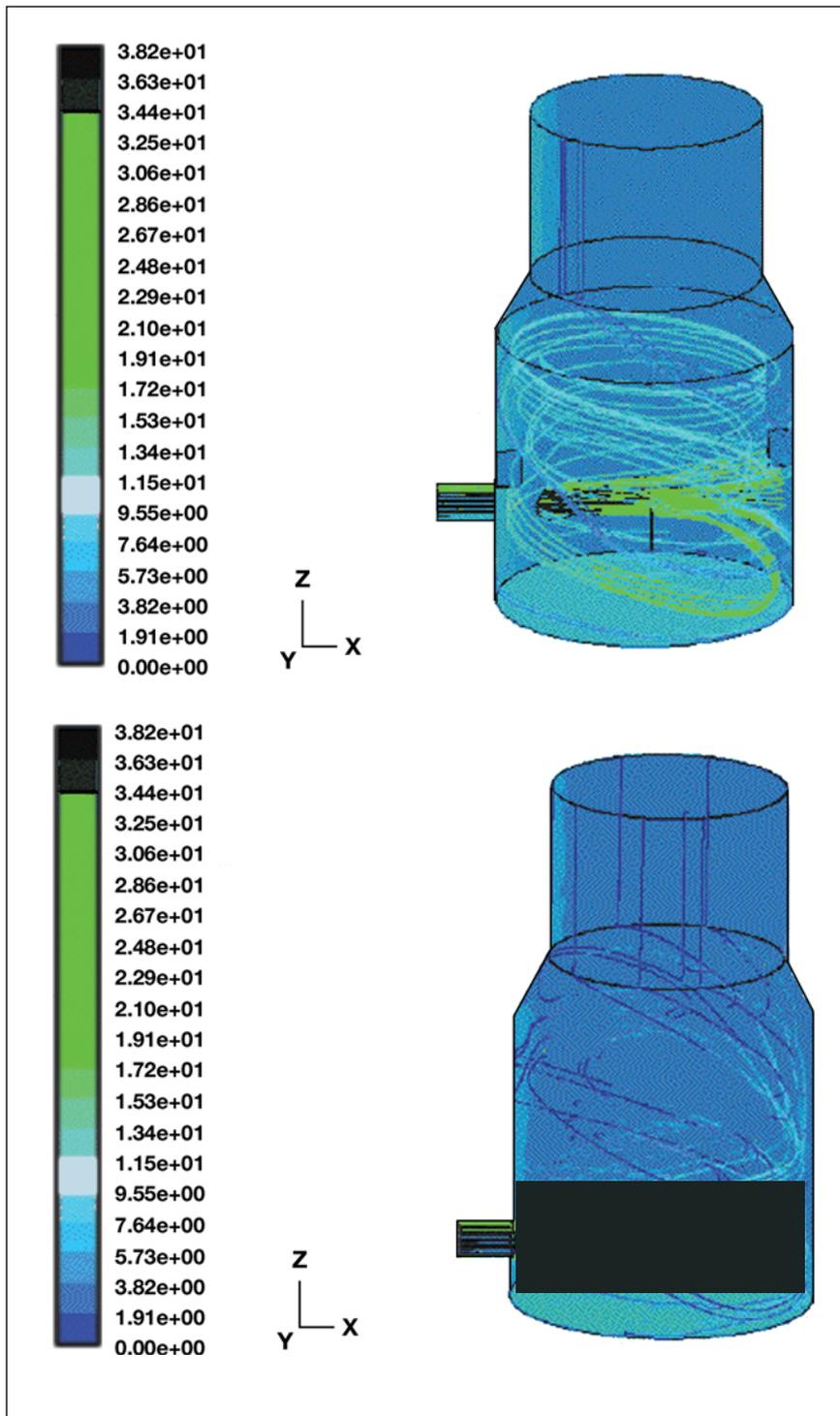


Figure 5 CFD analysis for no inlet feed device (top) and for fouling/erosion-resistant inlet feed device (bottom) for maximum vapour distribution. Vapour path lines coloured by velocity magnitude (m/s)

shutdowns.⁴ A properly designed vapour feed inlet device is often a cost-effective alternative to increasing feed nozzle size. In this case, during the limited window of a shutdown, an inlet feed device was the only option to provide the necessary vapour distribution for the success of the grid revamp. Vapour distribution analysis using computational fluid dynamics (CFD) has been done to create an inlet feed device specific to coking and erosion situations. Figure 5 illustrates CFD analysis on a high f-factor vapour feed in a coker main fractionator without

a feed inlet device on the top, and a Koch-Glitsch Model 798 severe service vapour distributor on the bottom. Without a feed inlet device, maldistributed vapour enters the grid bed, severely reducing the heat transfer capabilities of the zone and increasing the potential for premature plugging. With a properly designed Model 798 severe service vapour distributor, the inlet vapour feed is distributed more evenly, contributing to the increased performance of the grid bed in the slurry pumparound zone.

Reliability concerns (fouling)

A database of over 900 malfunctions states that fouling (coking/scaling) accounts for over 15% of all cases.⁵ This percentage is increasing as operators push units to maximise asset utilisation and standard refinery design guidelines are used for this severe service operation. Coker gas oils typically contain high concentrations of hydrocarbons with a double bond one carbon away from an aromatic ring, called conjugated olefins or dienes. These conjugated olefins can polymerise to form coke in the temperature range of 232–324°C (450–615°F). Unlike hard thermal coke, coke formed from the polymerisation of conjugated olefins is brittle and puffed, and called popcorn coke. The measure of the concentration of conjugated olefins in an oil is by the diene test (UOP method 326–82). Oils with a diene value of 4 or more typically form popcorn coke in the temperature range of 260–304°C (500–580°F).² As a result, coker fractionators are prone to popcorn coke formation.⁶ Interestingly, there may be a case that running at higher temperatures can move the operation out of this type of coke formation. Regardless, fouling is a major issue and its impact and the mechanism involved needs to be accounted for when designing the coker fractionator.

Since fouling cannot be fully removed from a separation vessel, there are many products available to address the level of fouling and the overall severe operation found in the coker main fractionator:

— **Fouling-resistant valves** Figure 6 shows a relative comparison of reliability between different tray deck panels used in the same column. Two separate operating cases were used to develop the relationship shown in this figure. Different valve types were used in the pumparound zone to try to increase run length. Sieve trays were originally specified, but due to the severe operation were heavily fouled, restricting performance well before the expected run length (approximately 1.5 years). Next, high open area fixed valves (VG-10) were used to improve run length to 2.5 years. Finally, proprietary Provalve valve trays were used, with a significant increase in run length (close to four years).

The Provalve is a very open, fixed valve with “push” features that are designed specifically for fouling service. Figure 7 shows a comparison between a standard sieve tray and a Provalve tray in heavy fouling service.⁷ In this example, the process had two towers operating in parallel, processing the same stream, at the same flows and conditions. One tower was equipped with sieve trays (the original design choice) and the second tower was equipped with Provalve valve trays.

Figure 7 shows the accumulation of foulant material on the two trays after five months of operation. The sieve tray was over 90% plugged, to a point where the tower needed to be shut down and new trays installed.

The Provalve valve tray had only 10% of the active area plugged. In operation, this valve tray was able to increase the run length of the column by a factor of five, leading to significant savings

- **Sloped collector trays** Minimise residence time of liquid in tower to reduce chance of material coking

- **Downcomers** Have funnel designs to prevent particle accumulation (reduce dead spots) and nozzles in locations where water wash will reduce salt build-up

- **Construction of trays** Trays can be reinforced with larger beams, thicker tray decks, tighter bolting and shear clips. A key consideration for ensuring reliability is to validate the features of the trays and to confirm material weights as the diameter of the column increases. Figure 8 relates expected material weights for different reliability designs (standard, 1.0 psi, 2.0 psi uplift) to diameter size (not linear)

- **Integral designs** Grid/packing beds should have j-bolting and through-rods with hold-down plates to reinforce the beds for any process upsets

- **Double-layered grid** Weld grid layers together to increase robustness and reduce installation time (vs more weight per piece).

Conclusion

There are numerous options available to the end user when determining desired coker fractionator design. Choice depends on the value associated with performance and reliability. Operators should obtain all the necessary pros and cons for overall designs and tower internals choices, based on their value requirements before settling on one path. Regardless of the configuration, internals can be designed to improve chances of providing necessary reliable operations.

Provalve (PROVALVE) is a mark of Koch-Glitsch.

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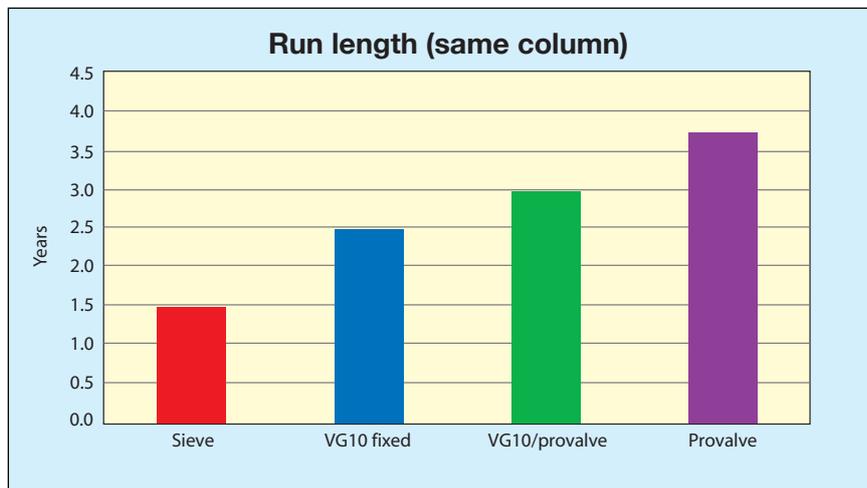


Figure 6 Qualitative observation of valve tray fouling resistance

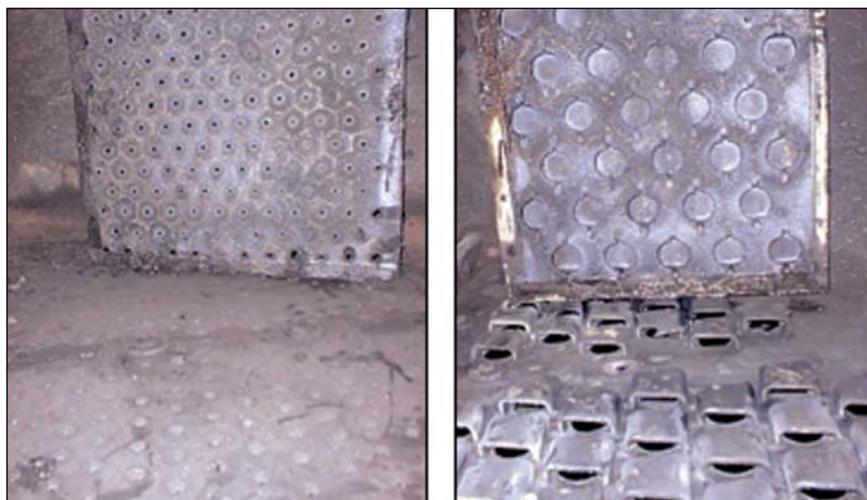


Figure 7 Comparison between a standard sieve tray and a Provalve tray in heavy fouling service⁷

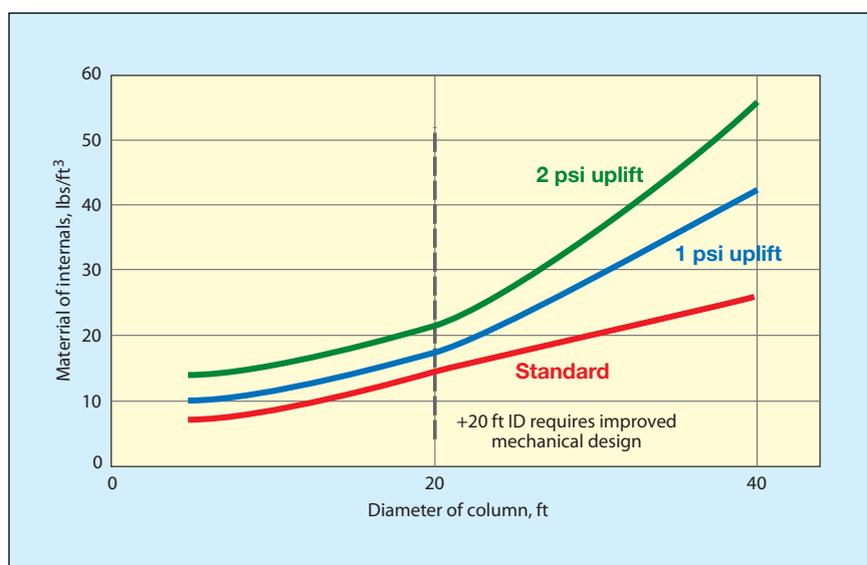


Figure 8 Consideration for uplift protection: tray weight vs diameter

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Darius Remesat, PhD, MBA, Peng, is a Process Consultant and Business Development Director for Koch-Glitsch Canada.
Email: darius.remesat@kochglitsch.com