

PROCESS & MECHANICAL DESIGN FOR DISTILLATION COLUMN RELIABILITY

#39A

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INTRODUCTION

Several key distillation columns within refineries and chemical plants are prone to uplift, corrosion, and fouling, which can result in off-specification products, inefficient operation, or premature shutdowns. Past experience with these problems has led to the development of process and mechanical design best practices that mitigate these issues and foster reliable operation. The columns most often associated with these issues include:

- Crude Pre-flash Column
- Atmospheric Crude Column
- Pre-Vacuum Flash Column
- Crude Vacuum Column
- Coker Main Fractionator
- FCC Main Fractionator

PHILOSOPHY

It is often a question of when, not if, many of these potential problems become a reality. While implementation of these design practices requires additional investment, some of them can provide relatively inexpensive insurance. The decision to purchase this insurance must be based its cost versus the probability of the problem occurring, the desired turnaround interval, and severity of the problem's effect.

Equipment metallurgy and mechanical solutions often receive the most attention because they can be these easiest to implement. However, these solutions may only treat the symptom of the problem, and not cure the cause. It is possible that a change in the process may eliminate the need for the mechanical solution. To effectively do this, reliability requirements must be analyzed prior to requesting bids for equipment and should be specified in the bid package. The cost of this, too, must be weighed against the cost of addressing the cause versus treating the symptom. It may be better to periodically treat the symptom.

UPLIFT PROTECTION

A common cause of refinery upsets is the sudden and explosive flash that occurs when water contacts hot hydrocarbon fluids. Superheated steam under vacuum at 20 mmHg and 160 °F will occupy nearly 4,600 times the volume of liquid water. The uplift forces resulting from this sudden expansion can result in severe damage to tower internals. Damaged internals will lead to reduced operating run times, or at best, continued operation with subpar column performance. There are several mechanical and operation design practices that can minimize or prevent this occurrence.

The choice to upgrade to severe uplift conditions can be compared to a decision to upgrade metallurgy based on the refinery crude slate. If it is decided that a sour Venezuelan crude is to be processed rather than a light sweet crude, metallurgy of tower internals and piping

must be upgraded to handle the acid corrosion that will result. Similarly, if operating companies realize that upsets are likely to occur, they should decide to upgrade towers to handle uplift conditions to improve run length and reliability.

Mechanical Solutions

The standard design for column internals withstands between 0.25 – 0.50 psi of uplift force. However, it has less than a 10% chance of surviving a moderate upset without damage. The uplift resistance is most often upgraded to 1 or 2 psi for certain column sections, if not the whole column. These sections include:

- Steam stripping trays of Atmospheric Crude and Vacuum Columns
- Wash Zone of Atmospheric Crude, Crude Vacuum, & FCC Main Fractionators.
- Slurry Pumparound of FCC Main Fractionator

Trays

Design features for uplift depend on whether the internals are trays or packing. The features for trays are summarized in Table 1.

Table 1: Features of Uplift Designs

FEATURE	STANDARD < 0.5 PSI UPLIFT DESIGN	1 PSI UPLIFT DESIGN	2 PSI UPLIFT DESIGN
Bolt Spacing	6" spacing	4" spacing	4" spacing
Panel Connectivity	Frictional bolts	Frictional bolts	Through-bolted
Deck Thickness*	14 ga standard (alloy)	14 – 12 ga.	12 – 10 ga.
Shear clips	None	None	Required
Support Ring Clamps	Standard	Standard	Heavy Duty 12 ga.
Beam Depth	Minimized	Deeper	Deeper

* Tray thickness will depend on the panel width and length.

Packing

With an open area of approximately 95-98% of the tower area, packing has an inherent resistance to uplift. Pressure drop can be absorbed throughout the bed. In comparison, each tray is a discrete pressure drop point that bears the full uplift conditions. In spite of the open area, however, packing is still susceptible to uplift damage.

All uplift designs for packed beds contain a holddown grid (they are cheap insurance even with standard designs). The method of keeping the holddown grid in position can vary depending on the situation. One option is to weld screw-jacks to the perimeter of the vessel. These devices contain a foot and the end of a threaded rod that is lowered in place above the holddown grid. Similar devices can be attached to the liquid distributor to support the grid in the middle.

Another option is to use drive tie rods through the packing. These rods connect the bottom support plate and top holddown grid together, effectively making the entire bed one structural member. Any surge will have to move the whole bed before any part of it can be damaged.

Tie rods do not require any welding to the shell and can provide for a safer installation compared to screw-jacks. Welding above packing is a serious fire hazard. Unless the packing is removed, the screw-jack design is not recommended.

Tie rods also have several disadvantages. There must be sufficient clearance at the top of bed to be able to swing a hammer and drive the rods into the bed. The smaller the packing crimp, the more difficult it will be to drive the rods through the bed. With extremely heavy packing, such as FLEXIGRID®, the tie rods have a tendency to bend as they are driven through the bed. There must also be access to the bottom of the bed after it is installed. This is because a nut and washer is added to the end of the tie rod to keep it in place.

Disadvantages Of Uplift Design

Equipment cost must always be taken into account when budgets are limited. Uplift resistant equipment can be 15-30% more expensive than standard equipment depending on the size of the column, the material of construction, and the degree of uplift required.

The installation of uplift resistant design is also more extensive. Uplift resistant designs will require more pieces of hardware per tray, more parts, and shorter panels of equipment. Adding holddown grids or additional beams in a revamp may require additional welding to the column shell.

In some cases, the cost associated with an uplift resistant design cannot be justified by the unit economics. The run time for one particular crude atmospheric column was planned for two years. After one year of operation, stripping section trays would plug due to coking. The refiner would purposely introduce a slug of water to remove the trays and continue operation without the stripping section for the next year.

In this particular case, 2 psi uplift resistant trays may have not have been blown out. Rather than continuing operation of the unit and having time to plan for the turnaround, the plant would have been forced to shutdown immediately. For this reason, the plant deliberately chose to install lower uplift design trays.

Process Solutions

Designing equipment for uplift conditions deals with the results of tower upsets. It does nothing to remedy the root cause. Preventing the upset by careful operation is the only way to prevent massive damage that can even damage equipment designed for uplift conditions.

Draining

Draining lines of water (such as from condensed steam) cannot be overemphasized. The simple draining of process lines before hot hydrocarbon is introduced can eliminate many column upsets. Unit P&ID's should be reviewed before start-up to ensure that sufficient low point drains are available. During operation, any bypass line not in use should be carefully drained before being activated. This is especially true of Delayed Coker Units where semi-batch operation leaves ample opportunity for water to collect. Process lines should be sloped towards the nearest drain or vessel. Thermal expansion should be considered when evaluating the degree of slope.

Cool Oil Circulation

Dehydration by cool oil circulation is used to remove water before the unit is brought up to temperature. Pumparound systems should circulate at least 50% of the design rates, while continuously draining low points in the circuit.

As the column is brought to operating temperature, trace amounts of water not removed during cool oil circulation will vaporize and go overhead. This steam will condense and concentrate in a cooler part of process piping. When hot fluid from the column is sent to this process piping, an upset can occur similar to when a slug of water enters the column.

A key design rule is to prevent the hold-up of liquid on the trays at shutdown. Drain holes are, therefore, specified in the low points of the tray where liquid could collect. While most distillation column internals will contain many holes, this does not guarantee that all the water will be drained. Use of excessively large or numerous drain holes will effect the performance of tower internals. Circulating cool oil will reduce the chances of water buildup and is a safer practice

Steam Arrangement – Alternate Design

Working with refiners and consultants, Koch-Glitsch has applied a system to prevent upsets due to water introduction to the tower. The system is based on anticipating the volume increase upon vaporization of water. A general schematic for this system is shown in Figure 1.

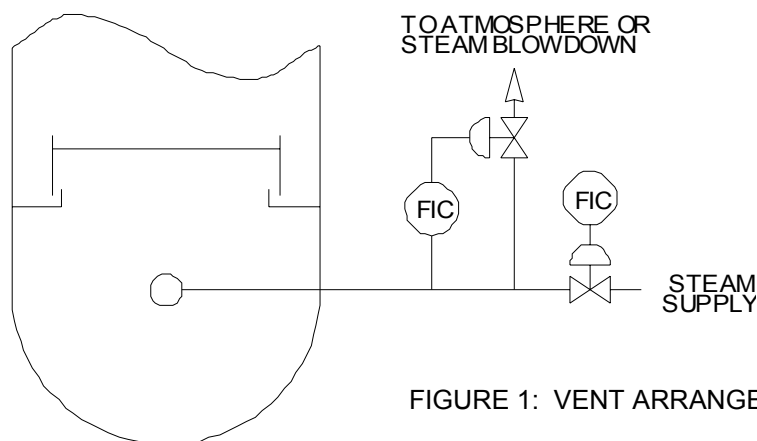


FIGURE 1: VENT ARRANGEMENT

A steam sparger is used to introduce the steam into the tower. The pressure of the steam is monitored on the outside of the column, downstream of the flow control valve. When a slug

of water is ready to vaporize, the volume will suddenly increase causing a pressure surge in the piping prior to the sparger. When the pressure surge occurs, the PSV will open and vent the wet steam to the atmosphere or other designated place outside the column.

ANTI-FOULING DESIGN

Protection against fouling must be considered at the design stage. Some recent trends in refinery operations have made this even more important. For example, salt deposition and associated corrosion and fouling in FCC main fractionators is probably going to increase as more refiners undercut to trim gasoline sulfur. The lower overhead temperature required to reduce gasoline endpoint is often below the salt dew point. Even if the bulk temperature is above the dew point there are often localized cold spots where salts will precipitate. While many main fractionators are being packed to realize capacity gains, some cooler towers may benefit from a couple of fixed valve trays at the very top. These trays will be more resistant to salt deposition than packing. They can also be water washed on line to remove deposits that occur.

The choice of liquid distributor above packed beds is also vital to reliability. There are two types of distributors currently applied to vacuum tower wash zones – the conventional spray distributor and the trough distributor. However, the type of distributor that should be selected depends on the type of vacuum tower in question.

Trough distributors should be applied in lube vacuum towers. This type of distributor provides the quality of distribution necessary for the tight fractionation this service requires. Yet the severity in lube vacuum towers is low enough that the small feed holes in the troughs are not a great liability.

Spray distributors are best suited for fuel vacuum towers. The conditions in these towers are more severe than in lube vacuum towers. Coking, therefore, is more of a concern. While the quality of distribution is inferior to trough distributors, the risks associated with trough distributors far outweigh the potential benefits.

Trough distributors are designed with a “trash zone” below the drop holes to accumulate solids and reduced the potential of plugging the drip holes. However, this trash zone exposes a stagnant layer of liquid to high residence time and temperature in vacuum wash zones. This, coupled with the low liquid velocity in the ends of the laterals, promotes coke formation that will plug at least some of the holes and precipitate liquid maldistribution.

The smaller holes on trough distributors, compared to the free passage of spray nozzles, requires much smaller external strainers to remove solids before the wash stream is fed to the distributor. This small strainer size will result in increased maintenance of the strainers due to more frequent plugging.

The concern of entrainment with spray distributors can be mitigated through the use of nozzles with a 90° spray cone. The standard 120° spray cone allows fewer nozzles to be used.

However, this wider cone shears the liquid more than a 90° cone. This shearing creates smaller droplets that are easier to entrain.

Spray distributors offer an additional level of safety in the event of loss of wash oil flow. Spray distributors are essentially free draining with minimum liquid holdup. Trough distributors maintain a liquid level that is exposed to elevated temperatures until wash flow is reestablished. This means they are more susceptible to coking. While even a spray distributor will be susceptible to coking with an extended loss of flow, a well designed spray distributor can overcome minor fouling.

It is the experience of Koch-Glitsch that the successful applications of trough distributors in fuels vacuum towers have been in Europe on a Brent or similar crude slate. Where trough distributors are used in a heavy crude service, such as South America, they have coked which then led to coking of the wash bed. Koch-Glitsch spray distributors have been successfully used in towers on four plus year turnaround cycles with cutpoints up to 1100 °F. If adequate wash rate is used to maintain the velocity through the spray nozzles, it is very unlikely that coking will occur in the spray nozzle distributors. Unexpected loss of wash oil to the wash bed will cause coking whether a spray nozzle or trough distributor is used.

Vapor distribution to wash beds is also critical to their performance. The high feed inlet velocity found in vacuum towers makes entrainment and maldistribution a concern. Koch-Glitsch has had success with our patented vapor horn technology. This device uses centripetal force and baffles to separate vapor and liquid droplets. In addition, other baffles are used to reduce the swirling of the vapor upon exiting the vapor horn. This flattens the velocity profile as seen by the bottom of the bed and eliminates localized high velocities that promote entrainment. CFD (computational fluid dynamics) studies have proven the effectiveness of these devices. In addition to improved gas oil quality, good vapor distribution will reduce the risk of coking. A tower with maldistributed vapor feed may result in localized “dry” areas, a prime candidate for coking.

Coking is caused by high temperatures coupled with long residence time. Sloping the panels towards the sump and sloping the sump towards the draw nozzle can minimize the residence time on chimney trays.

In FCC Main Fractionators, the Slurry pumparound can be a coking concern. Mixture of the wash liquid and slurry pumparound return is critical to minimize coking. The liquid from the wash section is much lighter and at it's bubble point compared to the subcooled slurry pumparound liquid. A large quantity of the wash liquid is vaporized inside the slurry pumparound grid. If the wash liquid is not properly mixed with the slurry pumparound, it will vaporize inside the grid bed causing part of the bed to coke.

Increased paraffinic material in the slurry pumparound may also be the cause of premature coking. Paraffinic material may leak through the slurry pumparound exchangers, or may bypass the reactor via a fresh feed bypass line. This paraffinic material is converted to coke and light ends at the high operating temperatures of the slurry pumparound, and may eventually

coke up the tower. An increase of the paraffin content of the slurry pumparound liquid can be an indicator.

CORROSION PROTECTION

The increasing acidity of the crudes refiners are running is also increasing the need to carefully select metallurgy for replacement parts. But exotic metallurgy is not always the correct solution. Even exotic alloys, such as AL6XN, have been known to corrode. When these exotic alloys do not corrode, the equipment can still become plugged with corrosion products from elsewhere (vessel shell, exchangers, etc.). In addition, it may not make sense to use exotic metallurgy relative to a thicker, lower metallurgy on trays or grid that also utilize a fouling resistant design. An initial cost of 2–3 times that of lower metallurgy does not make exotic metallurgy an attractive option, especially if turnarounds are on a 4-6 year cycle.

A better solution may be to change the process to prevent the corrosion.

Poor desalting or poor water removal in the overhead accumulator may be the cause of severe corrosion in refinery crude, coker, and FCC main fractionators. The water dew point should be evaluated on the top trays. A temperature within 15 °F of the water dew point may indicate a water draw in the top of the tower is needed. Increasing the top temperature to 15 - 20°F above the dew point may help control the formation of free water on the trays. However, maintaining the temperature above the water dew point is not always sufficient. Localized cold spots occur where cold feeds or reflux streams are introduced. These inlets must be properly designed to mitigate the corrosion and fouling effects.

When salt deposition is anticipated and cannot be avoided, the column should be designed to facilitate on line water washing. The water wash can be introduced with the reflux in trayed towers operating above the water dew point. A water draw nozzle should also be provided from a tray inlet sump a few trays below the top of the tower. When the tower is intentionally operated below the water dew point, a collector tray should be designed at the water draw to provide residence time for water disengagement. Tower operation must be controlled to insure water does not condense below the draw tray. For packed beds, a separate wash header should be provided for introducing the water wash. Even with this consideration, water washes are not as effective for packing as for trays and will not fully restore performance.

MISCELLANEOUS

There are many “minor” best practices that can lead to improved reliability. These include but are not limited to:

- Internal draw piping should be avoided because it can leak or can be damaged in upsets.

Draw sumps should be aligned with the draw nozzles to avoid this situation.

- Design temperatures should be specified clearly in bid packages so they can be considered early in the design process. This is especially critical in FCC Main Fractionators where inlet temperatures can approach 1000+ °F.
- Critical bolts should utilize jam nuts (double nut) to insure they do not vibrate loose.
- Spray nozzles should be tack welded in place.
- New feed or reflux piping should be flushed prior to commissioning to insure it is free from foreign objects, which may plug internal piping. New spray headers or feed pipes should be inspected or flushed to insure they are free from debris.
- Seal welded collectors should be designed to allow for differential thermal expansion.
- Impingement plates should be provided where necessary to protect internals from high velocity feeds. All feed streams should be evaluated at column pressure to determine if flashing may cause higher velocity than anticipated.
- Draining of lines used intermittently is important. When switching over with dual line strainers, special care should be taken to drain the out of service strainer and line to remove any condensed water.

CONCLUSION

Uplift, fouling, and corrosion are key issues that effect the reliability of operations. Operating companies do not have to simply accept that issues will continually cause problems. There are actions that can be taken both in design and operations to minimize, if not prevent, many of the events that cause off-specification products, inefficient operations, or premature shutdowns. It is important that these be given due consideration and not forsaken to time and cost.