API RP 572 Inspection Practices for Pressure Vessels

Annex B (informative) - Towers

- **Currently no red line on this ballot. 12 comments received in previous 2 ballots (4869 and 5300) and 0 comments in the last ballot (5449). Comments have already been resolved and are not tracked in this ballot.**
- **Accepting comments on all content.**
    - Comments on redlines will be resolved.
    - Comments on non-redline section will be reviewed and incorporated. Where comment resolution requires significant work, comment will be scorecard
- All moves accepted if not commented on during the last ballot 5449 or were the result of ballot 5449 comment resolution
- Non-move redlines accepted if they were not part of Ballot 5449 comment resolution

When voting "Negative" please label the specific comments regarding your negative so we may be able to identify the concern.

Note to balloters: Please ignore formatting and numbering issues and focus on technical/editorial content. Formatting and numbering issues will be cleaned up before re-publication.

To properly organize the ballot resolution spreadsheet please be sure to enter the section numbers under the ballot spot labeled "clause/sub-clause number"; and then under "paragraph/table/figure number" simply indicate which paragraph in the section you are commenting upon.

Please be sure to label comments

- "technical" when a substantive change is being made
- "editorial" when you are just suggesting some wording improvements.
- "general" should be those that apply to the multiple sections or the whole document.

Annex B
(informative)

Towers

B.1 Trayed Towers

B.1.1 General

Trayed towers consist of cylindrical shell courses with both top and bottom heads, with nozzles where appropriate, filled with tray decks to facilitate the gas/liquid contact. They may include conical transition sections, internal sumps/baffles, demisters, inlet distributors, or a variety of other components. Multiple towers may even be fabricated as a single pressure vessel, stacked on top of each other.

Trayed towers come in several different configurations, from cascade-type trays such as disk and donut trays to sieve trays, bubble cap trays, and high-capacity valve trays.

B.1.2 Cascade Trays

The two common types of cascade trays are shed trays and disk/donut trays. Cascade trays utilize a different approach to gas/liquid contact than regular trays. Shed trays may be anything from angle iron to half pipes. Large numbers of shed trays are arranged in rows, installed perpendicular to each other and to the gas and liquid flow such that breakup of the falling liquid takes place. Gas flow up through the droplets of liquid is the primary source of contact for mass transfer. In disk/donut trays (see Figure B.1) the disks and donuts are installed in alternating sequence, with the donuts mounted to the shell and the disks suspended in the center of the tower, with both the disks and the donuts being perpendicular to the gas and liquid flow. As liquid repeatedly cascades from the disks to the donuts, sheeting and breakup of the liquid takes place.

Figure B.1 - Disk/Donut Tray

Baffle trays (sometimes called “splash trays”) are solid baffles, installed on alternating sides, perpendicular to the gas/ liquid flows. These individual trays each typically obstruct about 60 % of the tower so falling liquid impacts the tray below. The baffle tray arrangement is depicted in Figure B.2.

Contact with the falling and/or splashing droplets is the main source of liquid/vapor contact for all cascade-type trays. Internals associated with cascade trayed towers are usually limited to simple pipe inlet distribution with steam spargers in the bottom to provide heating and gas flow volume.

B.1.3 Sieve Trays

Sieve trays are tray plates with perforations in them similar to a sieve (see Figure B.3), hence the name. No valves are present. Sieve trays can be subdivided into single-flow and dual-flow trays. Single flow refers to the flow through the tray perforations. On single-flow trays, the primary flow path of the liquid is across the tray and down the downcomer to the tray below.

The downcomers act to transport the liquid to the next tray, and promote disengagement of the gas and the liquid. The primary flow path of the gas on single-flow trays is through the tray perforations. The perforations in single-flow sieve tray are sized with this in mind. Single-flow sieve trays are customarily used where light-to-moderate fouling by precipitates and/or polymers is anticipated.

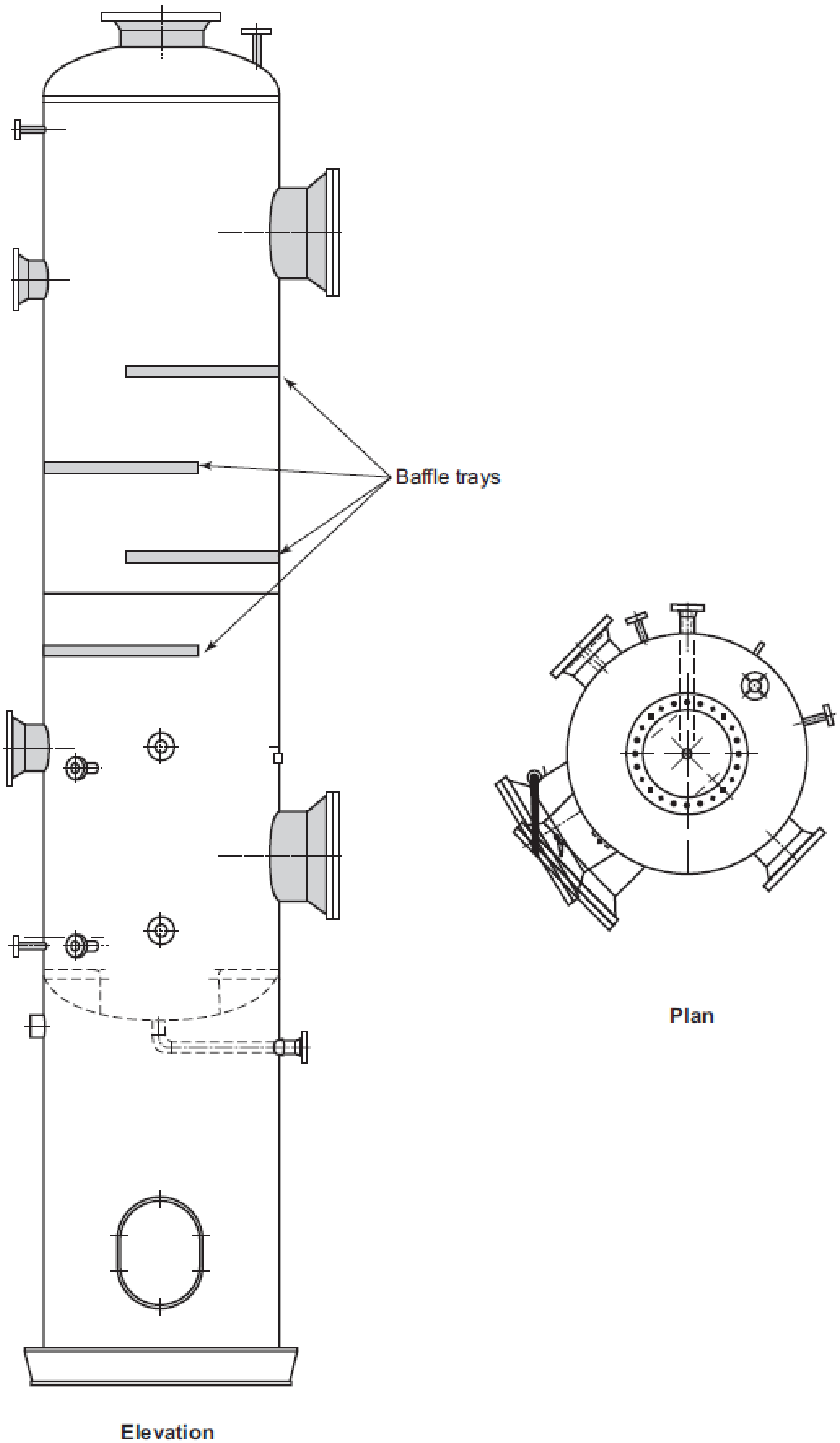


Figure B.2 - Baffle Tray Arrangement

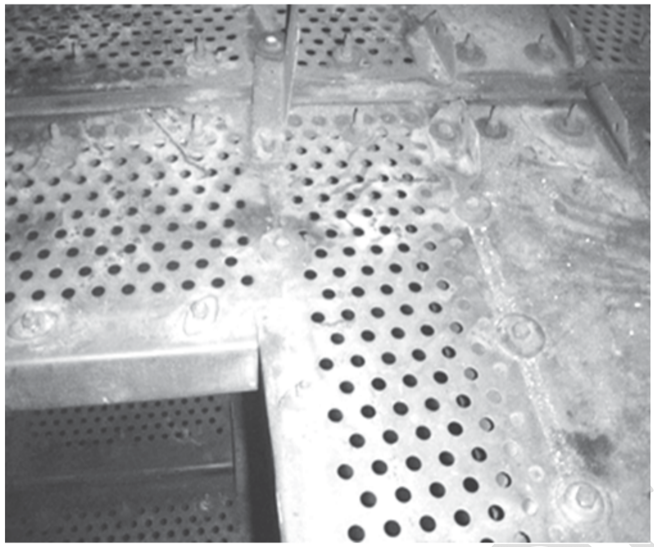


Figure B.3 - Tray

Dual flow also refers to flow through the tray perforations. On dual-flow trays, there are no downcomers. The primary flow path of both the descending liquid and the ascending gas is through the tray perforations. In response to liquid falling from above and gas bubbling from below, the standing liquid on the tray forms waves throughout the liquid. Gas flow up is primarily at the wave troughs, and liquid flow down through the perforations is primarily at the wave crests. Jet tabs similar in appearance to very small upward facing scoops are utilized to promote even liquid flow throughout the sieve tray. Ripple trays are a type of dual-flow tray that magnifies the crest/trough relationship via the corrugated design of the tray panels. Dual-flow trays are customarily used for processes that exhibit heavy fouling due to the formation of precipitates or polymers. Both types of sieve trays have better anti-fouling characteristics than standard valve trays, but should operate in a very limited range of operating conditions to be efficient.

Sieve trays need to be installed and maintained level. Sieve trays that are not level can rapidly lose efficiency due to blow through where areas of the liquid level on the tray are shallow. Figure B.4 show a sieve tray that has been distorted.

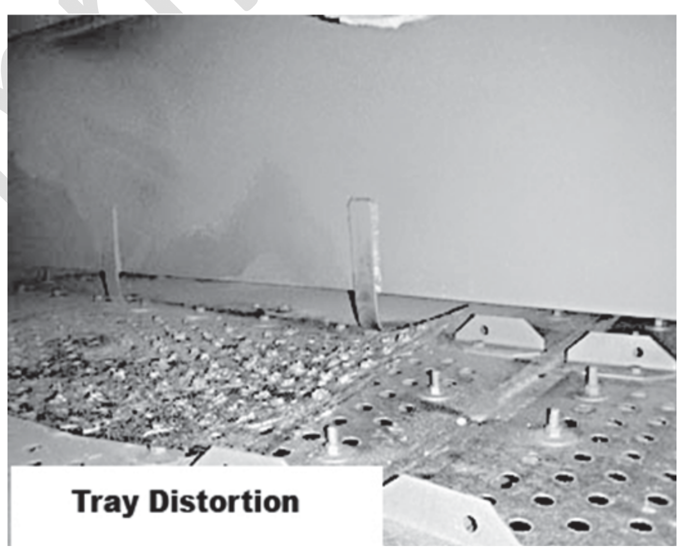


Figure B.4 - Sieve Tray Distortion

B.1.4 Valve Trays

Valve trays are trays that have valves installed at the perforations in the tray deck. Perforations are typically larger than those in sieve trays, as well. The advantage of valve trays over sieve trays is that the valve is able to close, or in the case of floating valves even partially close, allowing the pressure of the rising gas to be maintained. This allows the tower to operate over a much wider range of operating conditions than sieve trays would allow (Figure B.5 to Figure B.11 show typical tower drawings and types of valves). Trays are frequently designed to have more than one weight of valve installed to allow balancing of gas flow through the tray. This also allows the back pressure below the tray to be maintained. Valve trays can be subdivided into fixed valve and floating valve trays.

B.1.5 Fixed Valves

Bubble cap trays are fixed valve trays. For a good portion of the history of fractionation trays, bubble caps were the only tray valve. Bubble caps remain in service throughout the industry in systems where low liquid flow rates and high variations in vapor flow and resistance to heavy fouling are required. Bubble caps come in a variety of shapes and sizes, from round (mushroom caps) to rectangular (brick or bread loaf caps) in both slotted caps and solid fractionation research incorporated-type (FRI) caps.

While operating ranges are less than those allowed by moveable valve trays, significant increases in operating ranges and efficiency over sieve trays and bubble cap trays are possible using fixed valves extruded from the tray decks. Fixed valves offer lateral gas flow to inhibit fouling rather than the vertical gas flow of sieve trays, and higher mechanical strength than floating valve trays, with no moving parts to wear out.

Newer fixed valve designs offer even greater operating ranges, efficiency, and fouling resistance but at the cost of losing the single-piece construction of the extruded valves and at the cost of additional wear as valve tabs loosen or corrode.

B.1.6 Floating Valves

Moving or floating valve trays are trays in which valves have been inserted into or are placed above the tray perforations. These valves are retained in the tray perforations via bent or twisted “feet” and/or are kept positioned above the perforations by cages tabbed to the tray deck. Valves are allowed to move freely (or “float”) from the closed position (down) through fully opened (up) position as pushed by the vapor pressure below the tray. This allows very high turndown ratios and much less weeping than conventional fixed valve or sieve trays. As with the fixed valves, the horizontal gas flow limits entrainment and fouling.

Valves may be smooth edged or provided with tabs and/or dimples on the edges to prevent rotation and sticking of the valves (due to vapor lock between the valve and tray deck), respectively. Floating valves may be round or rectangular in shape. Floating valve trays of either type offer a higher efficiency (liquid/vapor contact) over a much wider operating range than sieve trays due to their ability to control vapor flow. Multiple valve weights are frequently installed in the same tray to widen the operating range. Caged valves are frequently utilized in low liquid flow systems.

B.2 Packed Towers

B.2.1 General

Packed towers all have basically the same configuration, with the only significant variable being the type of packing used. Packed towers have one or more packing beds, supported by bed supports, with distribution systems above the bed to evenly wet the packing (see Figure B.12).

Bed limiters may or may not be installed and may be integral to the distribution system. Collector (chimney trays)/ redistributors are commonly used between packed beds and in some services are installed below the bottom bed as well. Due to the larger surface area available for mass transfer, packing has the advantage of being able to handle larger liquid rates with higher efficiencies and with lower-pressure drop than all but the newest of the high-capacity trays. Packing can be subdivided into random packing and structured packing.

B.2.2 Random Packing

Random packing takes its name from the method in which it is loaded, i.e., allowed to fall at random onto the bed supports. Random packing comes in a variety of sizes, from 0.50 in. to 3 in. (13 mm to 7.6 cm) in diameter and can be custom ordered in any size and almost any material, from carbon steel to ceramic and plastic. Random packing shapes range from the original raschig rings through pall rings and various “super rings”. Figure B.13 shows pall rings for random packing.

Random packing provides low pressure drop, high capacity, and high efficiency, without the maintenance cost of fractionation trays, but is typically more expensive for large diameter columns. Random packing is less than ideal for large diameter towers with low liquid flow rates and high vapor flow rates due to the difficulty in maintaining packing wetting throughout the bed at low liquid rates.

B.2.3 Structured Packing

Structured packing gets its name from the fact that it is assembled into blocks to facilitate loading and assembly into beds. Structured packing is constructed of corrugated metal (typically, a noncorrosive high alloy) arranged such that the corrugations oppose one another. The corrugated metal is then bound into blocks. Most structured packing is installed such that each succeeding layer is 90° out from the previous layer—this can be noticed in Figure B.14 of structured packing. This allows an interfacial area for mixing and spreading of the liquid throughout the packing. Surface texturing is frequently present on the sheet metal to increase wetting and instill turbulence in the gas flow that facilitates mass transfer. Depending on service, wall wiper rings may be installed at each layer to rechannel any liquid or vapor that has migrated to the wall.

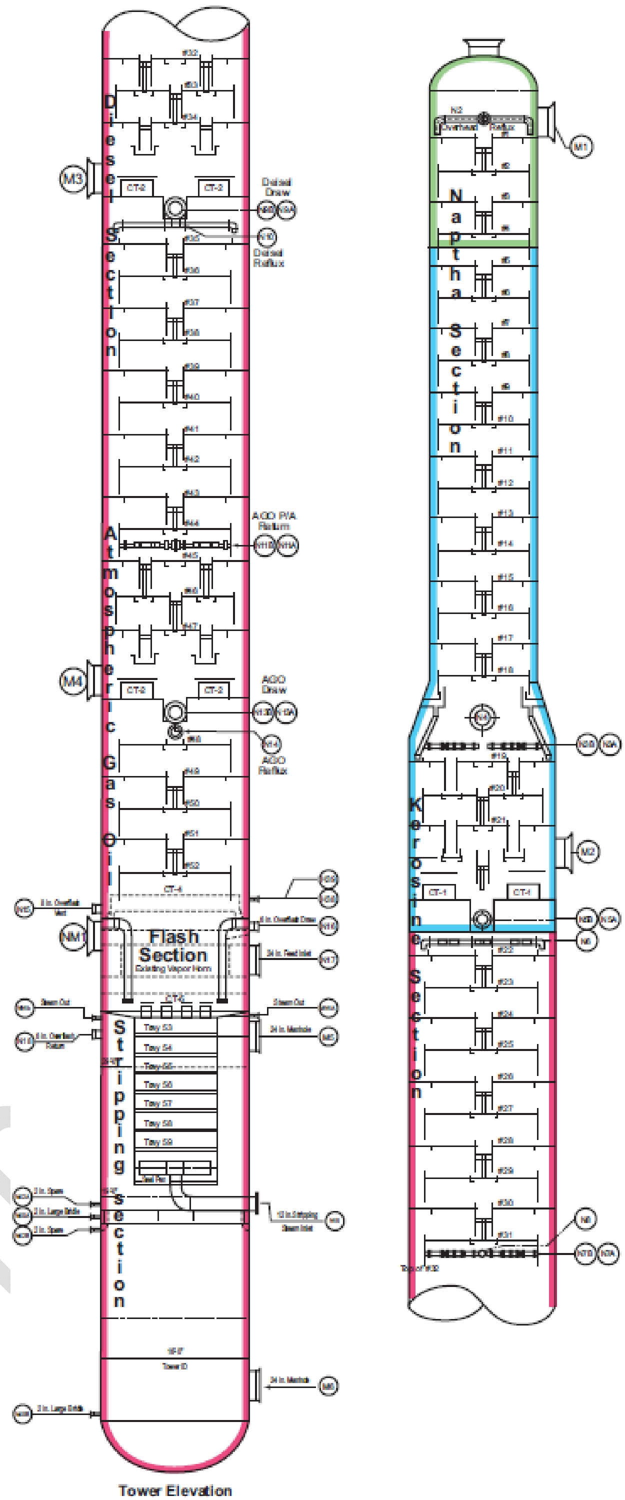
Within its operating range, structured packing provides higher capacity and lower pressure drop than crosscurrent trays or random packing.

Packing bed support grids and hold downs are typically much larger spaced. Frequently, box and trough distribution systems may be placed directly upon the bed, with little other support required. Grid-type packing is commonly utilized in heavy fouling service. The surface of grid-type packing is invariably smooth to allow any particulates to wash off inhibiting coke formation. The grid-type packing is depicted in Figure B.15.

B.3 Inspection of Towers

B.3.1 General

Due to the complicated structure of a tower, past reports and current prints are invaluable aids in performing a thorough visual inspection. Past turnaround reports provide critical data on the location and severity of ongoing corrosion and wear. An up-to-date elevation drawing of the tower not only allows previously identified problems to be mapped out for analysis and makes following capital work easier, it also allows inspection progress to be easily tracked while ensuring that those same history items are not overlooked.



Vessel Elevation

Figure B.5 - Typical Trayed Tower

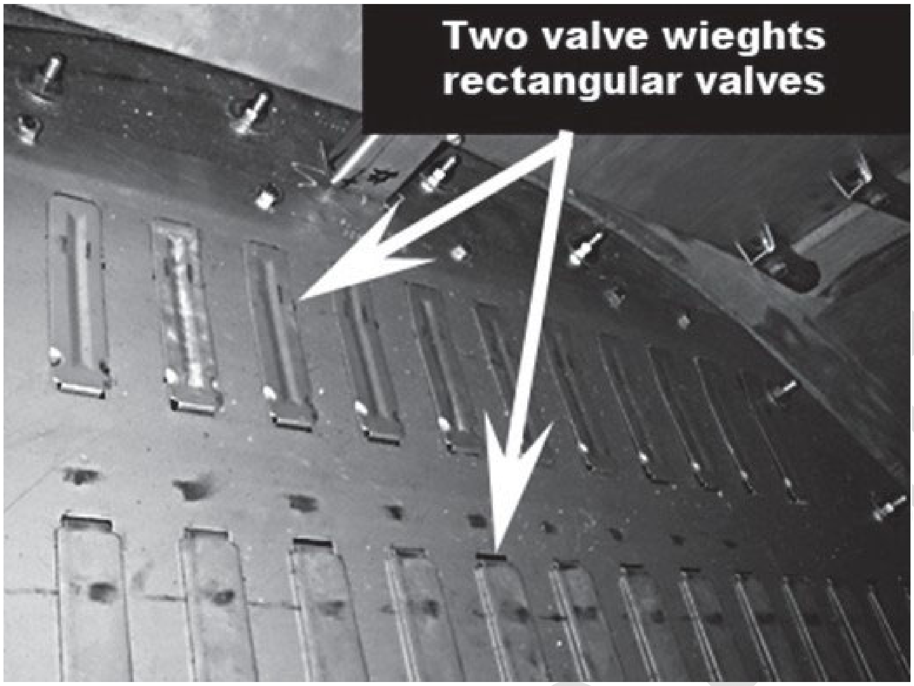


Figure B.6 - Float Valves with Two Wieghts

Figure B.7 - Fixed Valves

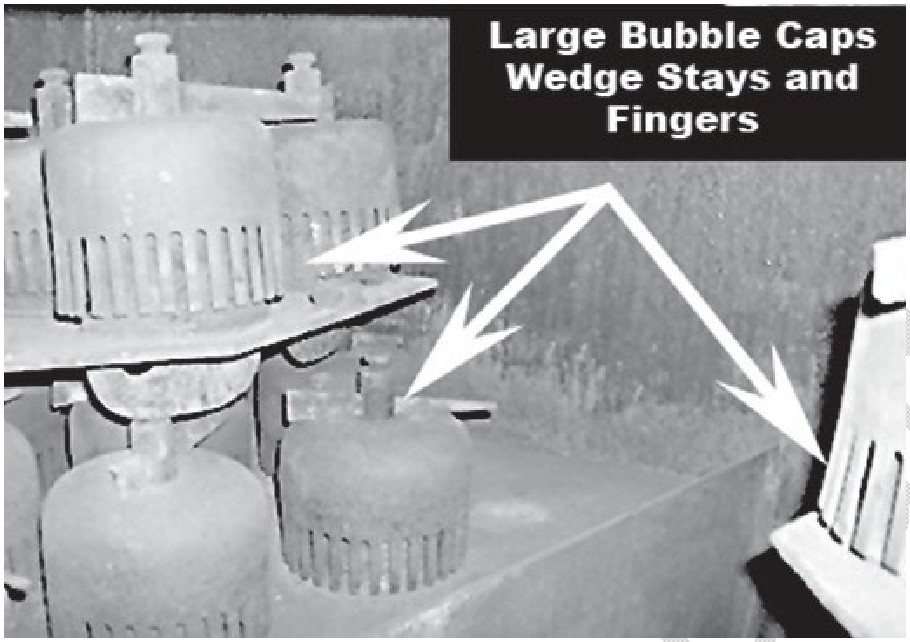


Figure B.8 - Bubble Cap Valves


Figure B.9 - Extruded Valves

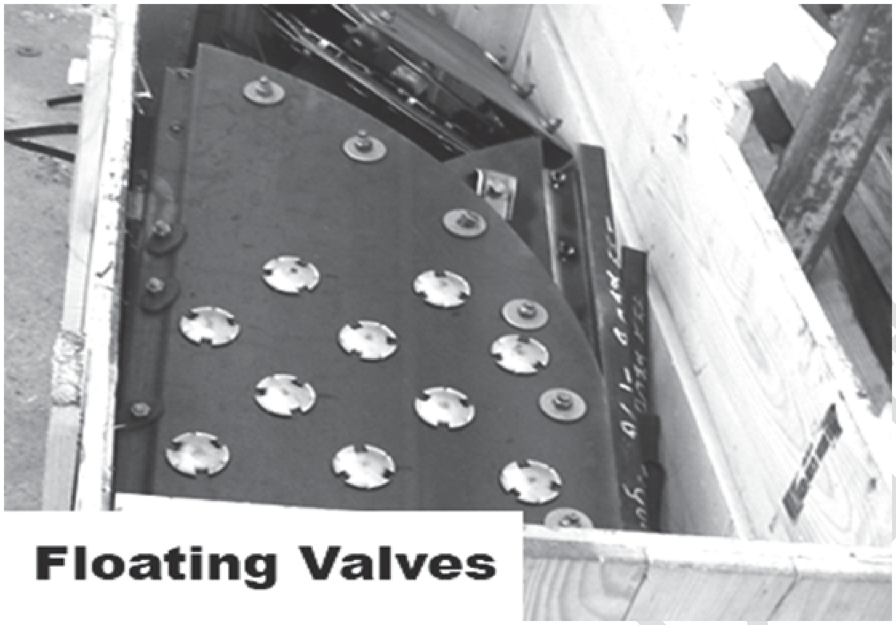


Figure B.10 - New Floating Valve Tray

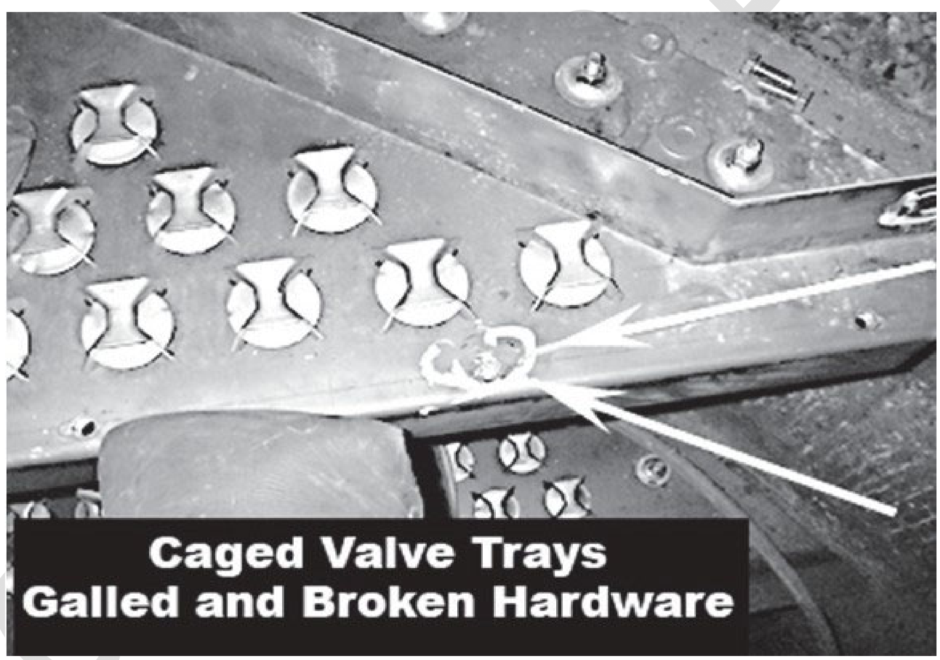


Figure B.11 - Caged Valves

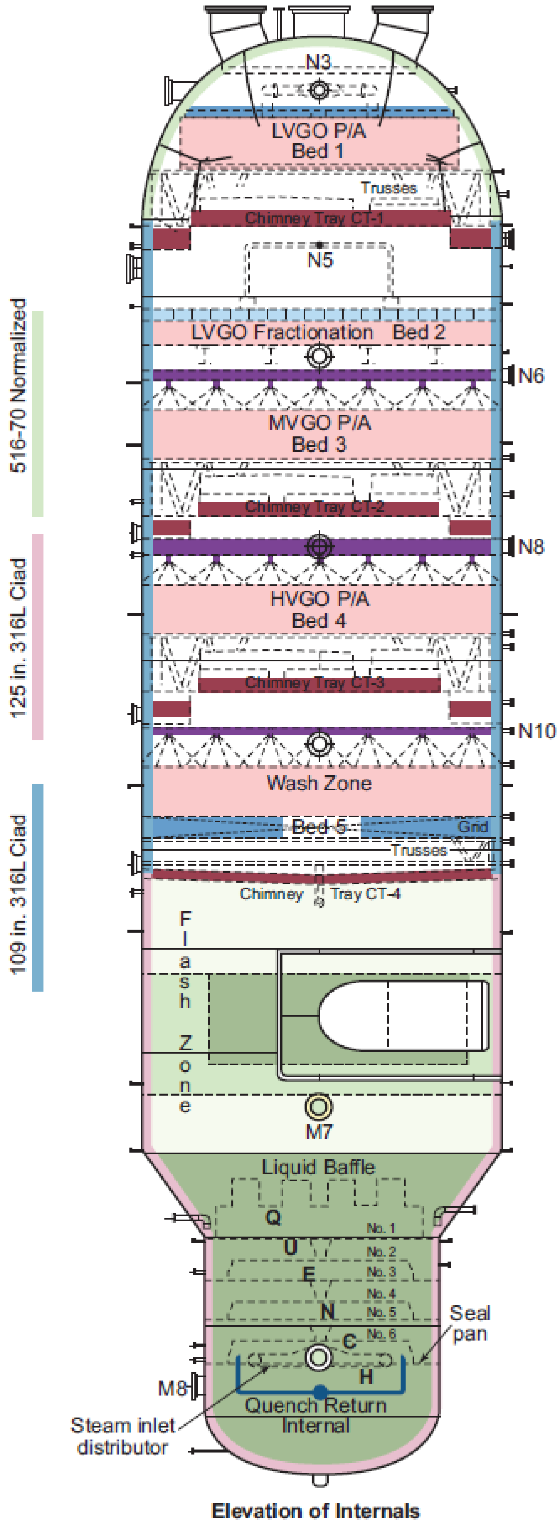


Figure B.12 - Typical Packed Tower Drawing

Figure B.13 - Random Packing, Pall Rings

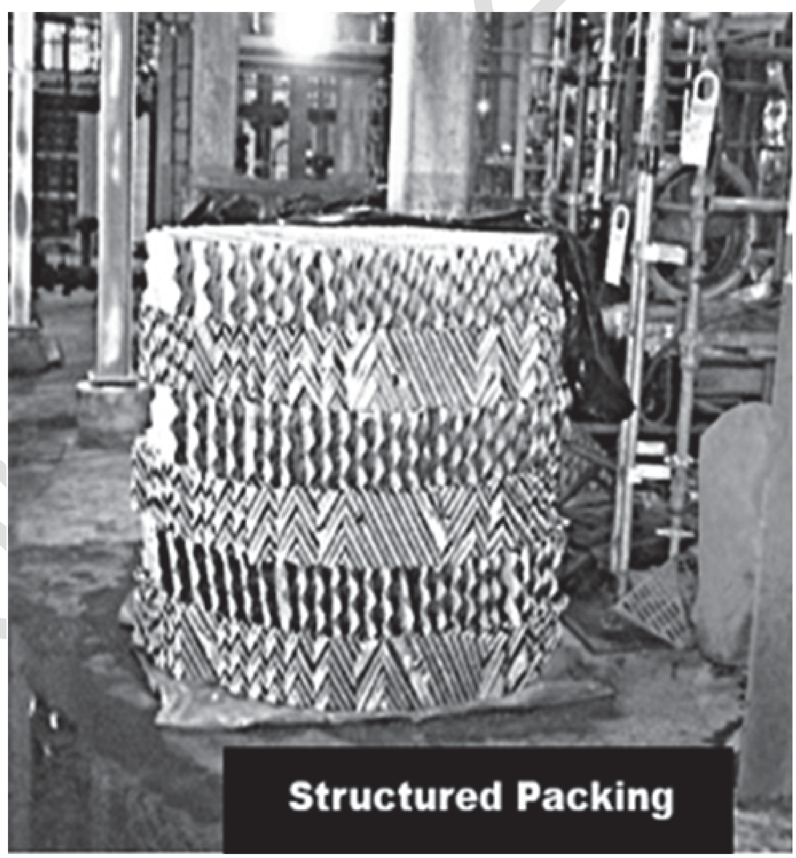


Figure B.14 - Structured Packing

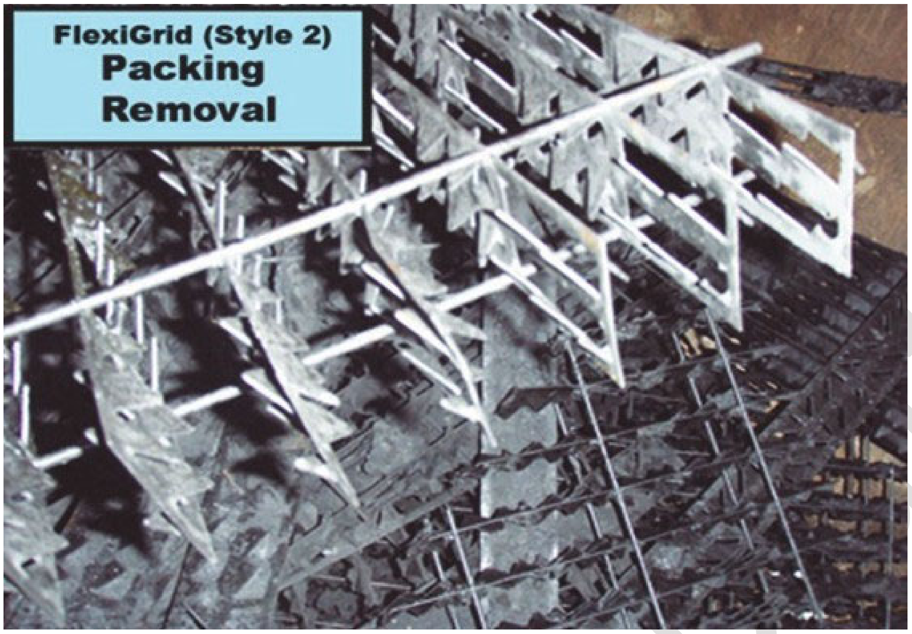


Figure B.15 - Grid-style Packing

B.3.2 External Inspection

The Anchor Bolts—Due to the leverage applied by the height of the tower and the corrosion masking effect of fireproofing, particular care should be taken when inspecting the anchor bolting of towers (see Figure B.17 and Figure B.18).

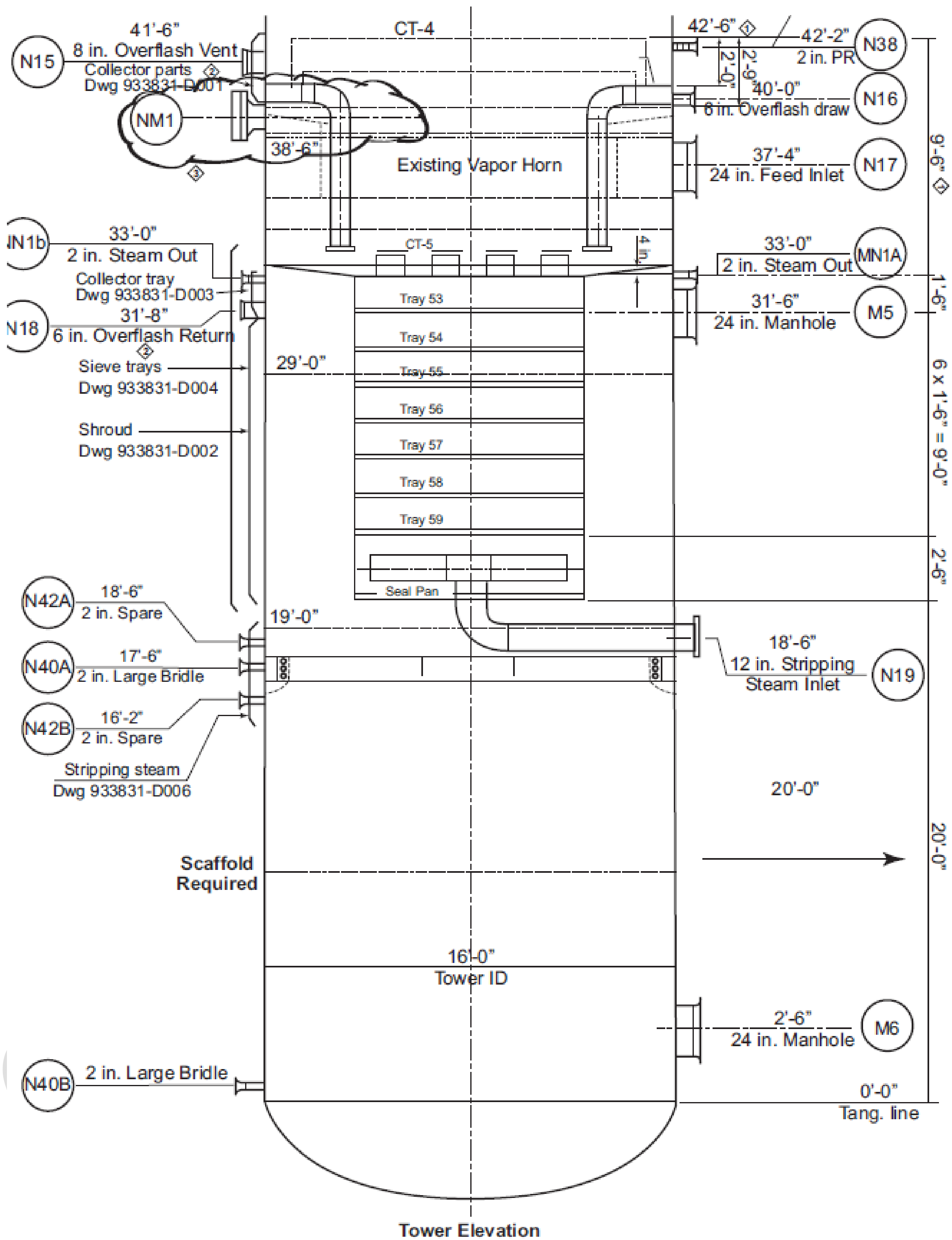


Figure B.16 - Diagram of Suggested Scaffolding

Figure B.17 - Corroded Anchor Bolting

B.3.2.1 Skirt Fireproofing—

Any crack over 0.250 in. (6.4 mm)in width, and any crack that has displacement or bulging of the concrete fireproofing material should be investigated for CUF. Identifying CUF, as with CUI, is a primary focus of today's mechanical integrity programs. Figure B.19 shows cracks within a tower's fireproofing.

Figure B.18 - Corroded Anchor Bolting

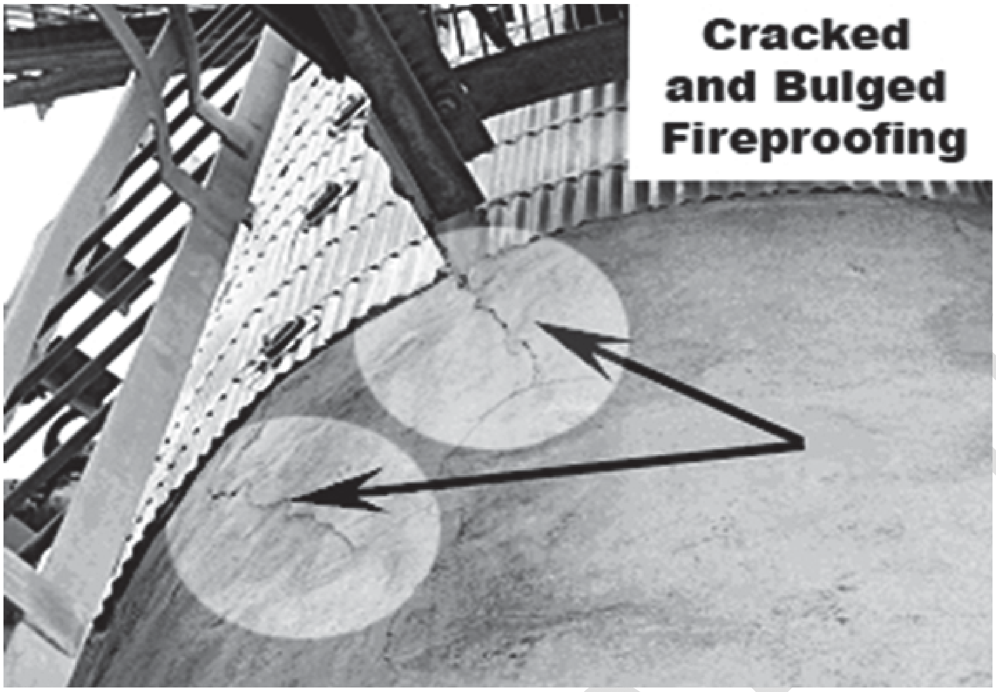


Figure B.19 - Cracked and Bulged Fireproofing

Tower skirts should be inspected for debris and skirt drains should be checked for obstructions. Debris in the skirt (see Figure B.20) is a fire hazard, and obstructed skirt drains foster corrosion of the anchor bolting and skirt, as well as allowing minor leakage at the bottom head/nozzles/flanges to go undetected.

B.3.3 Internal Inspection

Those tools that are normal to the visual inspector (see 11.1) are sufficient for the inspection of towers. No special tools or equipment are required to perform internal visual inspection of a tower.

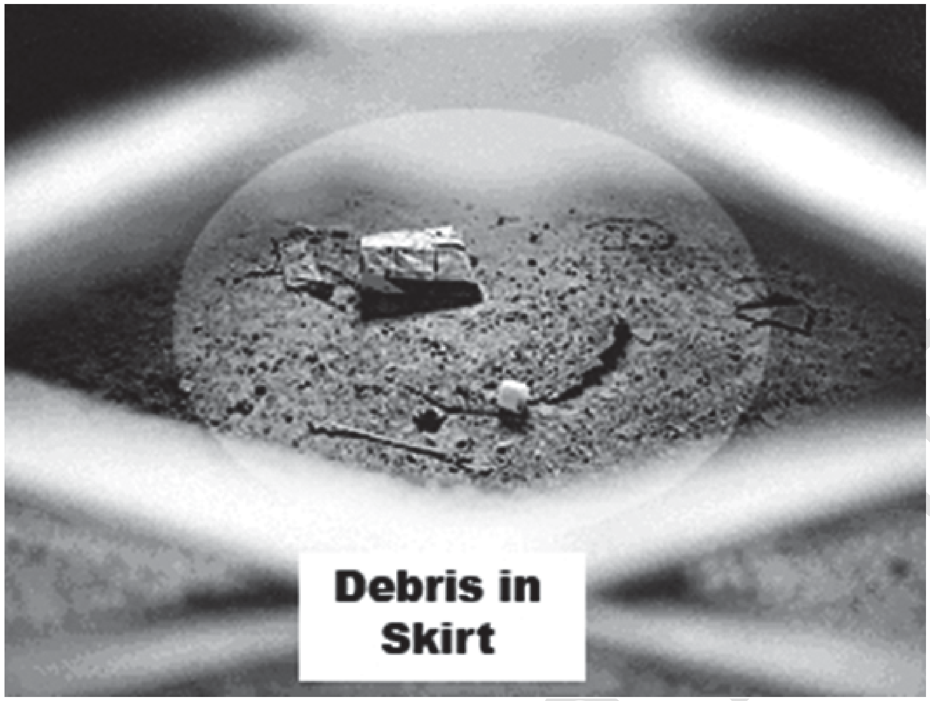


Figure B.20 - Debris in Skirt

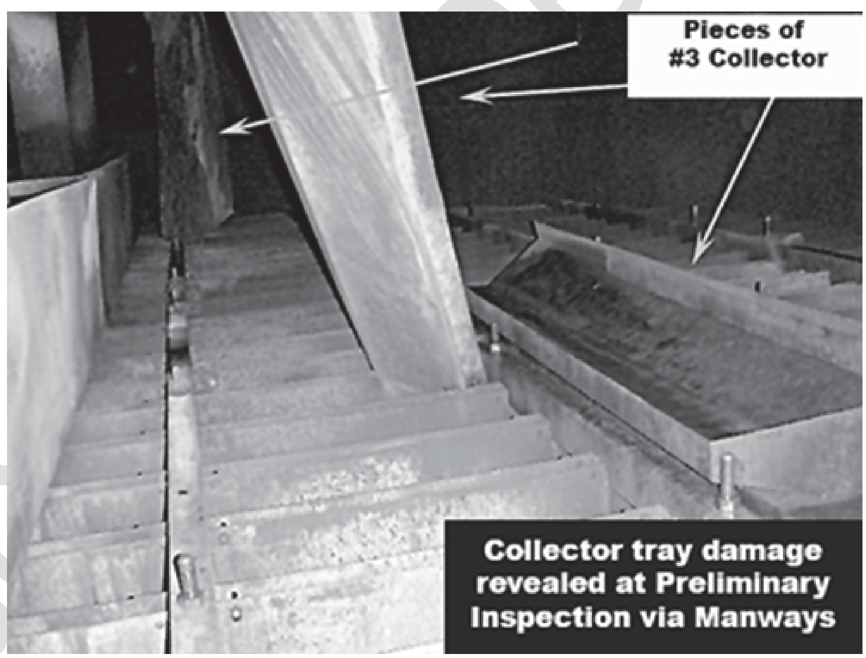


Figure B.21 - Preliminary Inspection

Preliminary, or “dirty inspections” shown in Figure B.21 through Figure B.27, should be performed upon opening the external manways, before whatever forced ventilation is to be installed is installed. Early detection of previously unexpected damage to internals due to upset and/or corrosion is crucial to the timely completion of repairs.

Figure B.22 - Bed Damage at Preliminary Inspection

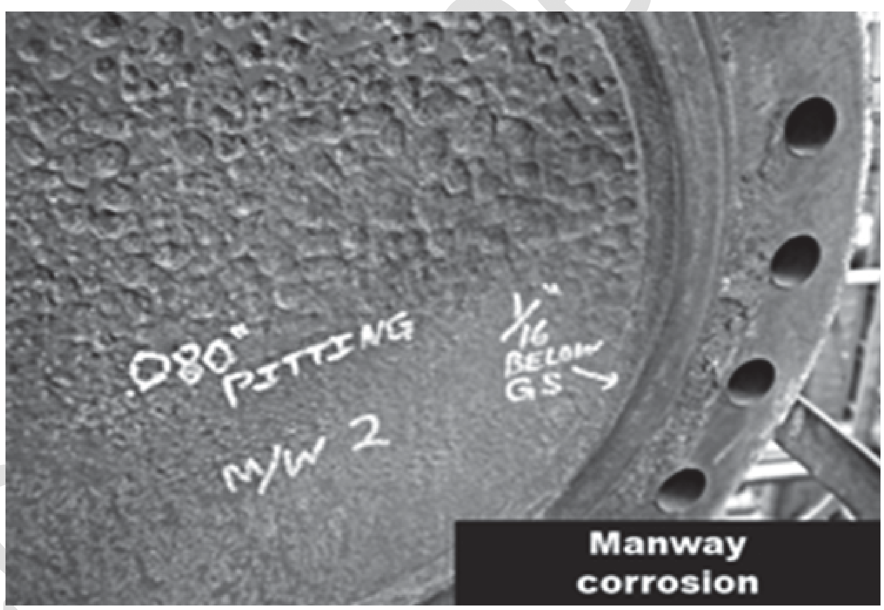


Figure B.23 - Manway Corrosion

Determination of the degree of additional cleaning that might be required is crucial to the timely completion of discovery work. Hand cleaning of those areas not adequately cleaned via steam-out and chemical cleaning is frequently required due to the complexity of the internal configurations.

Using the equipment elevation drawing, manway covers; manway gasket surfaces, and manway bore internal surfaces should be labeled and inspected.

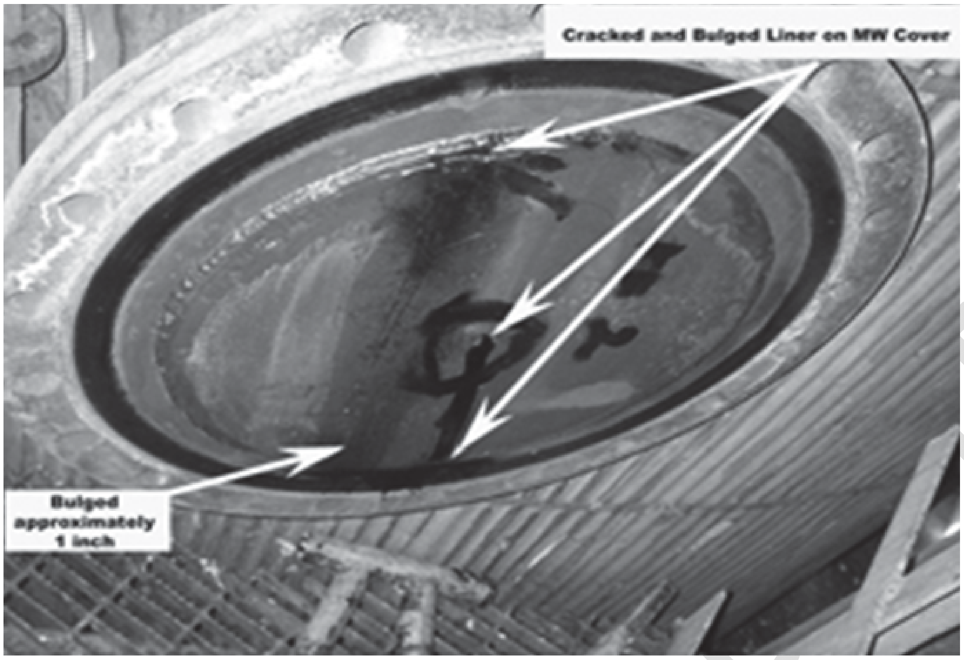


Figure B.24 - Manway Liner Damage

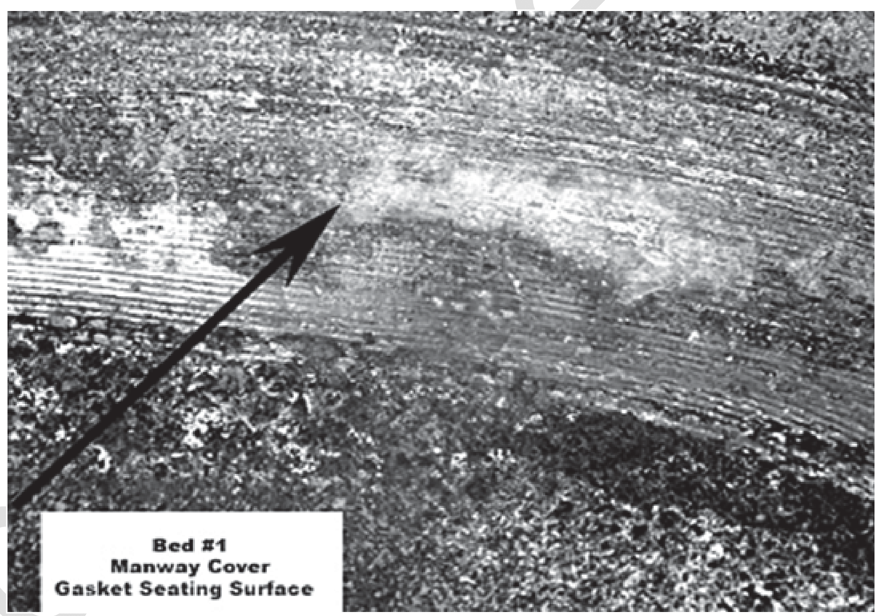


Figure B.25 - Corrosion on Gasket Seating Surface

Particular care should be taken with lined manways and covers.

Cracking and bulging at liner plug welds and consequential corrosion behind the liner, corroded or damaged gasket surfaces, and/or internal corrosion of the bore or stagnant areas should be discovered prior to installation of ventilation equipment.

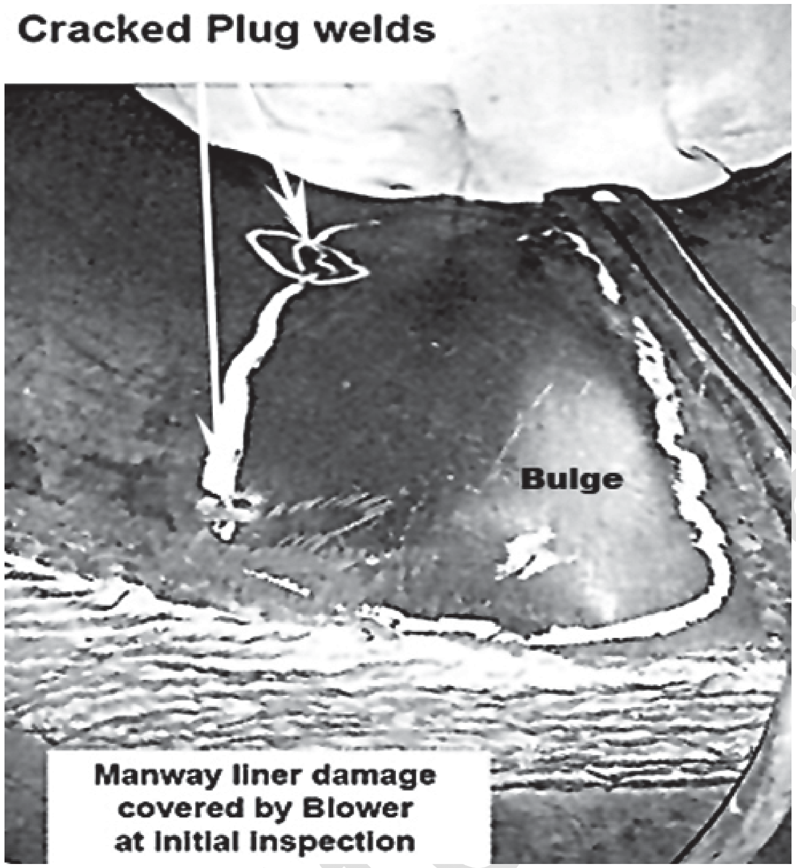


Figure B.26 - Corrosion on Gasket Seating Surface

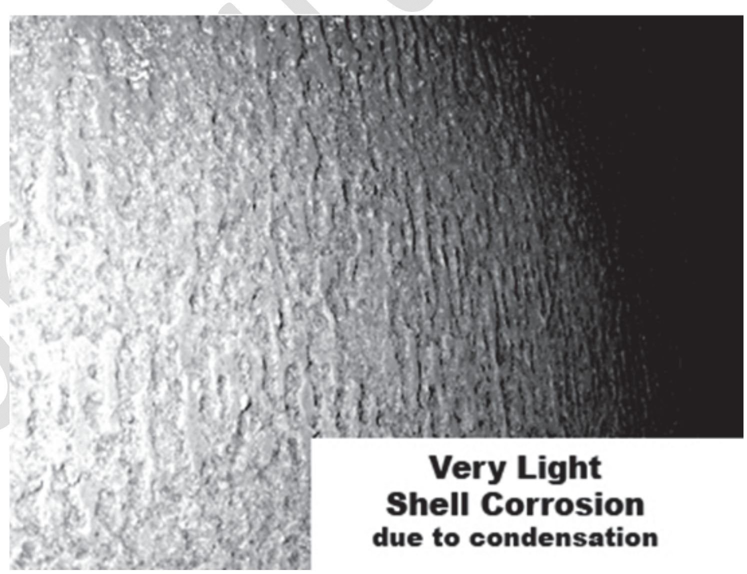


Figure B.27 - Surface Corrosion of Shell

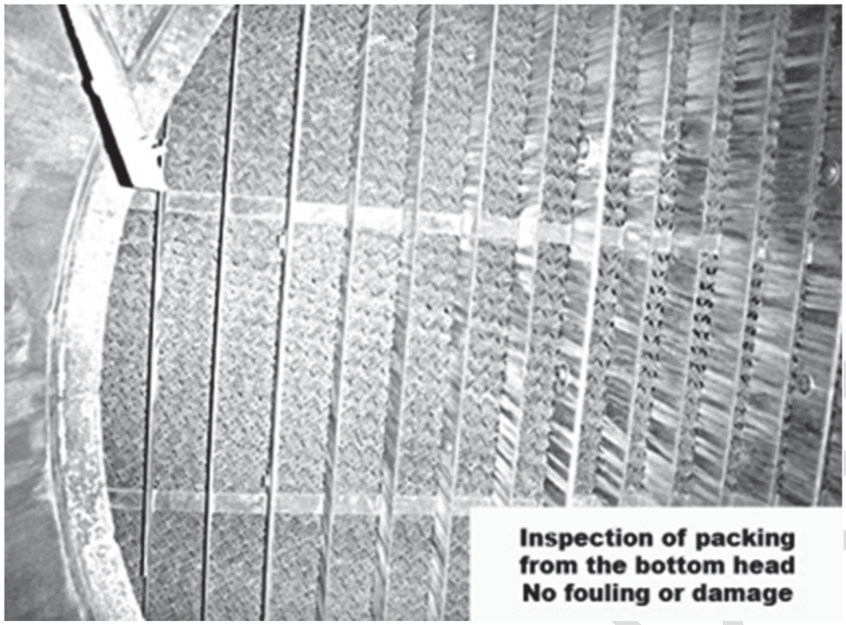


Figure B.28 - Inspection from the Bottom Head

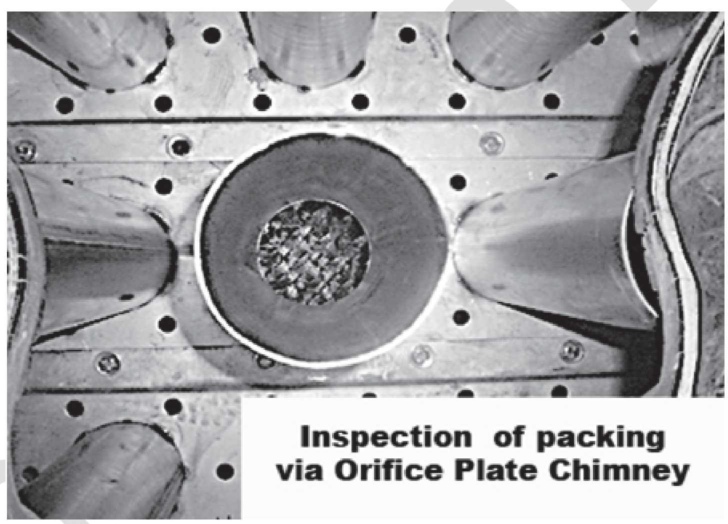


Figure B.29 - Inspection of Packing via Riser

B.3.4 Visual Inspection of Packed Towers

B.3.4.1 General

Packed towers have two basic sets of conditions; packing removed and packing in place. If packing is not removed, a limited or partial visual inspection is the most that can be performed. Under these conditions, the degree of inspection is a variable, controlled by the degree of disassembly of the internals, the type of packing, and the amount of access permitted by operations.

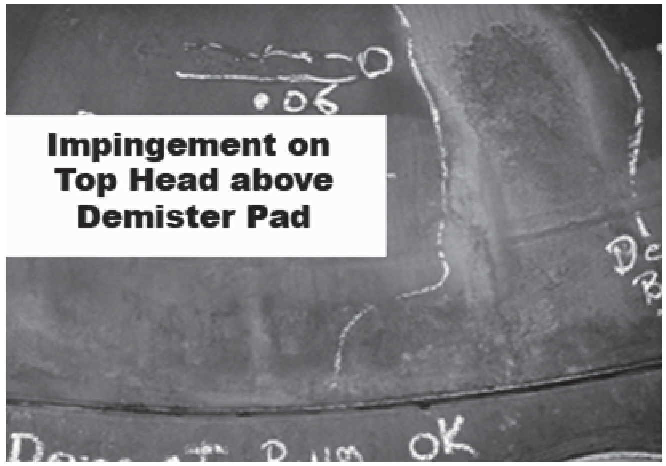


Figure B.30 - Demister Bypass Deposits

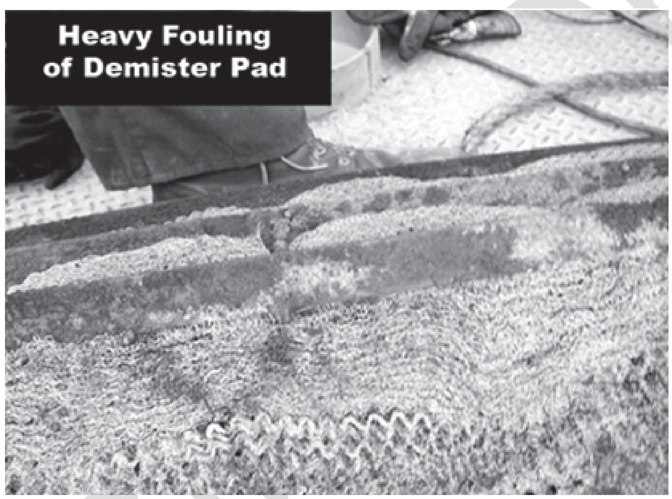


Figure B.31 - Fouled Demister Pads

B.3.4.2 Packed Towers—Packing in Place

Inspection of a tower with packing in place is limited to the top and bottom heads, the adjacent shell, and those other portions of the pressure retaining boundary that are accessible, the accessible nozzle bores, the top and bottom surface packing, and the internals (Figure B.28 and Figure B.29 demonstrate the limited visibility of a packing in place inspection).

Normal visual inspection and quantification of the surface texture and corrosion present on the top head and shell course may be supplemented with UT thickness measurements. Thickness measurements of susceptible areas or areas of visible impingement should be taken in conjunction with the visual inspection throughout the tower. Such areas of impingement can frequently be found above demister pads, and are indicative of pad bypass, usually due to improper installation or breakdown within the pad. If internal UT thickness measurements are to be taken subsequent to the visual inspection, identification and high-visibility marking of the areas where measurements are to be taken is of great importance. Figure B.30 to Figure B.32 gives examples of fouled demister pads and identify internal UT thickness measurement locations.

When not removed by inspection scope, demister pad installation defects warrant removal when indicative of demister bypass, damage to the pads or retention grid, or heavy fouling of the pads. Nozzle bores and nozzle

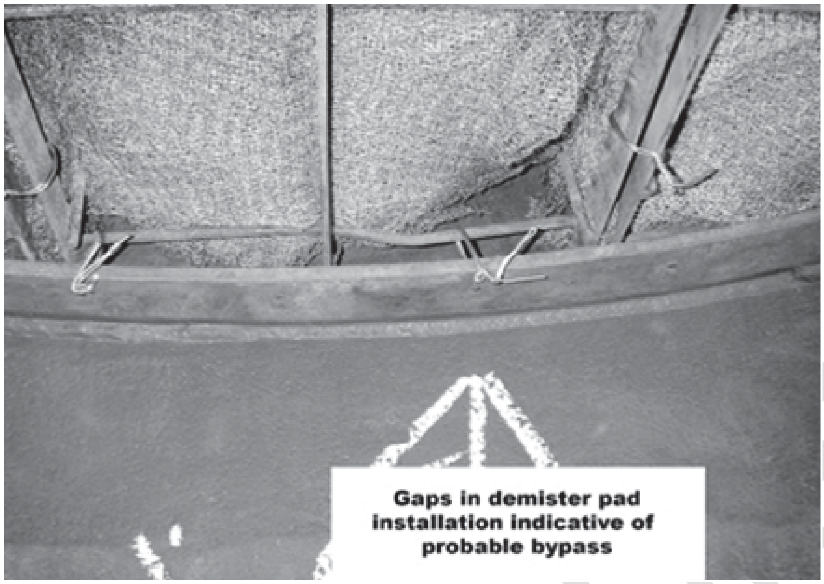


Figure B.32 - Faulty Demister Installation

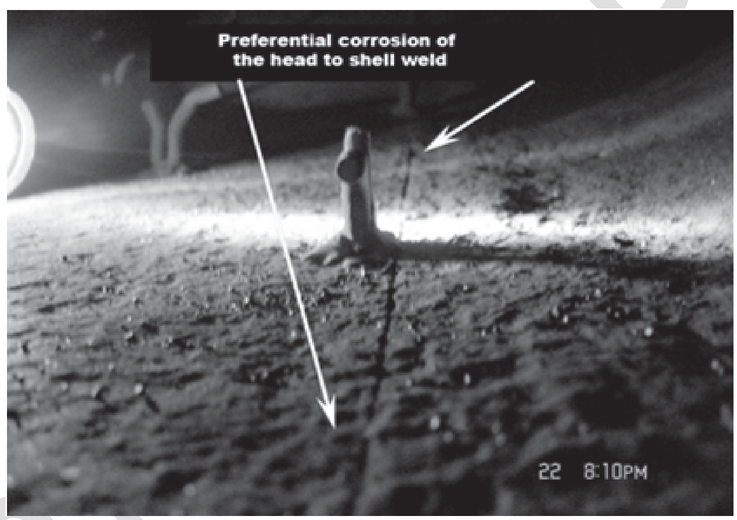


Figure B.33 - Preferential Corrosion of the Head-to-Shell Weld

attachment welds on the top shell course and the top head, especially those with little or no flow such as blind flanged nozzles and those for PRDs, should receive particular attention. Temperature differences between the top head and the nozzle bore may lead to precipitation of corrosive liquids from the overhead vapors.

In the case of contactor towers with random packing installed, removal of the packing bed is preferred. Vibration of the packing against the shell can cause or accelerate erosion/corrosion as contaminants from the process stream build- up in the solvent or scrubbing media.

All visible portions of the tower weld seams should be inspected for cracking, wear, pitting, and preferential corrosion of the heat affected zone weld or shell (Figure B.33 through Figure B.35 show examples of these damage mechanisms).

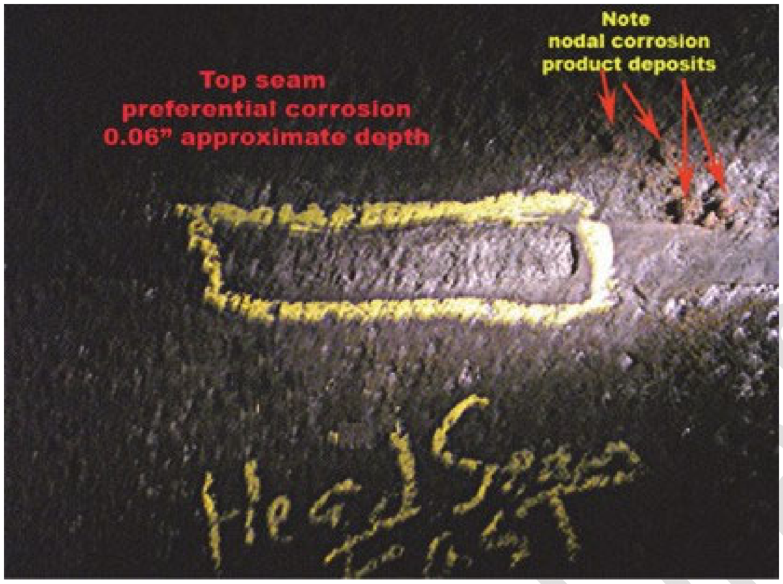


Figure B.34 - Head Seam Preferential Corrosion

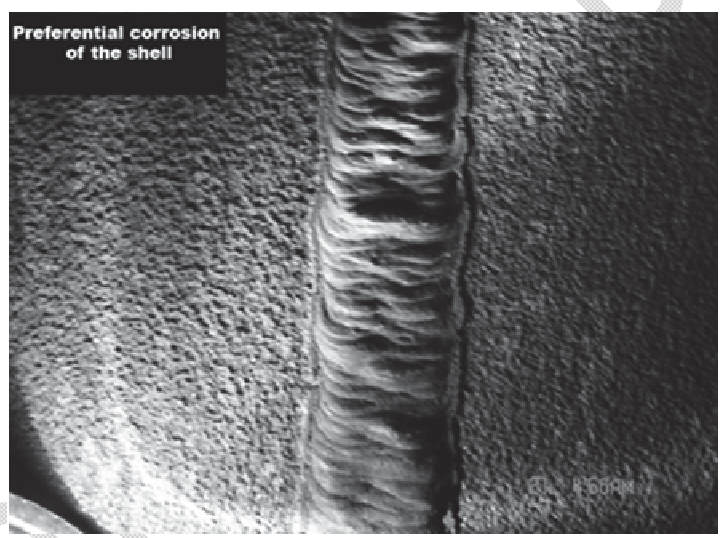


Figure B.35 - Preferential Corrosion of the Shell

When inspecting the internals of a packed tower with the internals still installed, access can be severely limited. As many perforations of the internal piping and the distribution system as possible should be inspected. All perforations should have appropriate shaping and square cut edges (see Figure B.36).

“Out-of-round” and loss of edge profile on internal distributor perforations are indicative of wear or corrosion. Note any visible obstructions of perforations or distribution piping for correction.

Chimney or collector trays frequently require supplemental cleaning, since they are designed to hold liquid. Proper cleaning of this area is required to allow discovery of corrosion or pitting of the tray deck and shell. Draw sumps, if present, should be particularly well cleaned to allow close visual inspection of the draw nozzle attachment weld and the nozzle bore for corrosion.

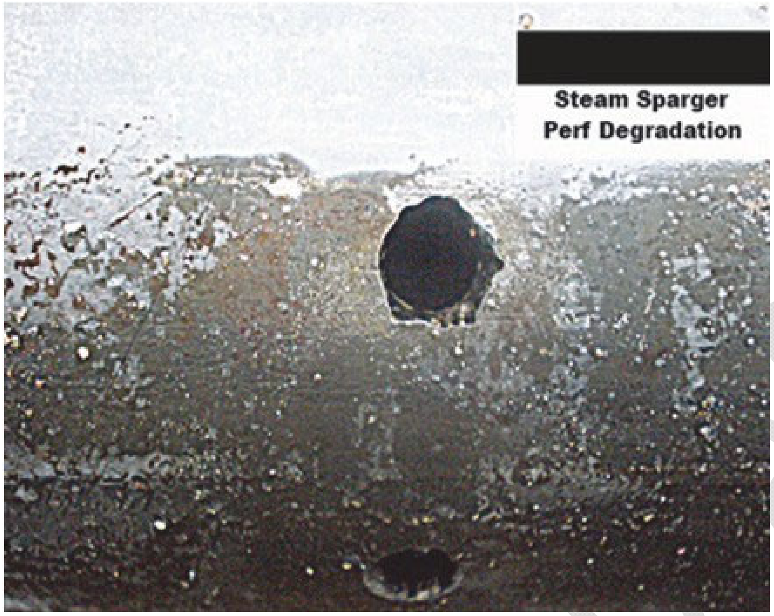


Figure B.36 - Perforation Degradation

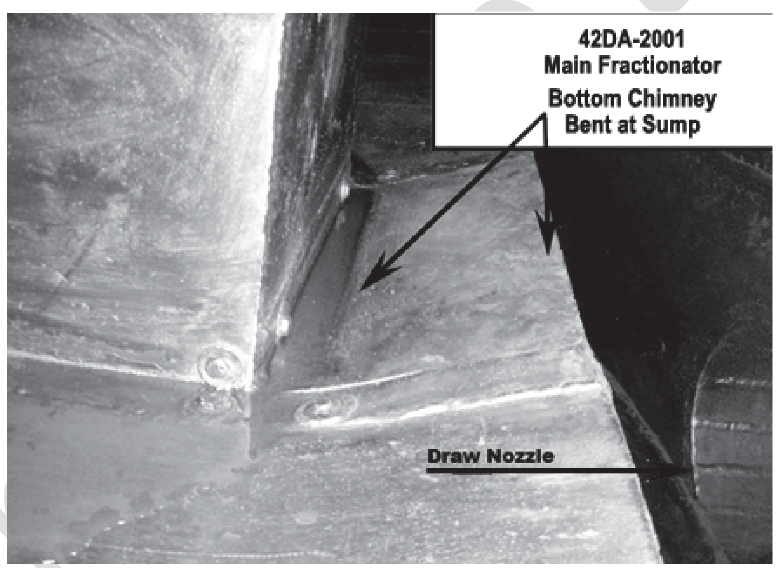


Figure B.37 - Chimney Tray Deformation at Draw Sump

Chimney trays are sometimes subjected to cyclic pressure due to variations in vapor flow and cyclic liquid loads. Chimneys should be checked for distortion (see Figure B.37) as well as cracking. Seal welded chimney trays should be inspected for cracking at the base and vertical edges of the chimneys, at the deck seam seal welds and at the ring seal welds.

Box and trough distributors, where installed, should be checked for internal debris, obstruction of any perforations and for any distortion or damage to drip point enhancement devices (where installed), see Figure B.38 through Figure B.40. Troughs that are holding liquid probably have obstructed perforations.

"Rattling hardware" on internals is the most common method of ensuring tightness, however, hardware that appears tight when "rattled" may be held in place by a single thread, with all exposed threading evenly degraded where in

Figure B.38 - Fouled Troughs on Box and Trough Distributor

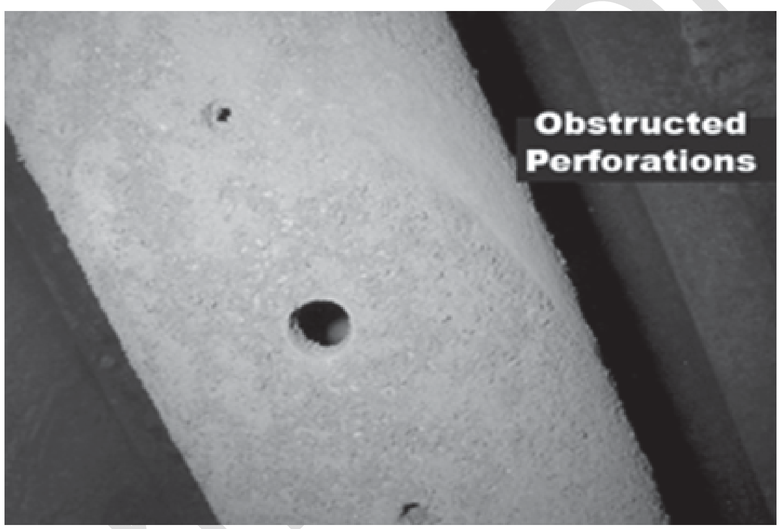


Figure B.39 - Obstructed Pipe Distributor Perforations

contact with the process fluids. This is fairly common on the reflux distribution system of amine towers. Striking several nuts/bolts sharply at an angle with the inspection hammer should reveal this condition (see Figure B.41). In all other cases, where hardware is actually hit with the inspection hammer, hitting the washer is best. The torque values on tower hardware are relatively low, and loosening may result from hammer blows. Tower attachments should also be sounded with an inspection hammer to check attachment welds are not cracked.

In all cases, the distance from the packing to the bed limiter should be recorded. Record this information prior to the removal of the bed limiter if the bed limiter is to be removed for access. Bed limiter integrity and hardware should be checked, as well as checking for packing migration due to overlarge grid size on the bed limiter (see Figure B.42).

Structured packing may or may not have a separate hold-down grid. Bed limiters for random packing are generally bolted to lugs or clips welded to the shell. Rather than bolted to the shell, hold-down grids are supported by the structured packing (see Figure B.43), and in distributor designs that have distributors sitting directly on the packing, hold-down grids are usually not installed. Any indications of packing migration, such as packing loose above the

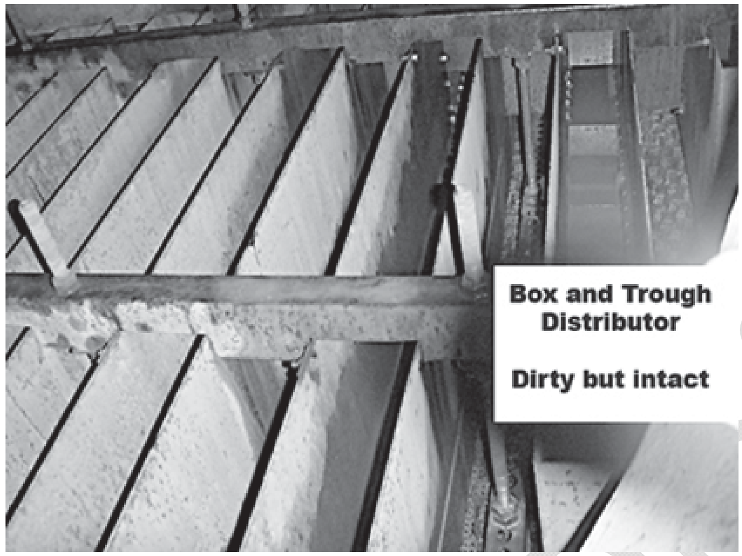


Figure B.40 - Box and Troughs

Figure B.41 - Hit the Washers, Not the Bolts

limiter or loose inside the box and trough distribution system should be noted. Migrated packing found on chimney trays or in adjacent process equipment should be noted in the tower report upon discovery.

Any indications of collapse or break up of the packing should be recorded. Visual indications of thinning and fragmentation of random packing are typically found at the gas injection support plate, or downstream in the bottoms filters/pumps. Bed collapse will be indicated by fragmentation and a significant drop in packing bed height as shown by the distance between the top of the bed and the bed limiter. Upset beds of structured packing are usually easily visible during the preliminary inspection. Fallen packing sheets or support grid members may be visible (see Figure B.44) on the collector tray below the bed.

A good "rule of thumb" for thinned random packing is that if you are able to significantly distort the packing with a finger and thumb, recommendation for replacement should be made. If it looks thinned, and has knife edges instead of the sharpness associated with the stamping process, it probably is thin.

Caution—Metal packing of all types is sharp. Care should be exercised and gloves should be worn when inspecting or handling metal packing.

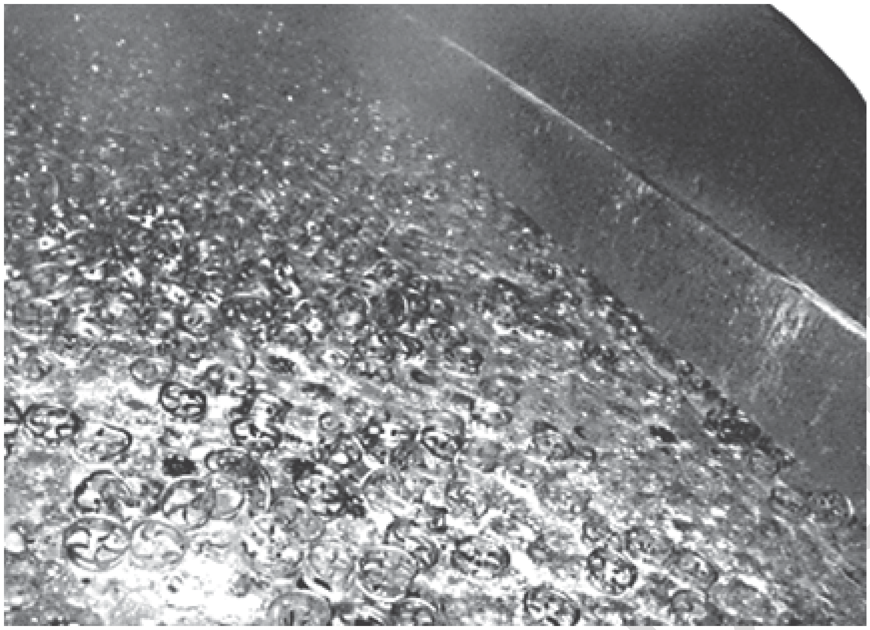


Figure B.42 - Random Packing on Valve Tray

Figure B.43 - Bed Limiter Above Random Packing

The inspection of the support ring, attachment welds and gas injection support plate or bed support grid is frequently be performed from the bottom head. Any indications of damage and/or wear visible from in excess of 5 ft (1.5 m) should be considered sufficient cause to provide for closer visual inspection.

Where close visual inspection of these components is possible, particular attention should be paid to the integrity of the gas injection support plate/support grid bolting and positioning (centering), as well as the support ring attachment welds (see Figure B.45 and Figure B.46).

Figure B.44 - Dislodged Packing

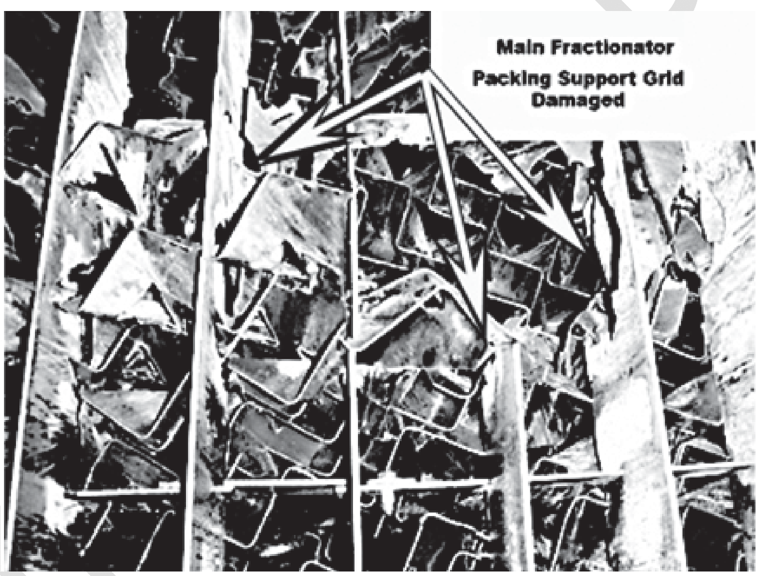


Figure B.45 - Damaged Packing Support Grid

During the inspection of the bottom head and accessible shell courses particular attention should be paid to the nozzle bores and attachment welds of sightglass nozzles (see Figure B.47) and any other nozzles that have little or no flow during normal operation.

Temperature differences between the bottom head, bottom shell course and the nozzle bore frequently lead to precipitation of corrosive liquids from the overhead vapors. An inspection mirror or camera should be used to inspect any shell, attachment welds, nozzle attachment welds and the nozzle bores that may be partially enclosed by still wells or inlet diffusers. The internal surface of the bottom head is frequently covered with debris or scale, even after mechanical or chemical cleaning. Scratching the internal surface thoroughly through minor debris with a scratch awl or pointed scraper will sometimes show any severe pitting previously obscured.

Figure B.46 - Support Grid from Below

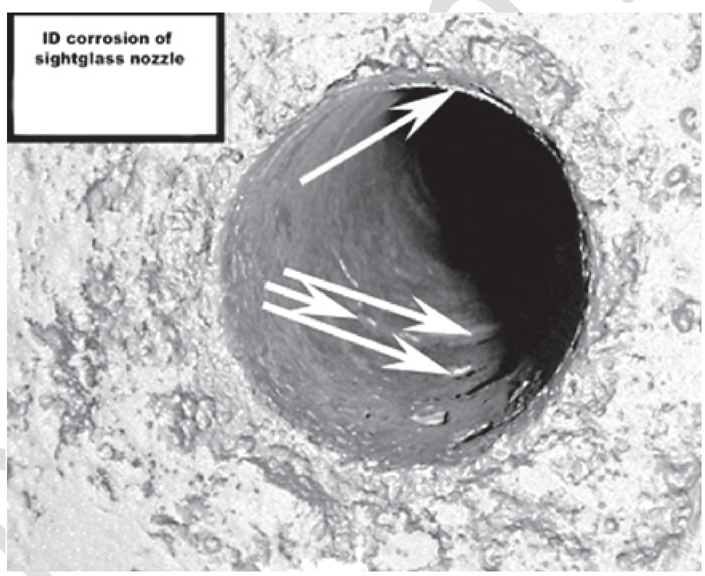


Figure B.47 - Corrosion Inside Sightglass Nozzle

Vortex breaker and anti-swirl baffles, where installed, should be sounded with an inspection hammer to insure sound attachment welds in addition to visually inspected for wear (see Figure B.48).

B.3.4.3 Packed Towers—Packing Removed

Packing removal allows the close visual inspection of the condition of the packing in the inner bed, as well as access to the tops of support grids and the remainder of the shell. Random packing should be checked for fragmentation and fouling of the packing surface. Fouled random packing may not be blocking flow similar to a fouled exchanger bundle. Fouled random packing appears dirty, but actually has a highly adherent coating of deposits that retard easy flow of liquid through- out the bed. Random packing should come out of the bed clean, or with easily rinsed deposits on it.

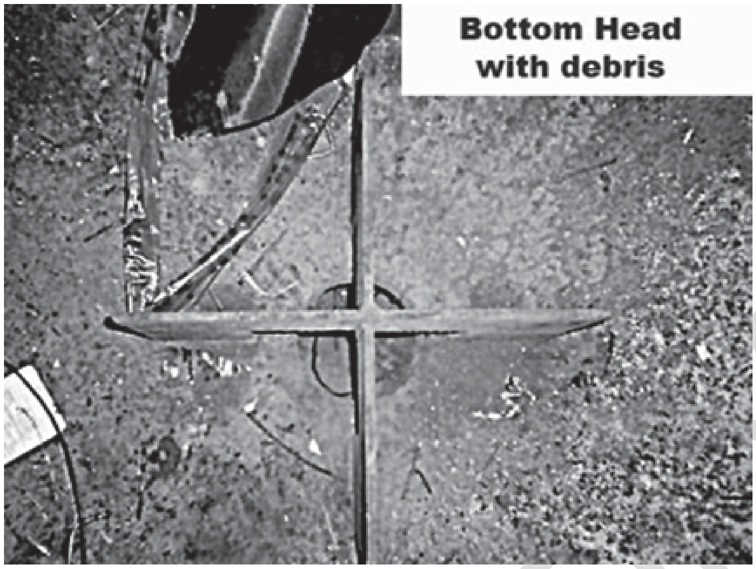


Figure B.48 - Bottom Head, Vortex Breaker, and Debris

Structured packing should be inspected for frangibility (see Figure B.49), as shown by edges that appear nibbled, and that are easily bent to fatigue failure. Structured packing that is fouled generally will have heavy deposits visible between the sheets of the block of structured packing. Highly adherent deposits, no matter the thickness, should be reported to process engineering for evaluation.

Visual inspection of the shell exposed by the removal of packed beds should be done with great care. Random packing in carbon steel shells will present a mottled appearance that may hide defects such as cutting of the shell or pitting due to carbonic acid. Structured packing that was incorrectly oriented during loading may have initiated channeling on the shell. These defects require close visual inspection to detect during the early stages and scaffolding is recommended to facilitate this inspection.

B.3.4.4 Strip Lining and Cladding

Many towers have all or part of the internal surface of the shell and heads lined with corrosion-resistant material. These liners range from stainless steel through concrete/refractory linings. Metallic liners may be installed in sheets or strips, with plug welds utilized to fasten the alloy material to the carbon steel. This is known as “strip lining”. Plug welds and attachment welds of liners frequently crack on this type of liner frequently crack due to expansion of trapped gases behind the strip liner (see Figure B.50). Coke or other corrosives may collect behind the liner, causing bulges of the liner. This may result in additional cracking of the liner as well as corrosion of the underlying metal. Repairs to strip liner usually involve the removal of effected section of liner and the removal of any coke or other process deposits.

If corrosion is present under the deposits, weld buildup with a like material is performed if required. Following the completion of the weld buildup, weld overlay with a corrosion-resistant material is usually performed. If strip liner is replaced instead of using corrosion-resistant weld overlay, upon completion of any approved repairs, pressure testing with air to 5 psig (34.5 kPa) is usually done to check that no gaps or defects remain in the strip lining that might allow additional access to the underlying metal.

Nozzles that have been lined will frequently have a threaded hole drilled through the bottom centerline of the nozzle to allow detection of liner failure. Unless liner failure has been detected during this operational period such that repairs have not been made, these plugs, like the weep holes of reinforcement pads, should not be plugged.

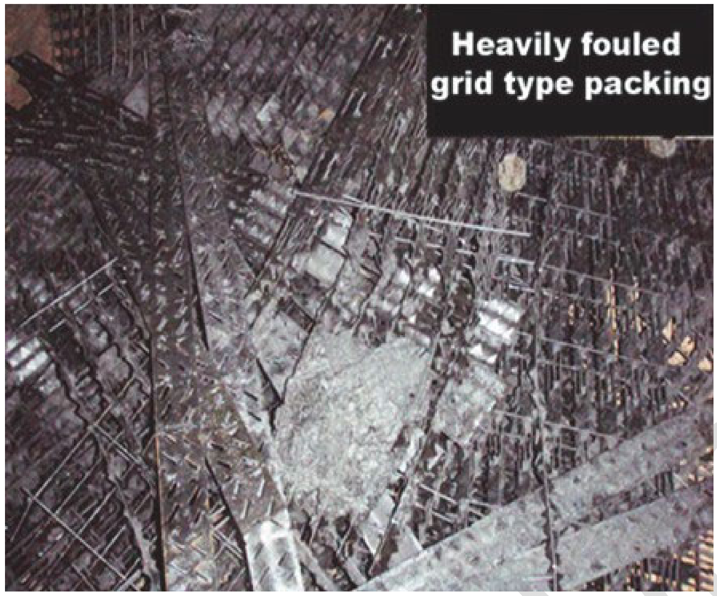


Figure B.49 - Fouled Grid-type Packing

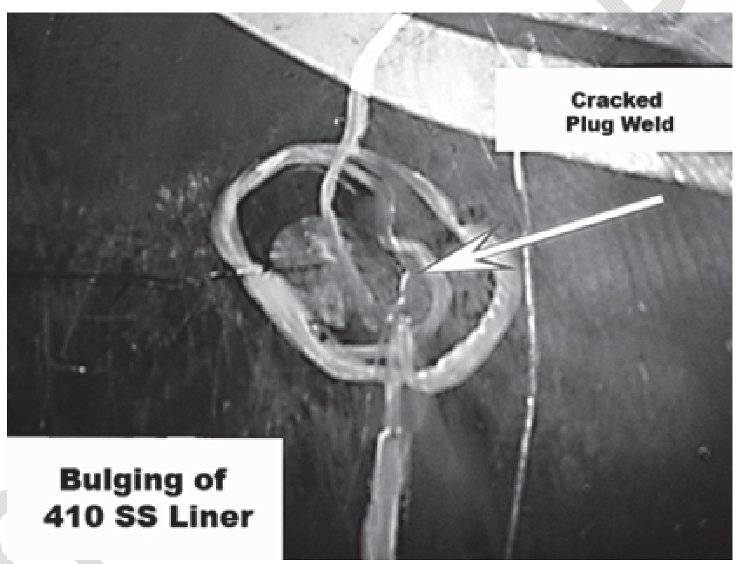


Figure B.50 - Cracked Plug Weld

Clad lining usually refers to explosion bonded stainless steel cladding on carbon steel plate. This material, if properly constructed, is free of most of the cracking and bulging associated with strip lining. Some clad plate vessels utilize “donut” strip lining to cover the nozzle attachment welds (see Figure B.51).

Most clad towers use weld overlay to cover the nozzle attachment weld with corrosion-resistant material and to tie the nozzle cladding into the shell/head cladding. This overlay and the “donut” liner used in pace of overlay, along with gouges to the cladding and the carbon steel shell to clad shell interface weld, comprise the primary areas of cladding failure (see Figure B.52 and Figure B.53).

Figure B.51 - Stainless Steel Donut Cladding Breech

Figure B.52 - Cladding Breech at Gouges in Bottom Head

B.3.5 Visual Inspection of Trayed Towers

B.3.5.1 Internal Manways Installed

When internal tray manways are not removed, a limited or partial visual inspection is the most that can be performed. Access should be provided onto the top tray, at the middle manway (if present), and onto the bottom head for inspection of the bottom shell courses and the underside of the bottom tray to inspect for damage. UT thickness measurements of suspect areas should be performed concurrently with visual inspection and the quantification of the corrosion characteristics of the shell and heads. If internal UT thickness measurements are to be taken subsequent to the visual inspection, high-visibility marking of the areas where measurements are to be taken is of great importance (see Figure B.54)

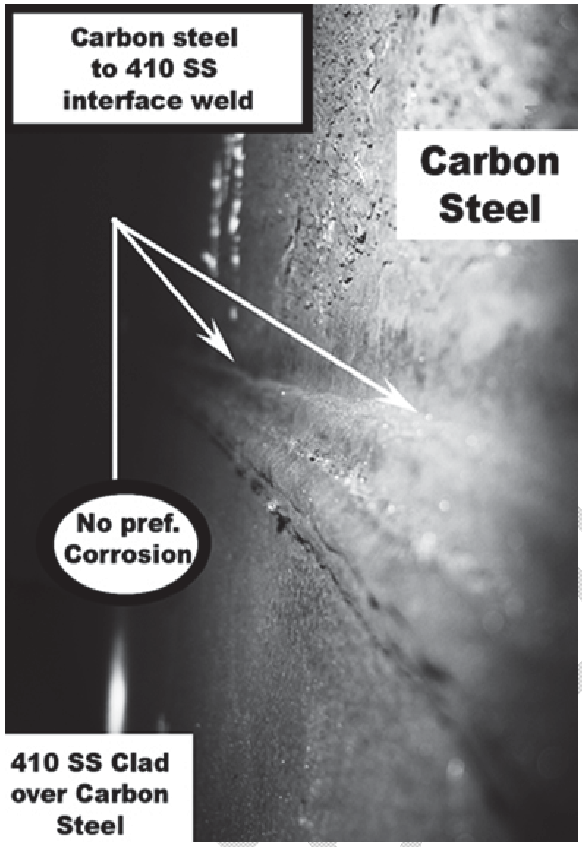


Figure B.53 - 410 Stainless Steel Clad to Carbon Steel Interface Weld

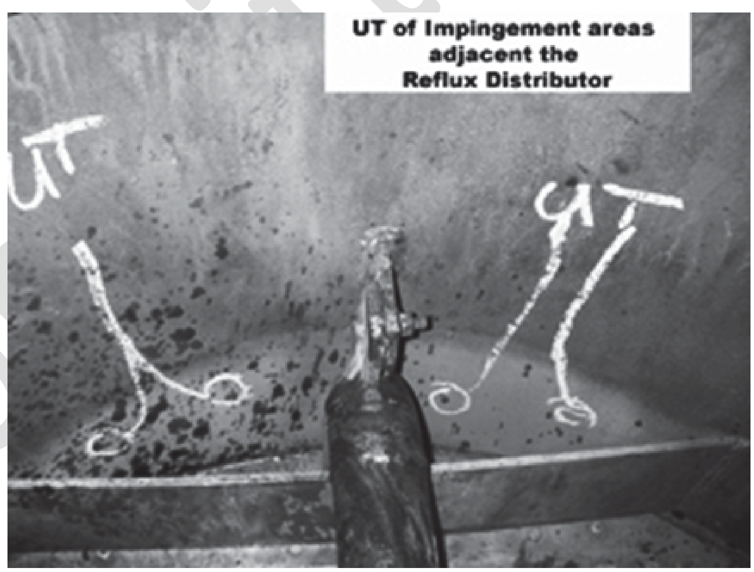


Figure B.54 - Supplemental UT Markings

B.3.5.2 Internal Manways Removed

B.3.5.2.1 General

The primary difference between the internal visual inspection of trayed towers and packed towers is the trays themselves and their support rings. Locations within trayed towers are defined by the tray number (from the assembly drawings) and the process activity taking place on the particular group of trays.

EXAMPLE Trays 1 through 10 may be referred to either by number or as a group as “rectification section” or “the reflux trays”.

Trays may be numbered from the top tray down or the bottom tray up, depending upon the designer and manufacturer. Check the drawings before inspecting the tower to understand specific numbering of the trays for reporting purposes. Towers may be constructed using several tray types and manufacturers within a process section, or may be consistent throughout a section or the entire tower. Basic understanding of the process purpose of each tower allows recognition of the sections and the type of chemical reaction taking place within that section. This in turn aids in the prediction of the locations where corrosion, cracking, or other damage mechanisms may be expected.

Each tray is a separate distillation stage, with chemical activity consequently taking place (against the shell) throughout the column. This chemical activity takes place in an environment of varying concentrations of corrosive substances that in turn leads to varying corrosion rates. Corrosion rates and characteristics vary across the trays, within the section and across the tower. The large number of internal attachment welds, coupled with the numerous horizontal surfaces, creates conditions that promote service type defects (see Figure B.*55* through Figure B.*57*), such as environmental cracking and/or corrosion at the tray support ring attachment welds, the downcomer attachment welds, and on both the upper and lower surfaces of the tray.

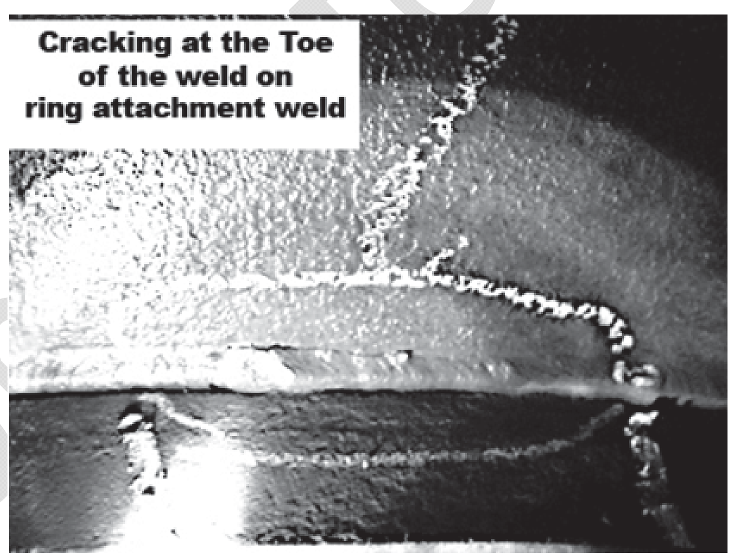


Figure B.55 - Cracking at Tray Support Ring Weld

Supplemental NDE, such as WFMT, may be required in certain services (i.e., amine or caustic). As a general rule, the upper third or the lower third of the tower is where the most corrosive environment is typically found. Where cladding is provided for corrosion protection, interface welds between the cladding and shell should be carefully inspected for localized/preferential corrosion.

Other locations to inspect for damage are as follows:

a) the area of the feed inlet and five to ten trays above and below the feed inlet;

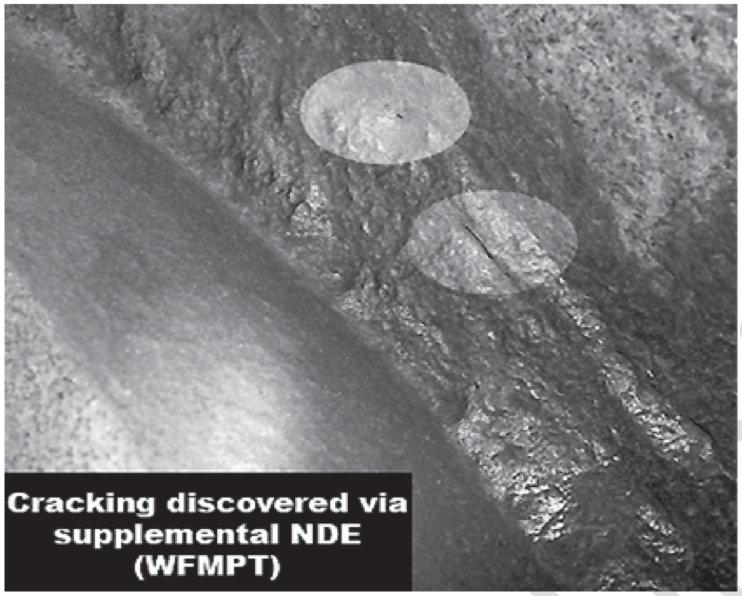


Figure B.56 - WFMT Discovered Cracking

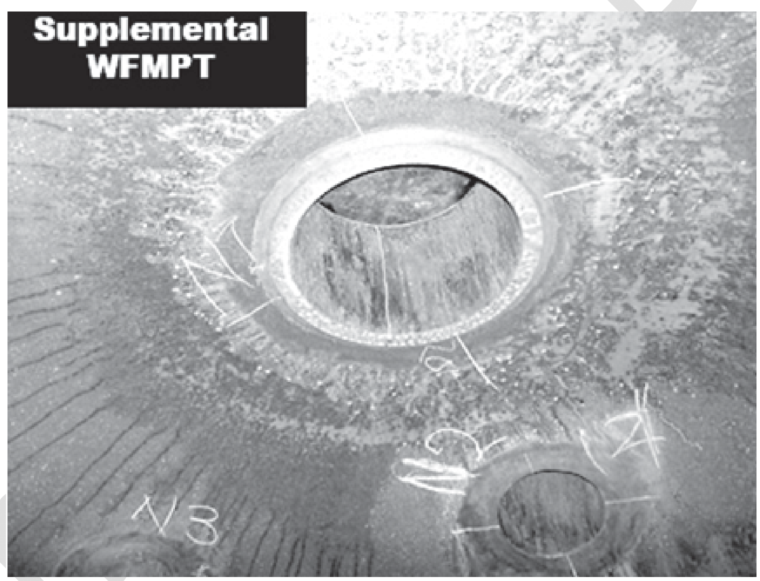


Figure B.57 - Supplemental NDE May Be Needed

b) the reflux inlet, the adjacent shell/head, and the first 5 to 10 trays below the reflux inlet;

c) the shell across from and adjacent to the inlet from the reboiler (if present). This includes the bottom head, bottoms nozzles and the head to shell seam.

These areas are usually subjected to the most turbulence within the tower.

The areas or zones between trays (see Figure B.58 and Figure B.59) where corrosion may be present are as follows.

a) **The Liquid Zone**—This area of the shell sees primarily liquid, and the beginnings of frothing. Corrosion in this area is sometimes further complicated by the presence of process deposits. Spot-checking (four to six locations per tray level) under deposits is recommended. Scrape spots 4 in. to 8 in. long, from above the weir height down to and including the tray support ring.

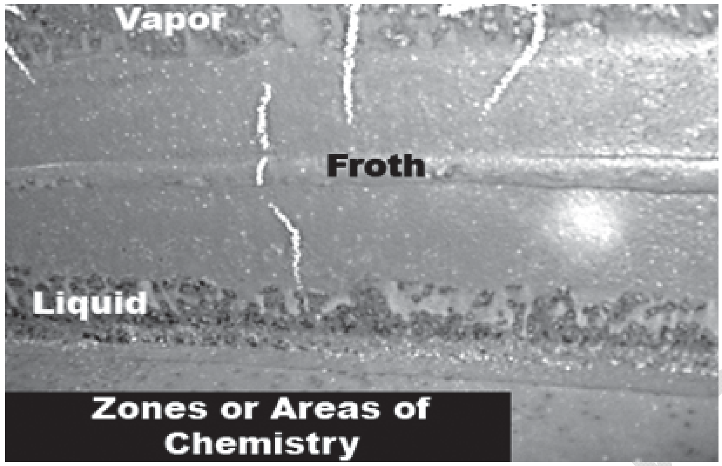


Figure B.58 - Areas of Chemical Activity

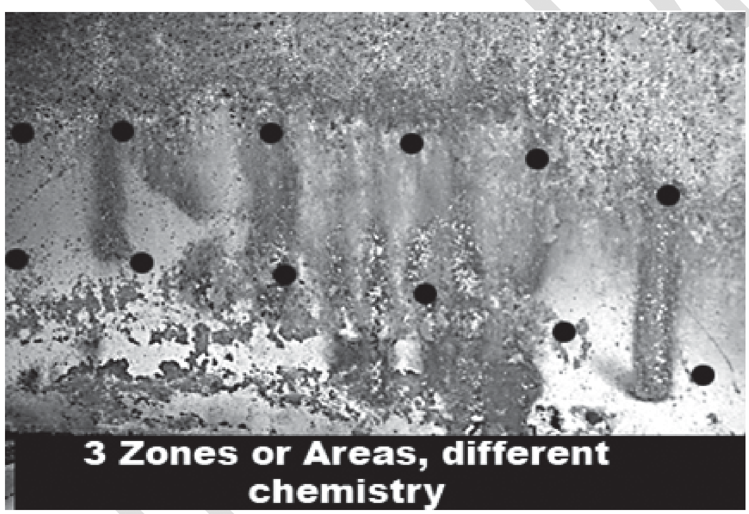


Figure B.59 - Areas of Activity

b) **The Froth Zone**—This area sees less liquid and if process deposits are present, they typically have a different, lighter consistency than those present in the liquid zone. Light spot checking is usually sufficient (two to three locations per tray level).

c) **The Vapor Zone**—This area consists of the last 3 in. or 4 in. (7.6 cm to 10.2 cm) below the tray. This area of the shell sees primarily relatively dry vapors, entrained droplets, and any weeping liquid from the tray above. The shell in this area usually sees very light corrosion; however, the tray support ring attachment weld and heat affected zone may be subjected to accelerated corrosion, and deposits may cause accelerated corrosion of tray hardware.

Mechanical cleaning of this area may be needed if the initial cleaning of the vessel has not removed the majority of the deposits from the underside of the tray (see Figure B.60).

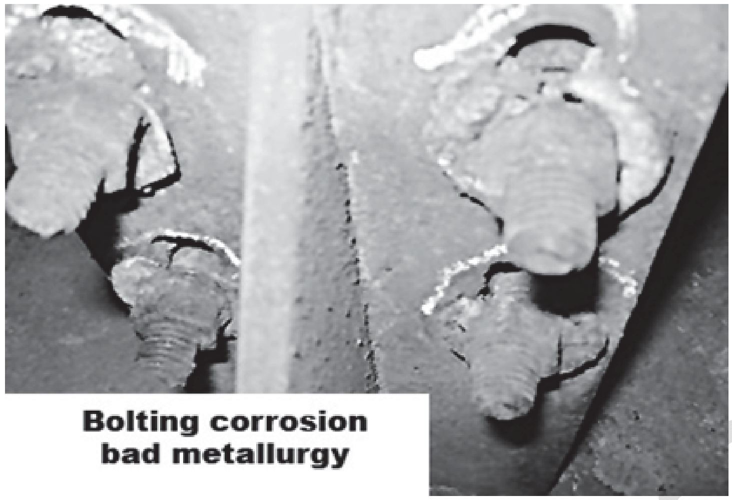


Figure B.60 - Hardware Corrosion

B.3.5.2.2 Trays and Valves

Tray valves fall into two loose categories. Moveable tray valves (see Figure B.61) are those that are designed to open with sufficient vapor pressure below the tray. These valves may be designed to remain either fully open or fully closed, or may be designed to operate in partially opened/closed positions as well. Fixed valves are valves that are designed to be open at all times. They may be extruded from the tray deck or be held to the tray deck by tabs pushed through the tray deck and bent.

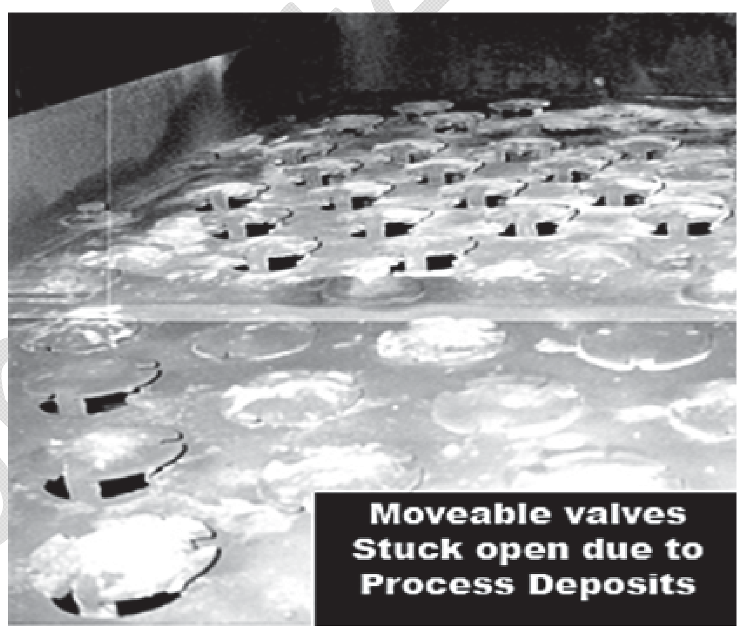


Figure B.61 - Stuck Valves Always Open

Moveable Tray Valves and Associated Tray Perforations—Tray decks, valves, and tray perforations are subject to a variety of corrosive influences ranging from process deposits to vapor impingement due to lateral vapor flow. Valve perforations that are unworn have square edges (see Figure B.62) and the perforation is round or rectangular, as appropriate.

Moveable valves and associated tray perforations are subject to mechanical fretting (corrosion due to mechanical removal of any corrosion barrier that the tray and/or valves may develop), corrosion due to impingement of entrained liquids, and high-speed vapor low.

With moveable valves, the tray deck immediately around the perforation should be checked for indentation due to fretting (see Figure B.63) by the valve dimples. Tray decks with severe indentation should be replaced.

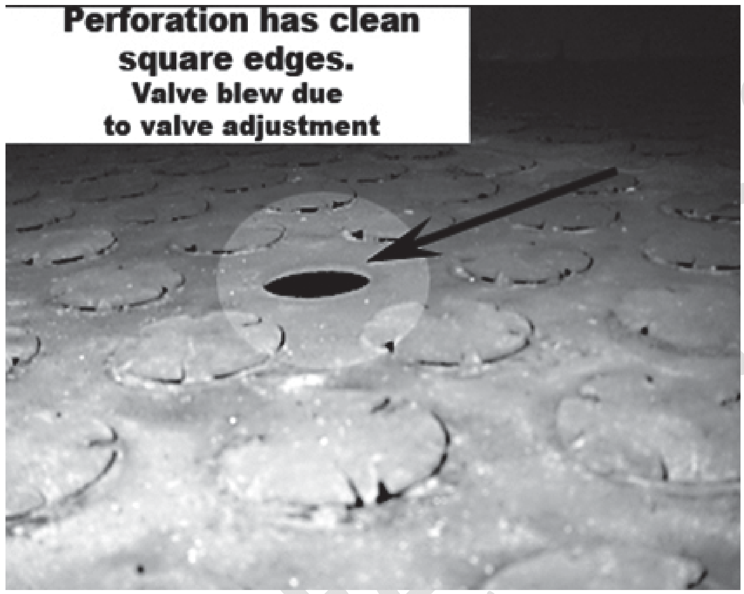


Figure B.62 - Clean Square-edged Perforation

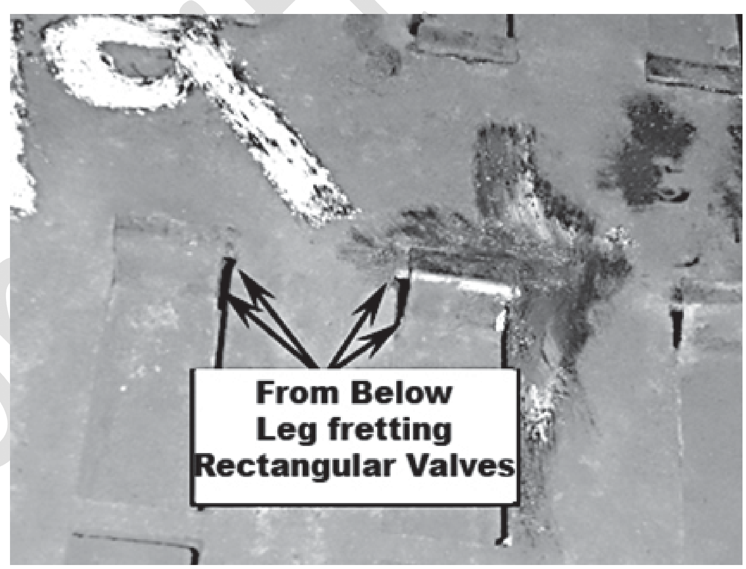


Figure B.63 - Valve Fretting

Perforation edges may be fretted by the valve legs to an “out-of-round” condition (also known as “key holing” or “slotting”, see Figure B.64). Key holing (or slotting in rectangular valves) is caused by rapid and continual cycling of the tray valve.

Inspection of the valve legs and perforations is easiest from underneath the tray (see Figure B.65). Valve feet may cause indentation of the underside of the valve due to valve rotation while open. Such indentation is seldom of sufficient depth to warrant tray replacement; however, should the indentation on the underside reach half the thickness of the tray, replacement should be considered.

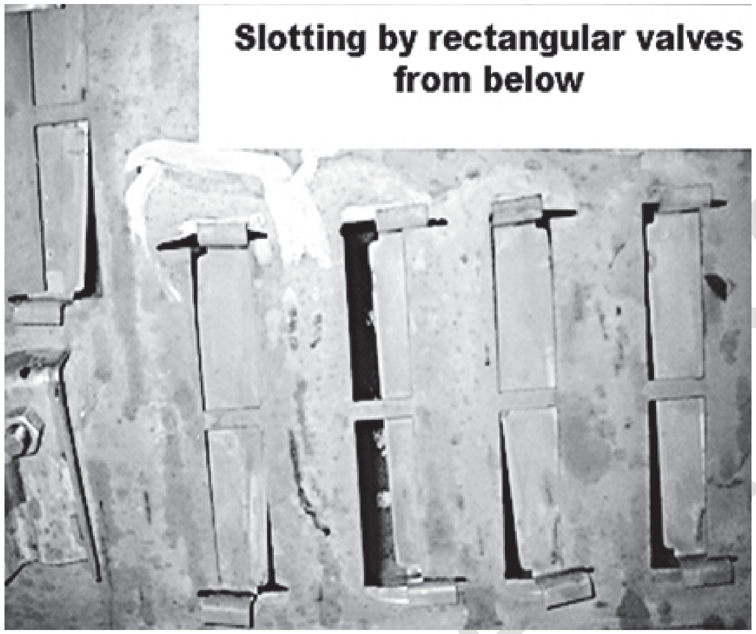


Figure B.64 - Slotting from Below

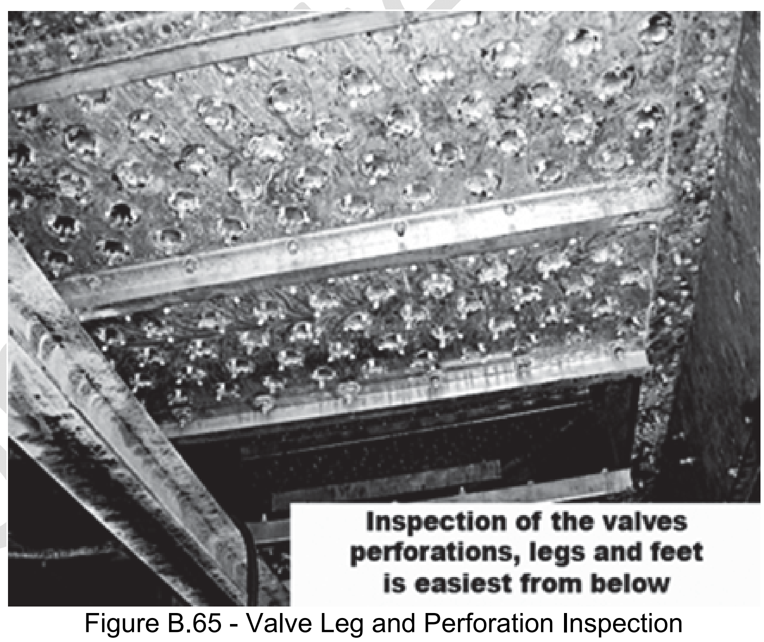


Figure B.65 - Valve Leg and Perforation Inspection

Some trays have anti-rotation tabs included inside the orifices. These tabs may be frequently found on perforations of round valves with key holing.

Moveable valves of all types should be manually checked for adjustment and/or thinning at each internal inspection.

Figure B.66 - Indentation of Valves

Round valves may be checked by pushing from below and shaking to attempt to push the valve “feet” into and through the valve perforation. Valves whose feet will enter the perforation are either worn out (see Figure B.66), installed in an enlarged perforation, or have leg/feet that have not been installed correctly. Properly installed and adjusted round valves have legs that don't touch the perforation when centered, and feet that have at least half the top length of the foot always in contact with the perforation edge when raised (see Figure B.67).

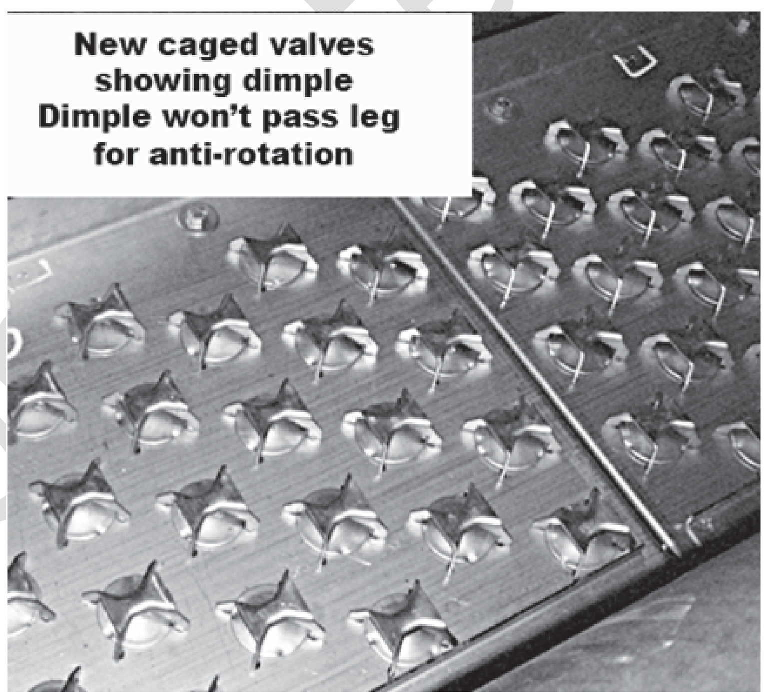


Figure B.67 - New Caged Valves with Dimples

Caged valves should have clean square edges. Most caged valve installations are done with valves without dimples. Inspection of the cage valves includes checking for fretting damage to the cage and/or the valve. Valves with worn edges should be replaced. Orifices should be visually inspected for out-of-roundness. Orifice edge profiles should be checked for vapor flow damage. If venturi-type orifices are present, check for scoring of the inner surface on the raised portion of the orifice. Cage installation should be checked by grasping the cage and lightly shaking the cage. Most cages are installed with small tabs run through the tray deck and bent/twisted.

When these tabs are not properly bent/twisted, the cage will come loose and allow the valve to escape (see Figure B.68). Corrosion of the cage tab or the tray deck penetration will allow cages to be removed in this manner. Cages that can be removed by hand may be replaced or adjusted to the limits of the cage and the tray deck to hold.

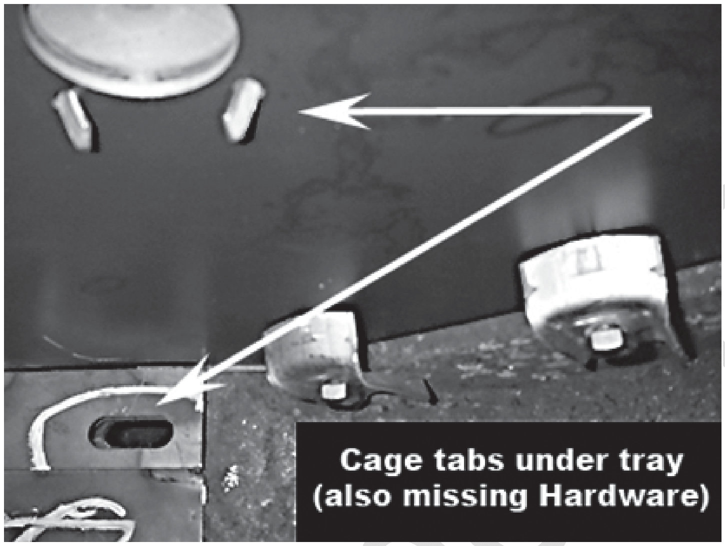


Figure B.68 - New Caged Valve Cage Tabs

B.3.5.2.2.1 Fixed Trays Valves

Fixed tray valves can be subdivided into two categories: those extruded from the tray deck itself and those that are removable. Removable fixed valves are fastened to the tray deck via tabs through the tray deck/perforation (see Figure B.69 and Figure B.70).

Extruded fixed valves come in a variety of shapes and sizes. Most fixed valves, both extruded and tabbed, are directional, e.g., the tray panel need to be installed with the valves facing a particular direction. As a general rule, one leg of the valve will be wider than the other. The wide leg goes toward the flow, and the thin leg goes with the flow.

Fixed valves are, by design, always open. Liquid bypassing is kept to a minimum by the design of the valve, i.e., by the wide end being toward the flow, causing liquid to impact and swirl out away from the perforation (open area) and by the lateral vapor flow from under the cap of the valve. This lateral vapor flow forces the swirling liquid away from the open area (perforation). Tapering of the fixed rectangular valve also imparts some directional impetus to the liquid. Valves that have three or more legs are generally nondirectional, and use the lateral vapor flow to prevent weeping, foster vapor liquid contact, and to suspend process particulates and detritus to reduce or prevent fouling.

Areas of interest to the inspector are the edges of the perforation and the edges of the raised cap. These areas are subjected to accelerated corrosion due to impingement of entrained liquids. To a lesser degree, these areas are also subjected to cavitation brought about by phase change of impacting entrained liquids due to high-speed vapor flow, particularly in vacuum towers. Such wear or corrosion will cause the valves to present a worn appearance at the edges of the perforation and cap. Overall, extruded valve trays are very robust and require little in the way of maintenance. Corrosion or wear of the cap and legs will create perforation growth and shrinking of the extruded cap and legs due to corrosion will eventually make replacement of the trays necessary.

Figure B.69 - Small Fixed Valves

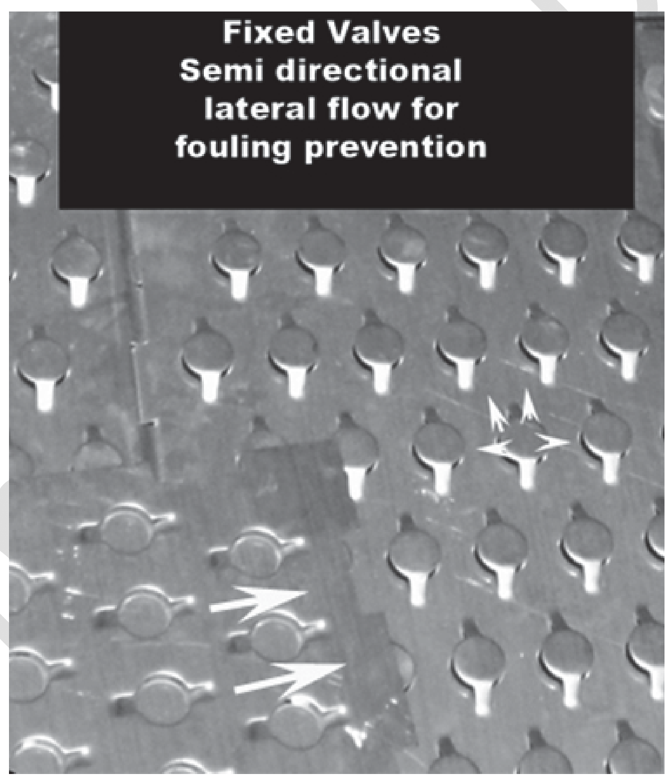


Figure B.70 - Fixed Valved Lateral Vapor Directional Flow

Removable fixed valves are directional valves, which typically provide enhanced liquid/vapor contact and resistance to fouling vs standard fixed valves (see Figure B.71). These valves are as a group more efficient but less robust than extruded valves. For tabbed valves, corrosion of the tabs or of the tab penetration and improper installation or handling of the tray decks may cause loosening of the valve and consequential side-to-side chattering of the valves in service, leading to blown valves and indentation damage to the tray deck (see Figure B.72).

Figure B.71 - Removable Fixed Valves Reduce Fouling

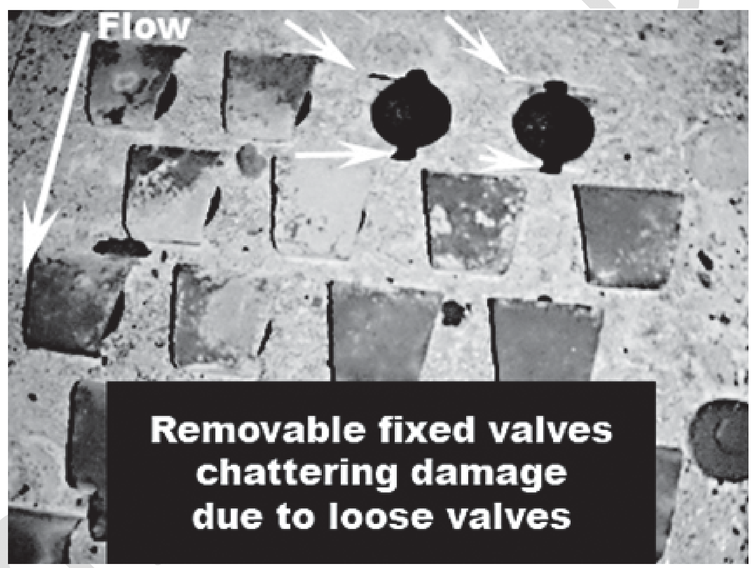


Figure B.72 - Removable Fixed Valves Tray Damage

Removable fixed valves that are fastened to the tray via the tray perforation (with wide legs) are less subject to loosening and hence less subject to chattering and indentation. However, due to the thinner-gauge metal used, they are subject to manual deformation. Care should be taken to prevent damage to these valves during maintenance and inspection activities.

B.3.5.2.2.2 Bubble Cap Trays

Bubble caps are very large fixed valves. Methods of mounting bubble caps to chimneys vary with individual designs, with bolting and tapered pins being the most common. Bubble caps come in three basic shapes: round (Mushroom caps, see Figure B.73), rectangular (brick or bread loaf caps), and (rarely) polygonal shaped caps. Tunnel trays use a type of modified bubble cap.

Bubble caps are designed in two basic configurations: with a skirt of bubble fingers descending to below the liquid level and solid caps in which the solid cap has a solid skirt that extends to below the liquid level. Solid caps are also known as FRI caps. Bubble caps are used in services where low liquid flow rates lead to long liquid residence time. Bubble caps are also used in severe fouling services.

Bubble cap trays are extremely durable. Properly installed bubble caps are very stable, with little or no maintenance required other than replacing the occasional cap broken or dislodged during tray opening. Bubble caps are subject to fouling of the chimney throat. Consequently, this fouling may not be readily visible and close visual inspection may be required across the entire tray bottom. Clearing of fouling by heavy and/or fibrous materials may require disassembly of the valve cap from the throat due to valve configuration (see Figure B.74).

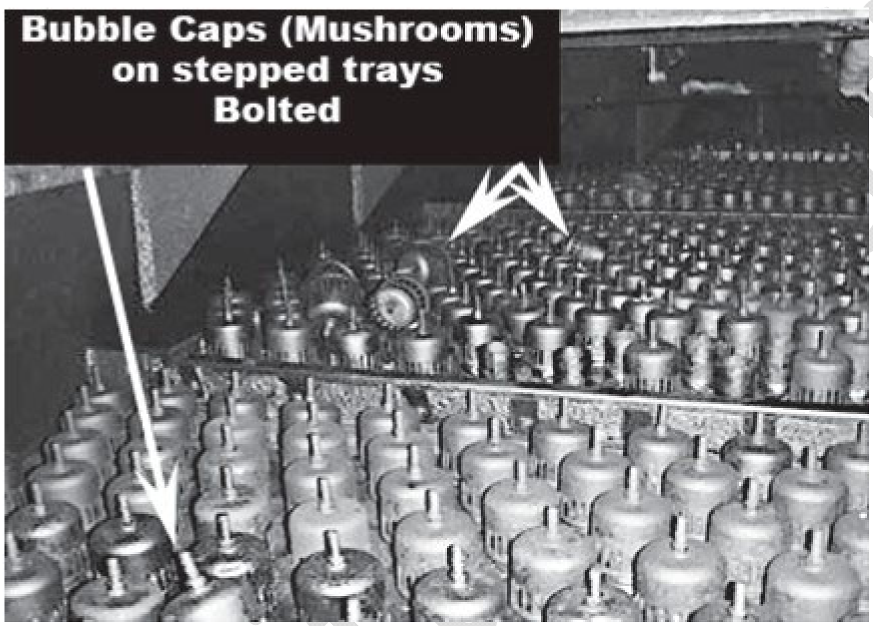


Figure B.73 - Bubble Caps on Stepped Trays

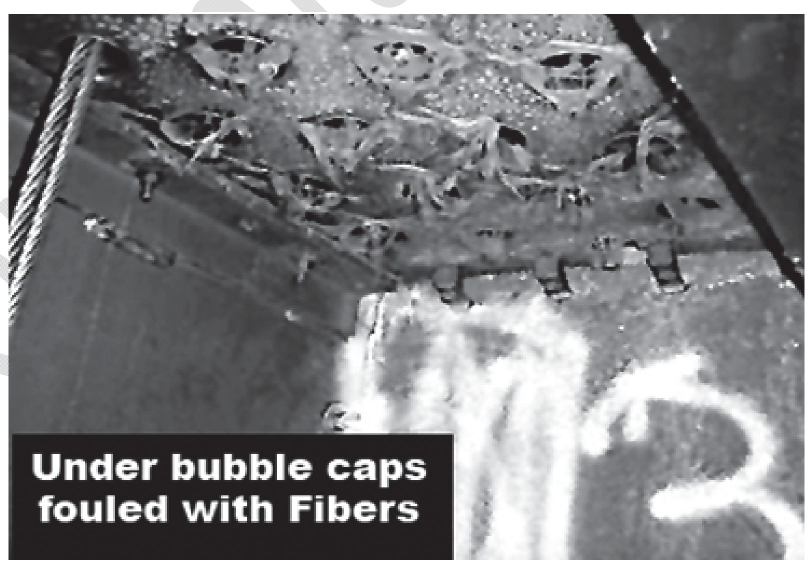


Figure B.74 - Fibrous Deposits and Fouling Under Bubble Caps

B.3.5.2.2.3 Tray Decks and Hardware.

Overall, tray deck corrosion and wear is usually fairly gradual when the areas actually impacted by the valves are not considered. Primary locations of concern are the active and inactive panels of deck, the weirs, the downcomer panels, and the hardware. Tray gasketing (if any) between the tray and ring as well as between the tray support ring and the tray deck itself should be inspected for gaps.

Corrosion of the tray panels may be generalized throughout the active and inactive panels if the tray is level. Random areas of the active and inactive tray panels should be scraped free of process residue and any process or corrosion scale (see Figure B.75). Note the presence of pitting or roughening of the tray panels. Bulging, sagging, and distortion of the tray panels may allow pooling or puddling of liquid corrosives that have precipitated from solution. Corrosive process deposits may collect in these areas as well. If present, these areas of corrosion are highly visible. Any disruption of the even plain of the tray deck should be scraped clear of process residue and any process or metallic scale for close visual examination for accelerated corrosion.

Many tray deck materials become embrittled under process conditions (i.e., 410 stainless steel in high-temperature processes). In addition, the vibrations of most modern valve trays may become pronounced under severe operating conditions, leading to cracking of the tray deck at support and stress points (see Figure B.76).

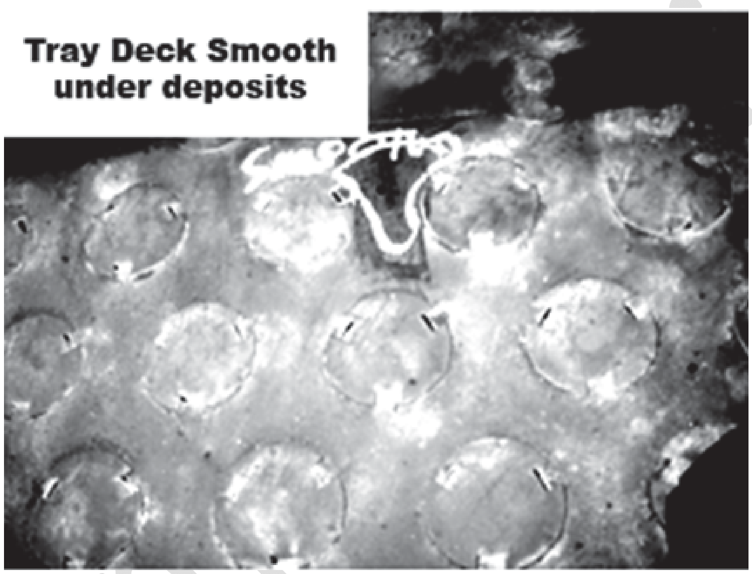


Figure B.75 - Tray Deck Should Be Scraped Clean

The aligned pinpoint corrosion at the breakover work hardened points is an example of the previously mentioned stress points. “Breakover” is a term used to describe the inflection point of a bend for formed products (see Figure B.77). Because of this, there is localized strain-hardening of the metal (usually on the tension side) that then can become more susceptible to corrosion due to the deformation in the grain structure and associated increase in hardness. Cracking of the tray deck is frequently adjacent to internal manway openings. Close visual inspection of these areas after wire brushing may be required to locate cracking.

Weirs and downcomer panels of cross-flow trays are subject to surface corrosion similar to that experienced by the tray decks (see Figure B.78), without the instances of pooling or puddling of corrosives mentioned above. Most damage or problems with downcomer panels are due to loose or missing hardware. Loose or missing hardware on downcomer anti-jump baffles or downcomer anti-vibration clips are the main point of failure for these tray components.

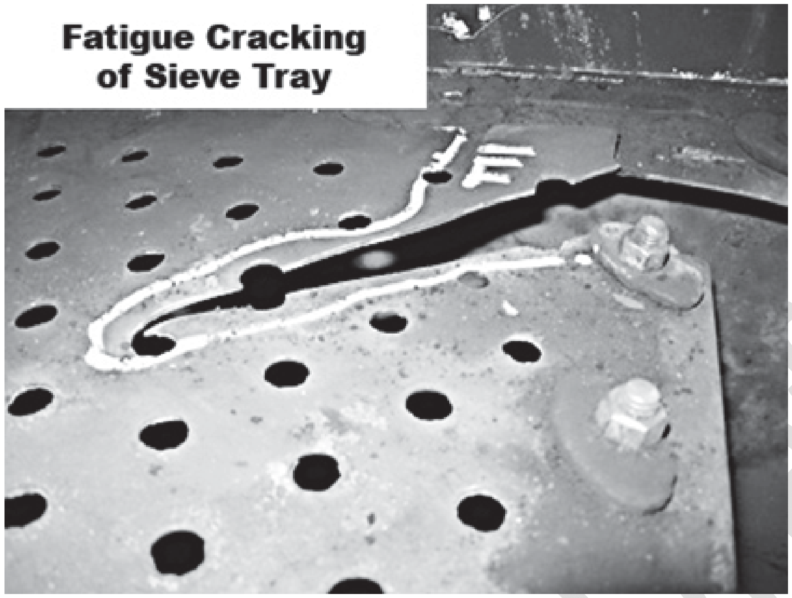


Figure B.76 - Tray Fatigue Cracking

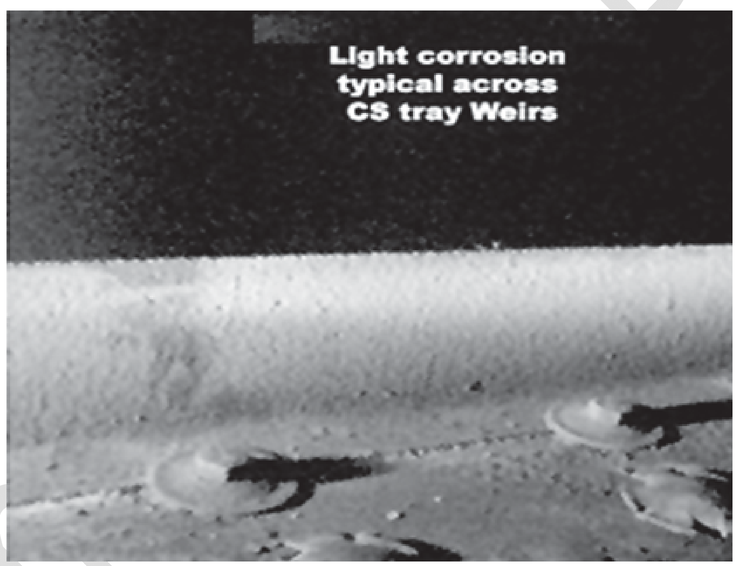


Figure B.77 - Light-to-moderate Weir Corrosion

Most hardware issues on trays result from mismatched hardware, i.e., carbon steel hardware installed instead of corrosion-resistant alloy hardware, hardware that is loosened due to tray vibration (see Figure B.79), galled stainless steel hardware, and improper installation. Inspection for loose hardware and hardware adrift on the tray decks is done by sounding of the tray and downcomer panels with a 4 oz to 6 oz ball peen hammer. When striking individual hardware, efforts should be made to strike the edges of washers as the washers will not gall (this also avoids damaging hardware).

Typical torque values for 0.375 in. (9.5 mm) tray hardware range from 10 ft-lb to 14 ft-lb (13.6 Nm to 19 Nm) and 0.5 in. (13mm) tray hardware torque values range from 18 ft-lb to 22 ft-lb (24.4 Nm to 29.8 Nm). Figure B.79 and Figure B.80 indicate areas that needed to be properly tightened. Particular attention should be paid to the intended purpose and location of hardware if direct contact with the hammer head is the preferred method of testing.

Figure B.78 - Loose and Missing Hardware Failure

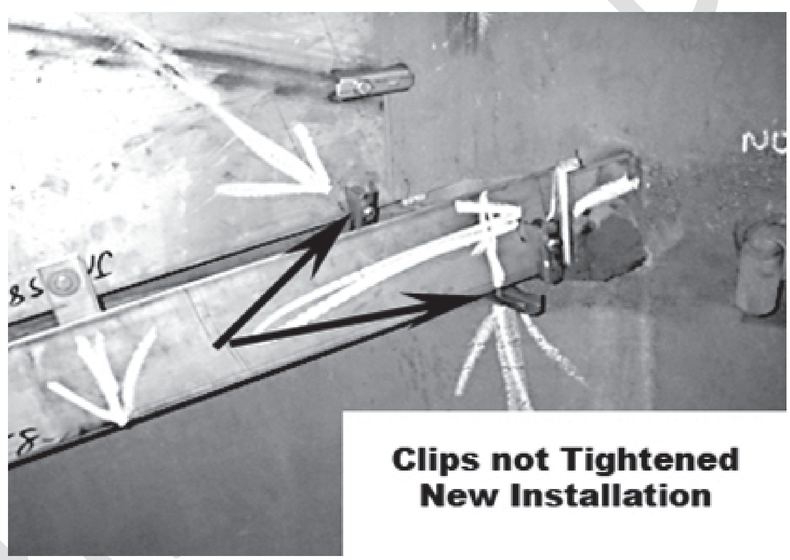


Figure B.79 - Downcomer and Seal Pan Clamps Loose

Tray clamps or clips are friction fittings, as is hardware in a number of other locations on the various types of trays. Movement of the washer/hardware/clip is to be expected. Friction clamps and hardware that do not show movement may have been over tightened.

B.3.5.2.2.4 Tower Attachments—Tray Support Rings, Support Clips, Downcomer Bars, etc.

Tray support rings are generally constructed of material that matches the shell or cladding material of construction. In towers that are clad with corrosion-resistant alloy material, tray support rings may or may not be constructed of clad material. The carbon steel tray support ring may be welded to the shell with carbon steel weld materials or it may be welded to the cladding itself, utilizing a compatible alloy welding rod. In towers constructed of corrosion-resistant alloy materials, carbon steel tray support rings may be welded directly to the shell with compatible corrosion-resistant alloy. Thicknesses vary with ring material, diameter, and applied corrosion allowance.

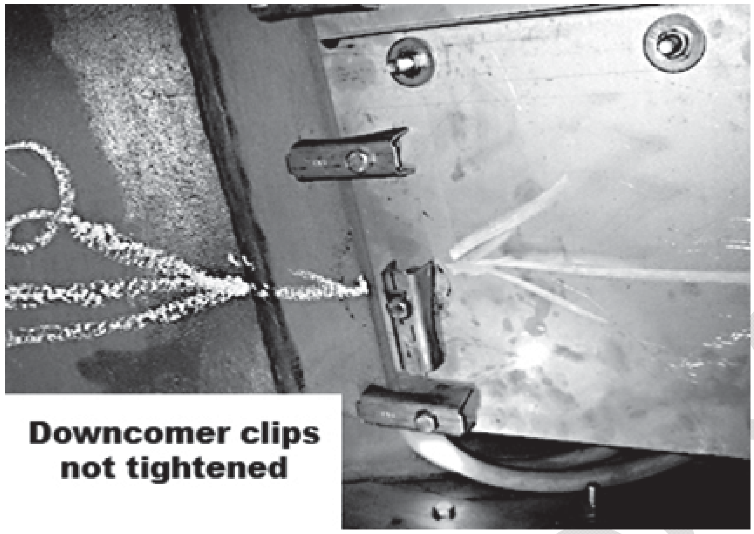


Figure B.80 - Downcomer Clamp Loose

Even with construction drawings and previous reports, direct visual confirmation of support ring attachment configuration may be the only way to ascertain how a particular ring or group of rings are attached. The tops of tray support rings (see Figure B.81), the tray support ring top side fillet welds, and the shell in this area are quite often the site of the most aggressive corrosion in a tower (see Figure B.82 and Figure B.83).

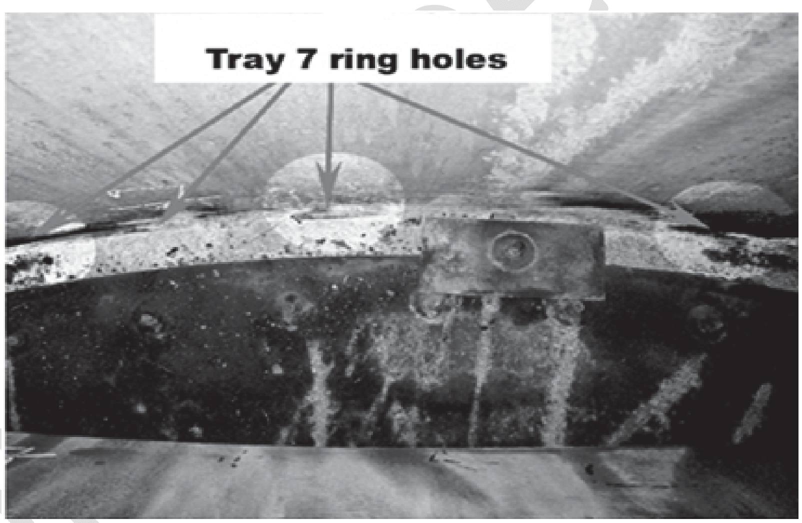


Figure B.81 - Tray Support Ring Corroded to Failure

The support ring and fillet weld are in the “liquid zone”. This allows any process debris and corrosion detritus that is not swept down column by the liquid flow of cross-flow trays to collect on top of the ring at the edge of the tray as shown in Figure B.84.

The tray support ring also supply's a horizontal surface (bound on one side by the shell and on the other side by the tray) for collection or puddling of any corrosives that may have precipitated out of process fluids. Corrosion of this type is often typified by bright orange colored corrosion residue on, and sometimes under, the ring (applicable to carbon steel support rings, see Figure B.85).

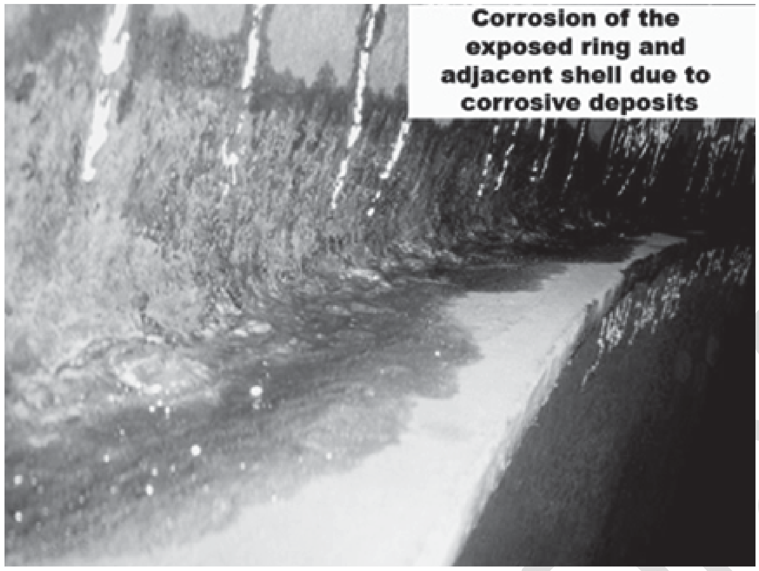


Figure B.82 - Shell Corroded to Half Wall Adjacent Top Three Rings

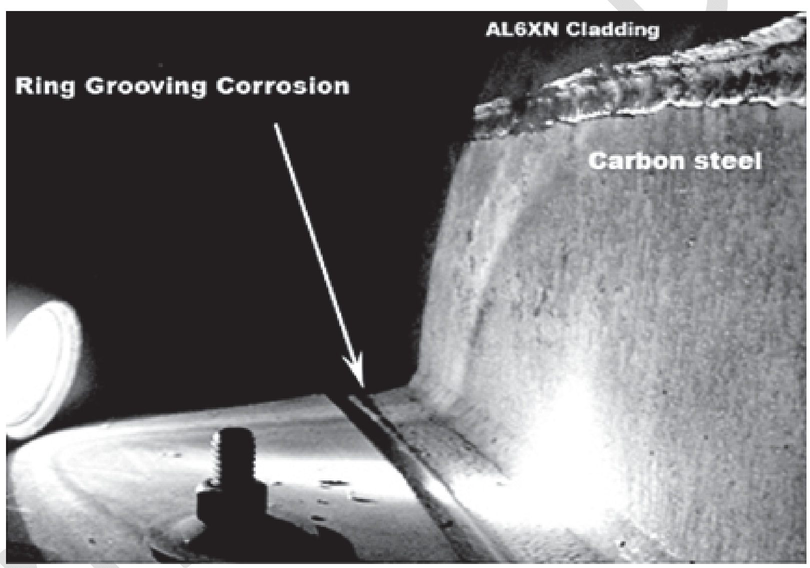


Figure B.83 - Support Ring Grooving

The area of a carbon steel ring covered by alloy tray decks may corrode under these conditions with little or no visual indications other than the above mentioned orange residue. If inspection of the ring between the tray and the shell shows localized corrosion to be present, consideration to removal of all or part of the tray to allow inspection of the previously covered ring surface, particularly where the possibility of formic acid precipitation exists.

Tray support ring upper and lower attachment welds are sometimes subject to localized corrosion in excess of that suffered by the shell or ring (see Figure B.86, Figure B.87, and Figure B.88). This preferential corrosion may be difficult to spot without wire brushing to remove surface debris and process deposits. Stitch welds are sometimes used to attach the lower side of the tray support ring to the shell. Cracking of these stitch welds is common. Careful examination of the stitch welds should be undertaken to check no crack propagation into the shell has taken place. Tray support ring butt welds are prone to cracking as well.

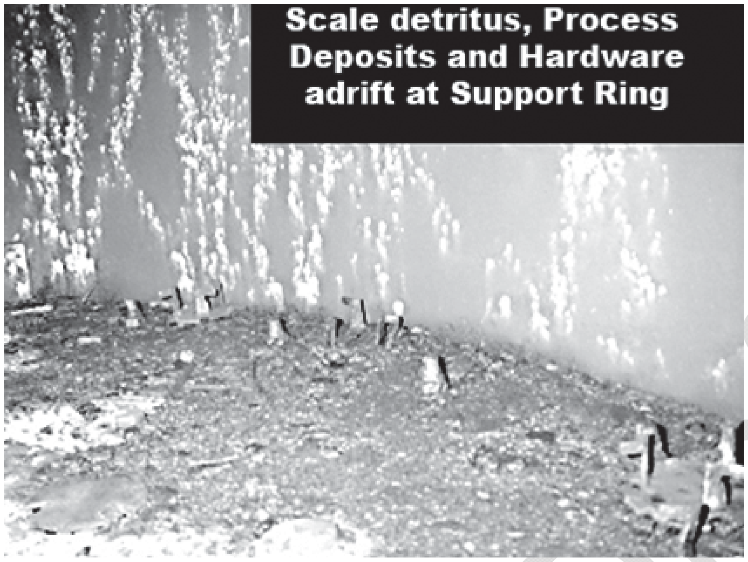


Figure B.84 - Deposits Adjacent to Shell Are on Ring

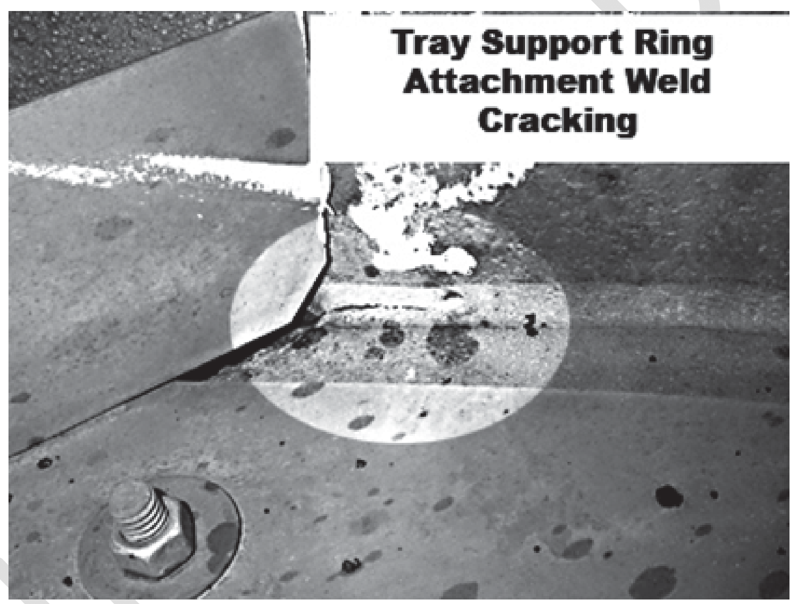


Figure B.85 - Cracking of Ring Attachment Weld

Propagation of cracking from this source into the shell is possible. When discovered, crack tip drilling may need to be performed if weld repair is not performed. If indications of corrosion between the shell and ring are present, such as corrosion residue leaking from between the stitch welds, additional NDE such as external UT should be considered. Tray support ring upper attachment welds are prone to cracking, particularly at the ends adjacent to downcomers. Careful examination of the welds should be undertaken to check no crack propagation into the shell has taken place.

If tray support rings are seal welded, close visual inspection/investigation of all possible breeches of the seal weld should be performed. Breeching of the seal welds may allow process fluids/deposits to accumulate between the ring and shell, leading to localized corrosion of the shell.

Downcomer attachment bars generally show corrosion characteristics similar to that of the shell. Downcomer bars are usually only welded on the outside edge due to the internal angle induced space limitations. The internal angle behind

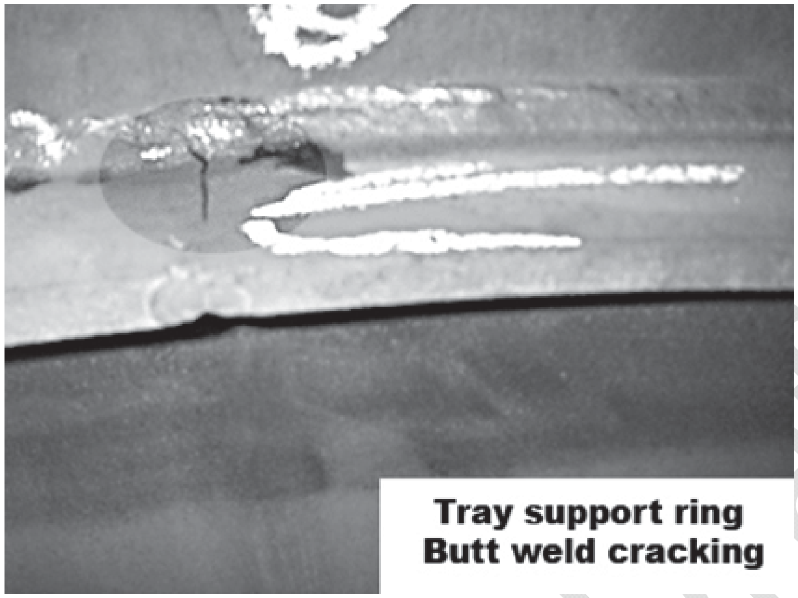


Figure B.86 - Breeching of the Seal Weld

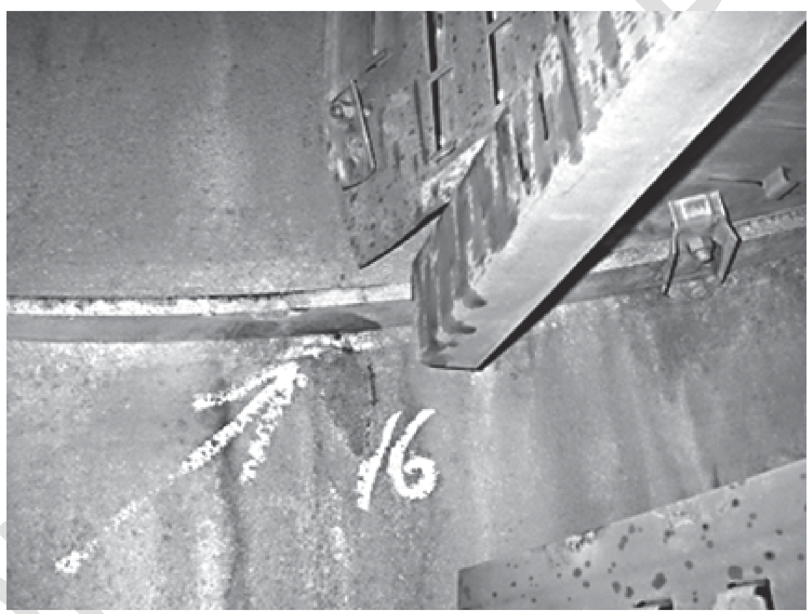


Figure B.87 - Breeching of the Seal Weld

the downcomer bar has the potential to develop contact or crevice corrosion and is subject to the buildup of possible corrosive deposits. This area may require additional cleaning. Downcomer bar attachment welds are sometimes prone to cracking at the upper and lower ends. Careful examination of the welds should be undertaken to check no crack propagation into the shell is present.

Support clips and lugs welded to the shell generally show corrosion characteristics similar to that of the shell/head. As with the above tower attachments, cracking of the attachment welds, and/or preferential corrosion due to bad welding metallurgy are the primary sources of failure.

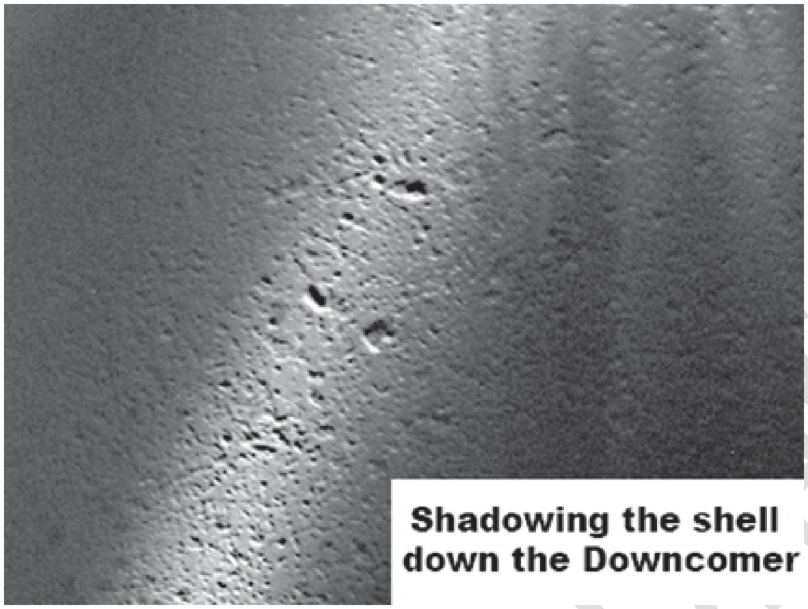


Figure B.88 - Shadowing Inside the Downcomer

B.3.5.3 Detecting Surface Corrosion in Towers

Corrosion in towers may be found at virtually every level and at any point of the circumference. When necessary, deposits should be removed by hand at a minimum of every other tray.

Shadowing the shell is a method of locating corrosion in these areas. The shell inside downcomers is the only location between trays where adequate room for shadowing exists (see Figure B.89 and B.98). This area should be shadowed at every opportunity.

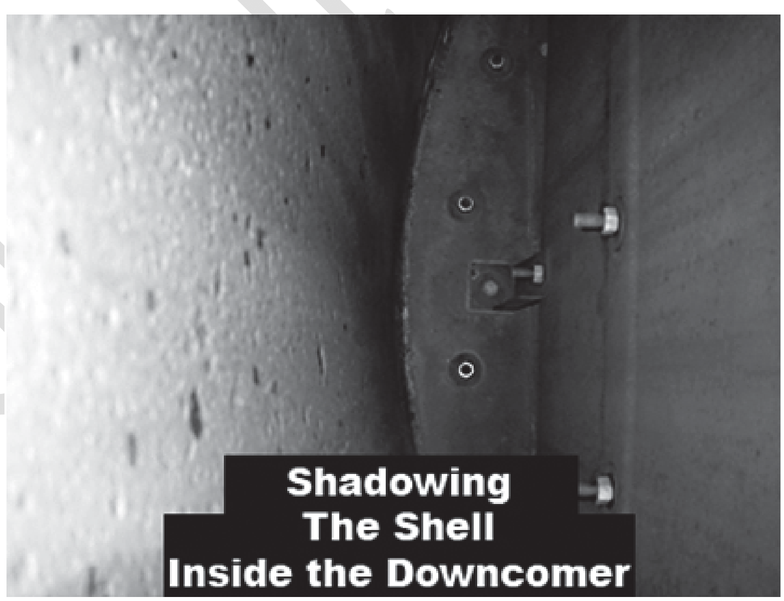


Figure B.89 - Shadow the Downcomer Shell Every Tray