# Mechanical and Operating Problems with Deaerators

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**KEYWORDS**

Deaerators, Deaerating Heaters, Feedwater, Dissolved Oxygen, Deaeration, Inspections

**ABSTRACT**

The paper provides examples of mechanical and operating problems with deaerators contributing to high dissolved oxygen and/or deaerator damage. Examples of mechanical problems presented include water entrainment in deaerator vent, failed baffles, erosion and flow accelerated corrosion (FAC) of deaerator vessel, too loose spray nozzles, too tight spray nozzles, leaking inlet water chamber, and failed trays. Detection and correction of the problems requires routine deaerator inspections.

## INTRODUCTION

This presentation focuses on direct contact steam heated deaerators for power and large industrial steam boilers which were inspected by the author. Some of the older deaerators relied on spray deaeration alone, and at least one deaerator relied solely on tray deaeration (no sprays). However, most of the experience obtained and related herein is based on deaerators using both sprays and trays. These are commonly called spray/tray deaerators.

## BASICS OF SPRAY/TRAY DEAERATION

Figure 1 presents a basic schematic of a spray/tray deaerator. Water enters an inlet distribution chamber which can be a hemispherical chamber with spray nozzles as shown or a large diameter pipe with spray nozzles mounted in the wall of the pipe. Water leaves the spray chamber typically through spring loaded spray nozzles, although one smaller power plant installed in the 1970s had fixed nozzles. The water spray creates a cone of small diameter water droplets which provides a large surface area for the water to heat up to the boiling point. The water then cascades down through a series of trays with an upward flow of steam. I recall one deaerator manufacturer design engineer telling me that the water actually reaches the boiling point by about the second tray down in the deaerator – although the point at which the boiling point is reached probably changes depending on the particular deaerator design, water inlet temperature, steam supply temperature, and load (total water flow). After deaeration, water flows to an integral water storage section, or more commonly, a separate deaerator storage tank (often called a feedwater tank).

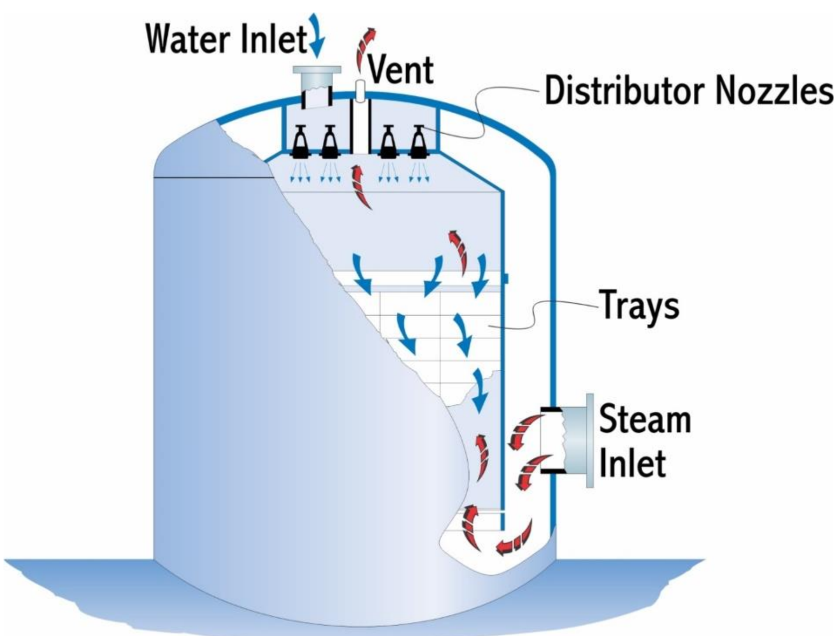


**Figure 1: Schematic of a Spray/Tray Deaerator Design**

Deaerators are direct contact heaters and for the deaerator to work as a deaerator, it must first work as a heater. The 1997 version of the ASME performance test code for deaerators (PTC 12.3) stated that the water temperature in the storage tank after the deaerator should be within 1

°C (1.8 °F) of the saturation temperature corresponding to the deaerator operating pressure. The NACE standard is more liberal and states that the water temperature should be within 1-2°C (2-4°F) of the saturation temperature (NACE, 2015).

The combination of the spray section and the tray section offer ample surface area and time for the noncondensible gases to leave the water phase into the steam phase. Figure 2 presents the solubility of dissolved oxygen at different pressures and temperatures. Basically, the solubility of dissolved oxygen in water is zero at the boiling point (212°F) at atmospheric pressure (0 psig – black line in Figure 2). As the pressure increases, the boiling point rises, so higher temperatures are required for deaeration. If the water is below boiling, the solubility of dissolved oxygen increases. The maximum solubility of dissolved oxygen in water at atmospheric pressure (0 psig) is at the freezing point (0 °C or 32 °F) and is 14.57 ppm (~14,570 ppb) as $O_2$.

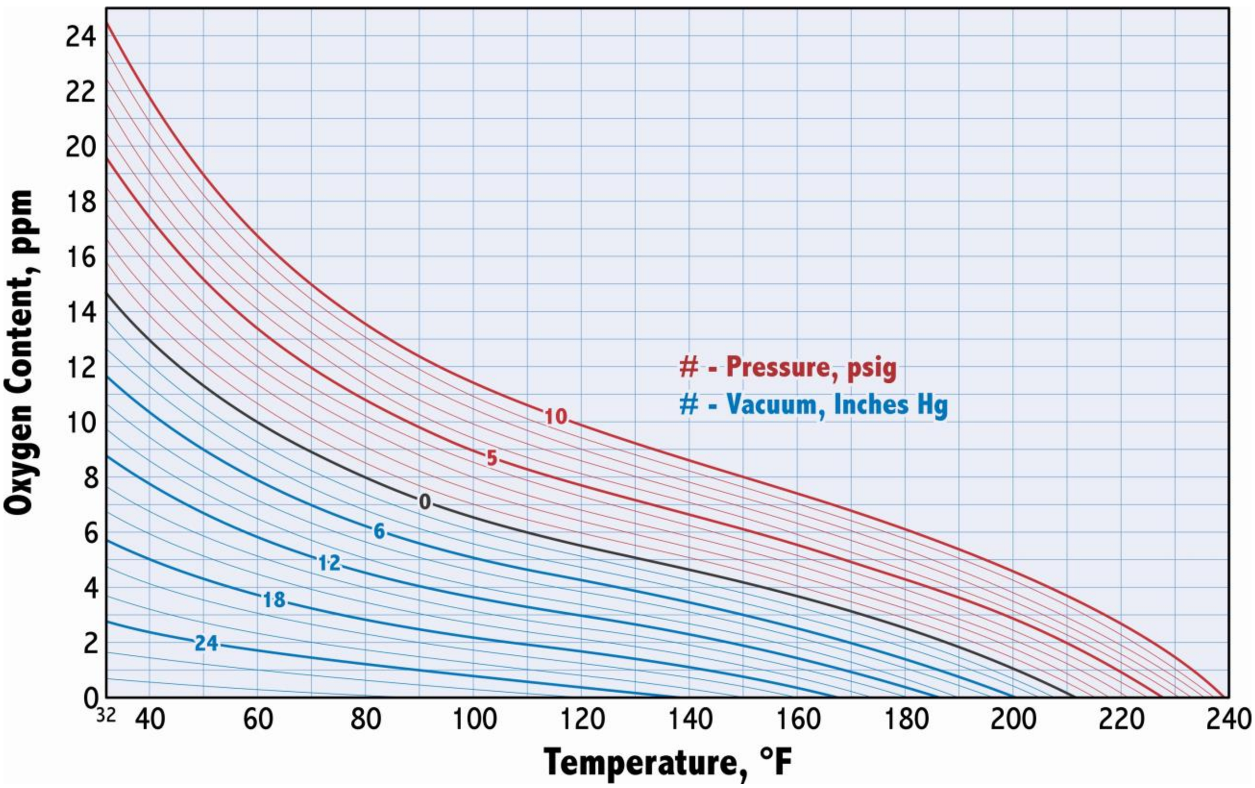


Figure 2: Solubility of Dissolved Oxygen in Water

The equilibrium level of dissolved oxygen in water also follows Henry's law of partial pressures, which essentially says that there is a limiting dissolved oxygen level in the water based on how much oxygen is present in the vapor phase around the water in the deaerator. Thus, one must purge the oxygen from the deaerator by venting or else oxygen will accumulate in the deaerator until no more oxygen can be removed from the water. The Heat Exchange Institute (HEI) specifies an effluent dissolved oxygen of 7 ppb at 10% to 100% of the design operating flow (2016). NACE indicated typical performances of 7 ppb for deaerators and 40 ppb for deaerating heaters (NACE, 2015)

## OVERVIEW OF PROBLEMS DISCUSSED

Table 1 summarizes the examples of mechanical problems which are briefly presented in this paper. Most of the problems can affect the effluent dissolved oxygen level achieved. However, some of the problems can directly cause damage to the deaerator pressure vessel wall and one problem can lead to contamination of the feedwater with impurities. In softened water or other applications with significant levels of salt in the feedwater, poor deaerator performance also can lead to corrosion and cracking of a deaerator, but that was considered a potential secondary effect of high dissolved oxygen and so is not also listed in the table as necessarily affecting the deaerator tank wall.

Table 1: Example Problems Discussed in Paper

| Example Problem Discussed | Increased Dissolved Oxygen | Damage to Deaerator Vessel Wall | Contaminated Feedwater |
|---|---|---|---|
| Water Entrainment in Deaerator Vent | X | --- | --- |
| Failed Baffles | X | X | --- |
| Erosion of Deaerator Vessel | --- | X | --- |
| Too Loose Deaerator Nozzles | X | --- | --- |
| Too Tight Deaerator Nozzles | X | --- | --- |
| Fluctuating Inlet Water Temperatures | X | --- | --- |
| Damaged Inlet Water Chamber | X | X | --- |
| Failed Trays | X | --- | --- |
| Failed Grating, Supports or Traybox Components | X | X | --- |
| Leaking Manway Door | X | --- | --- |
| Contaminated Steam | --- | --- | X |

## STANDARDS AND DISCLAIMERS

This paper focuses mainly on the internals within a deaerator. However, deaerator storage tanks and to a lesser extent heaters can be subject to cracking and failure at the welds, which has caused fatalities (NACE, 2015 and National Board, 1988). Standards for the prevention detection and correction of this cracking in the vessel walls are not covered herein, but are available from NACE (NACE, 2015). The HEI has guidance on the design of deaerators (HEI, 2016) and the ASME has guidance on performance tests (ASME, 1997). Information on risk-based inspections is available from both ASME (2015) and EPRI (2010). Information on assessing pressure vessel integrity or fitness for service is available from ASME (2007). Repairs to pressure vessel walls are covered by a separate ASME document (2012).

## VENTING PROBLEMS: WATER ENTRAINMENT IN DEAERATOR VENTS

I recall being trained with a set of Polaroid photographs of a deaerator vent with a large (maybe 8-10 feet (~2-3 m) high plume of steam from the vent and producing about 8 ppb of dissolved oxygen. When the orifice was changed and the vent plume was reduced to a 2-foot high plume, the effluent dissolved oxygen was reduced to 2 ppb. Thus, in that case less vent flow actually produced a lower dissolved oxygen level. Therefore, initially, I was trained to try to achieve a steady 2-foot high plume of dry steam as the first step in deaerator troubleshooting. The NACE standard (2015) also states "….. In many cases, the plume height should be 0.6 to 0.9 m (2 to 3 ft) out of the top and consist of 150 to 460 mm (6 to 18 in) of clear space next to the deaerator vent. No entrained water should be present in the vent." However, there have been many deaerators that seem to perform fine with greater venting flow rates. The key is to conduct deaerator performance tests to figure out if your deaerator works the better at a lower venting rate. Also, you may be unnecessarily wasting steam with a high venting rate.

The 1997 deaerator performance test code did not specify a vent plume height, it only specified that the vent flow be stable. If the deaerator vent flow pulses, this indicates a deaerator maintenance or operating problem, which should be investigated as it can lead to performance issues.

If you are in a very cold climate and/or have a really long vent line, condensate can form on the walls of the vent line, run down to the orifice plate, and form a water block over the top discharge side of the orifice. This can lead to a sudden cessation of vent flow. In one case, greater than a 1-foot thick accumulation of ice formed on the roof of a building in Canada due to this problem being encountered during a new deaerator installation. This was corrected by drilling a 0.5 inch drain line in the side of the vent line just above the orifice plate. This drained off the condensate before it could accumulate to the point that it would stop the steam flow and then be flung up to the roof.

The vent flow directly impacts deaerator performance and efficiency and is the one variable that operators have some discretion in controlling. Also, the appearance of the vent may indicate things that could be checked and fixed during routine deaerator inspections.

## POWER PLANT EXAMPLE

Figure 3 shows the vent plume from a deaerator at a power plant with 2000 psig boilers that had water entrainment in the deaerator vent. The boilers had copper alloys in the condensers and heaters and required dissolved oxygen levels <5 ppb and the feed of reducing agents (hydrazine). They also had a deaerating condenser, but sometimes they had leaks on the condensate pumps which severely tested the deaerator and contributed to high consumption rates of hydrazine and sometimes high feedwater dissolved oxygen levels. The amount of water droplets shown in the vent line was indicative of a possible problem with deaerator internals.

Figure 3: Example of Moderate Water Entrainment in Deaerator Vent

At this facility, there were several problems found in both deaerators that could have led to the water entrainment in the vents. In each deaerator, the inlet steam baffle was blown off its fittings (e.g., Figure 4) and the swing door (e.g., Figure 5) on the traybox was blown off the traybox at the steam inlet end. Figure 4 was photographed by looking out the traybox door in Photograph 5. During operation, it is likely that steam was blasting through the door, across the water sprays and some of the droplets from the water sprays were probably entrained up the vent lines.

Also note the numerous cracks in the traybox wall in Photograph 5. This is a common problem with thin-wall stainless steel trayboxes. In some cases a crack may form and then stop without being repaired. Depending on the severity, history and success with past repairs, cracks may be welded or sections may be replaced. Cracks on various carbon steel supports underneath the traybox also are commonly experienced.

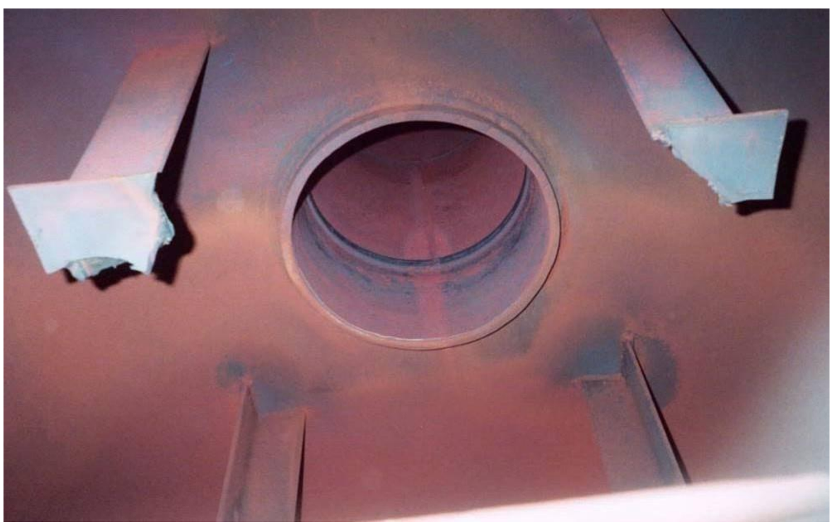

Figure 4: Example of Failed Steam Inlet Baffle

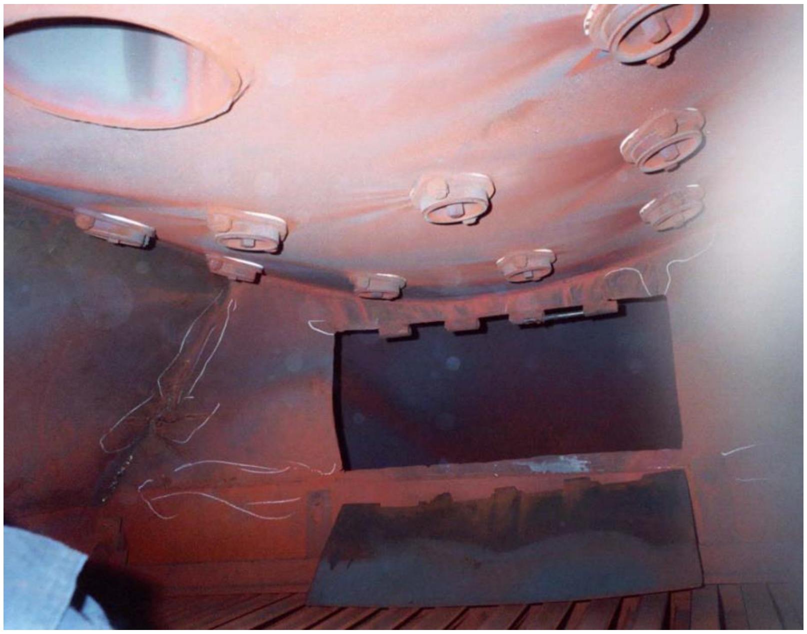

Figure 5: Example of Failed Traybox Door

Initially, these deaerators had a problem with water spraying from leaks in the water inlet chest in similar locations as those in Figure 6. This area is viewed by lying on your back on the trays and looking up the vent pipes through the water inlet chest. The red areas are where oxygenated water leaks from the water inlet chest. Actually, there were two sister units and when we first inspected them, welding repairs were made in this area due to much more significant leaks than shown in Figure 6.

Figure 6: Example of Water Spraying From Water Inlet Chest Into Vent Offtakes

**PULP AND PAPER MILL DEAERATOR**

A second facility was at a pulp and paper mill with a 780-psig black liquor recovery boiler with demineralized makeup and a number of power boilers sharing a common deaerator. The deaerator was not made available for inspection during past routine boiler outages because they liked to keep at least one boiler operating. Figure 7 shows the exterior of the deaerator. It happens to be not running at the moment, but we did not get a chance to actually inspect the deaerator. No information on the deaerator design was available. At some point, a cyclone separator had been installed on the deaerator vent line (above and to the right of the deaerator heater section) in response to the amount of water flowing out the vent during operation.

Figure 7: Deaerator Vent with Cyclone Separator on Vent

When this deaerator ran, before internal repairs, there was a continuous stream of water out the bottom of the separator and steam out the top. The deaerator had horrible performance. Despite a high feed of sodium sulfite, they obviously were not able to consistently control dissolved oxygen and severe dissolved oxygen corrosion occurred in the economizer inlet tubes during operation. They were not monitoring feedwater dissolved oxygen prior to our review. Sulfite consumption indicated a feedwater oxygen level of 344 ppb $O_2$. Figure 8 shows the dissolved oxygen tubercles which formed in the entrance off the economizer inlet header in the first pass economizer tubes. The economizer tubes in this unit were vertical.

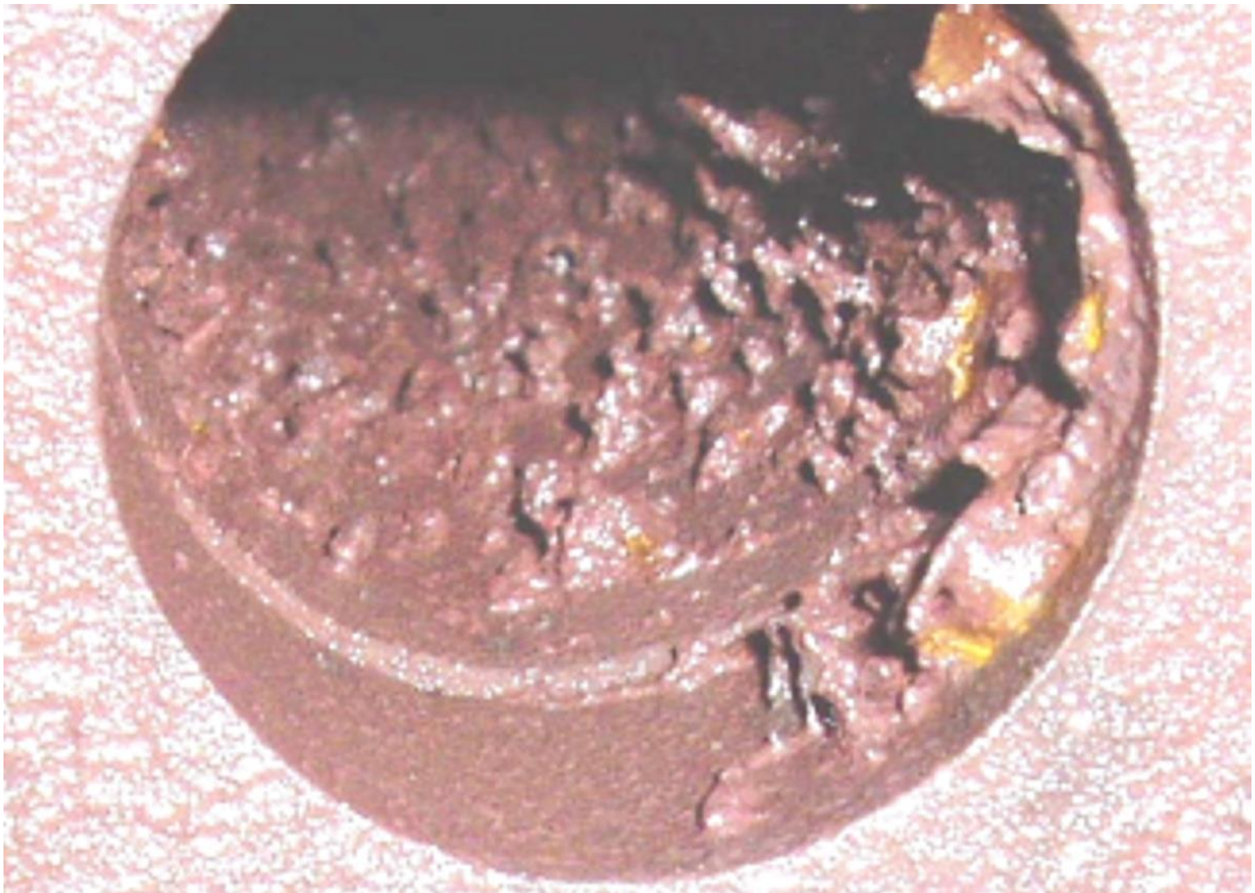

Figure 8: In-service Oxygen Pitting in Economizer Tube

Incidentally, this economizer was chemically cleaned and passivated, the 1-inch diameter carbon steel sample lines for feedwater were replaced with stainless steel tubing, dissolved oxygen analyzers were installed on the feedwater, the deaerator was repaired (again, details were not available), and – reportedly – control of the feedwater dissolved oxygen was achieved for at least a while.

While we are discussing vent flow rates, it is cautioned that if you perform heat recovery before the deaerator resulting in higher deaerator inlet temperatures, your steam demand to heat the water to the boiling point in the spray section may decrease and not necessarily provide sufficient steam flow through the tray section. Therefore, if the deaerator inlet temperature increases, you may need a higher steam venting rate from the deaerator in order to have enough steam flow through the tray section. This could impact units operating at low loads as the spray section can be less effective at low loads and the tray section can be more important under low load conditions.

High performance deaerators used for high pressure boilers typically have been specified to provide very low effluent dissolved oxygen levels, but not everyone specifies the HEI and NACE design limit of <7 ppb dissolved oxygen in the deaerator effluent. Actual design limits for the effluent of these deaerators have been most commonly listed as one of the following: <5 ppb, <7 ppb and <10 ppb. Some old deaerators have less restrictive dissolved oxygen specifications (e.g., <40 ppb. As discussed earlier, NACE refers to these poorer performing deaerators as deaerating heaters rather than deaerators.

A continuous flow from the deaerator vent normally is required to keep the partial pressure of noncondensible gases very low and achieve the desired level of deaeration. Therefore, do not install steam traps in lieu of a continuous flow of steam from the deaerator vent as steam traps may allow the levels of noncondensible gases to accumulate to a level that could interfere with oxygen removal and heat transfer. If you want to recover the energy lost in the deaerator vent, an external vent condenser should be installed.

Finally, there are all-steel cycles with high efficiency deaerating condensers that provide inlet dissolved oxygen levels of <5 ppb to the deaerator. In such facilities, provided the makeup is demineralized (and the condensate is equivalently pure) the plants need to operate with the deaerator vent closed in order to avoid excessively low feedwater dissolved oxygen levels, which can contribute to flow accelerated corrosion (FAC). FAC from low dissolved oxygen concentrations is mainly only a concern for high pressure power industry boilers with very pure makeup and condensate and which rely solely on ammonia or amines for elevation of the feedwater pH

## DEAERATOR NOZZLES

Deaerator nozzles need to be set at the correct spring tension to provide the desired, even distribution of water throughout the deaerator. At least from some suppliers, the deaerator nozzles are not set at the factory for a particular deaerator's design condition. On some deaerators, the spring tension for each nozzle should be set on site before it is installed. Nozzle spring tensions usually are set by adjusting a nut on the spray nozzle. I have heard reports that some deaerator nozzles actually have an eye that enables using a hanging weight to set or verify the proper spring tension. However, for many common nozzles there is physically nothing on which to hang a weight to check the spring tension. We recall one such nozzle in which the design information specified that the nut for the spring should be set to a certain number of exposed threads to achieve the design spring tension.

## WORN SEATS AND TOO TIGHT NOZZLES

Figure 9 shows a nozzle (circular plate in middle) and seat after the first year of operation of a new deaerator. The plant elected to install the spray nozzles themselves rather than pay to have the deaerator manufacturer install them and all of the nozzles were too tight. The plant had just installed the spray nozzles without adjustment as they were received from the manufacturer. Operators reported that the deaerator made a chattering noise when it operated. The nozzles were so tight that the nozzles had to push open let some water out and then slam shut. Pushing the water through a compressed orifice eroded the side of the nozzle seat. Eventually, the springs probably failed from high cycle fatigue. Thus, not only was the seat eaten out (see blue arrow), but the nozzle failed. During an inspection also check that the seats are firmly attached to the inlet chamber.

Figure 9: Example of Eroded Seats Due to Nozzles Being Too Tight

**LOOSE OR DEFORMED NOZZLES**

A more common problem in operating deaerators is loose (Figure 10) or failed nozzles. During routine inspections, it is standard inspection practice to snap (pull down and release) each nozzle and ensure that they have similar spring tensions. Over a number of years of operation, some nozzles will no longer reseat flush or snap back as firmly. This is attributed to spring deformation. When this occurs the nozzle should be replaced as you need a water spray of small droplets not a deluge of water flowing through a few nozzles.

Figure 10: Loose/Deformed Spring

At one of the more recent deaerator installations we inspected, we circled 11 nozzles that were found to be noticeably looser than the other spray nozzles. Interestingly, the deaerator manufacturer said that they actually specified 11 looser nozzles. They did not provide an explanation, but it is expected that this may have been to provide a vent space to relieve pressure from the deaerator back into the water inlet chest during a trip. This design had no inverted nozzles in the water inlet chest.

## INVERTED NOZZLES

Following a collapse of the inlet water chest at some facilities, a small proportion of the spray nozzles were inverted (Figure 11) to relieve the pressure differential across the inlet water chest during a trip.  It is cautioned that you should not invert more than a few percent of the nozzles because when you invert a nozzle you increase the water flow that needs to go through the remaining nozzles. If you are nozzle limited, it may be preferable to increase the total number of nozzles in order to install a few additional inverted nozzles rather than invert the nozzles you have.

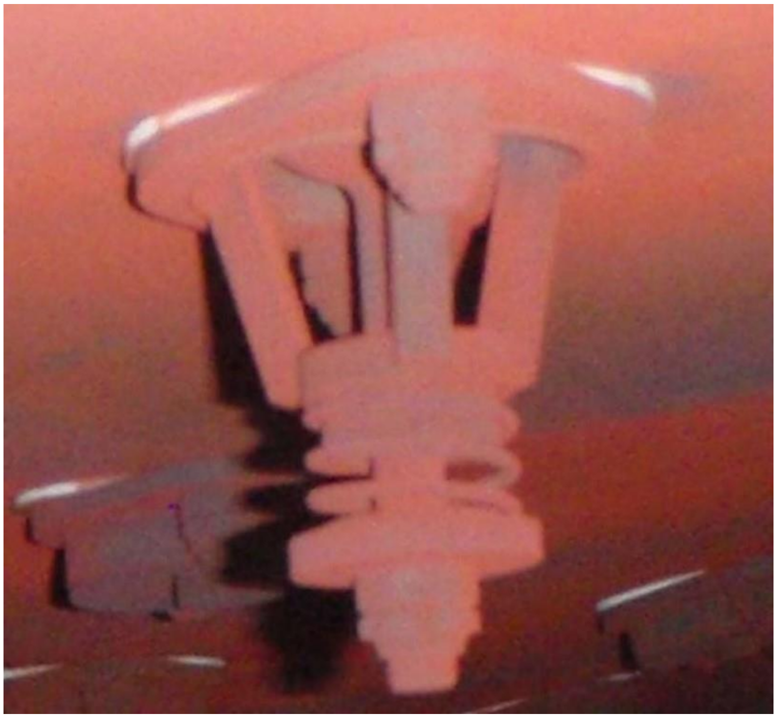

Figure 11: Inverted Nozzles

## NOZZLE GASKET FAILURE

In addition to checking for loose or tight nozzles and loose seats, it is suggested to check the condition of the gaskets between the seat and the water inlet chamber. The gaskets are typically thin Teflon and they can experience leakage. The leakage can cut the gasket and cause gasket failure. Gaskets also can be sucked up into the water inlet chamber during a trip which will leave a large gap between the nozzle seat and the inlet chamber. Thicker Teflon gaskets have seemed to work better when replacing nozzles because you get a tighter seal which is less subject to leakage and failure.

## FAILED INLET WATER CHEST

Figure 12 shows an example of a failed inlet water chest within the traybox. This chest had failed on a number of occasions and was repaired by welding (see blue arrows). Inverting a few nozzles seemed to alleviate the problem. Deaerator manufacturers have sturdier designs of water inlet chests that are based on thick wall pipes rather than thin wall stainless chambers. An example is provided later in this presentation.

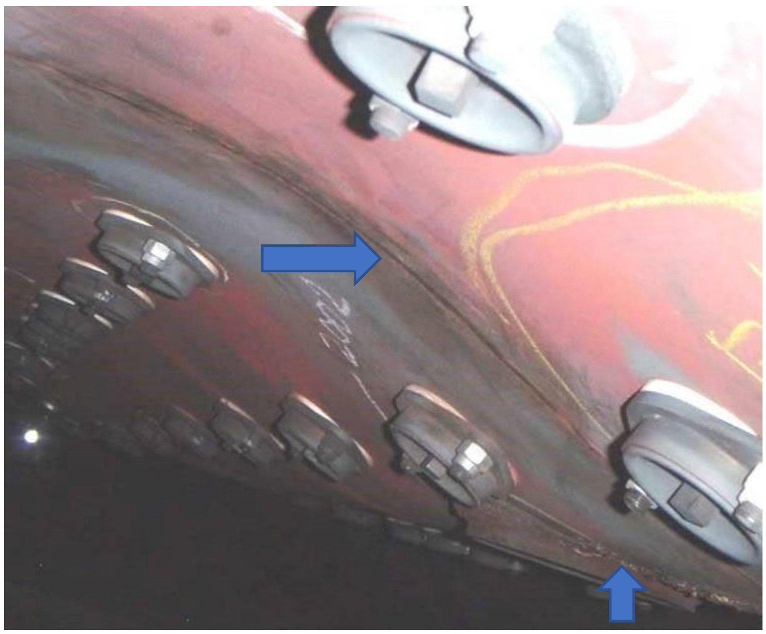

Figure 12: Failed Inlet Water Chest

Figure 13 shows a more problematic type of failure of the inlet water chest. The water inlet chest was torn and was spraying outside of the traybox. The top of the deaerator is the right side of the photograph, the traybox exterior is the bottom of the photograph and the wall of the vessel is the top of the photograph. The cold inlet water was spraying along the vessel wall. Inlet steam is drawn to the cold water and flow accelerated corrosion (FAC) of the wall occurs. No oxygen scavengers had been fed for years and the deaerator vents are usually kept closed because the inlet and feedwater oxygen levels do not require venting to achieve their feedwater dissolved oxygen limits. This type of failure is much less common.

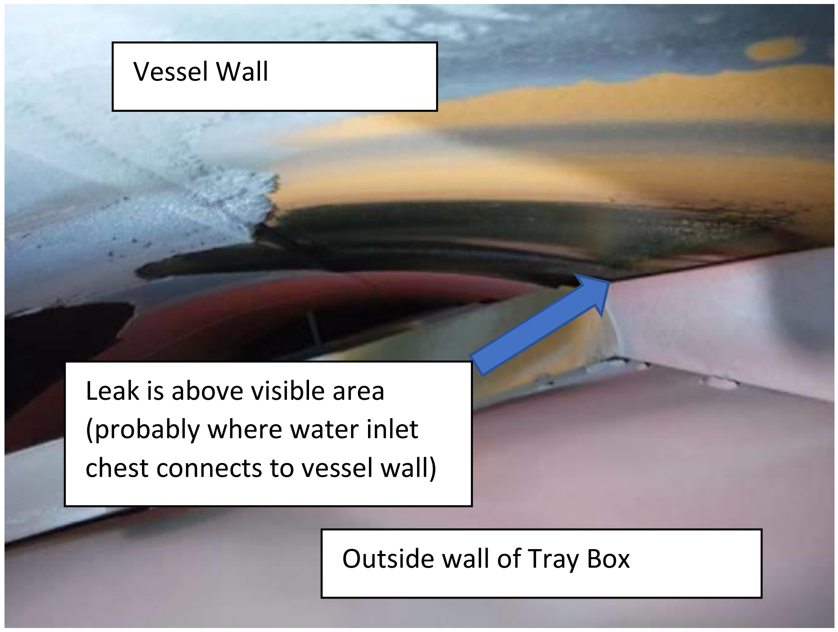


Figure 13: FAC of Wall from Failed Inlet Water Chest

## FLUCTUATING INLET WATER TEMPERATURES

A fluctuating inlet water temperature can cause thermal cycling of the water inlet chamber. While we could not locate a write-up of the failure, Mr. Poole (deceased) reported that this caused the inlet water chamber to experience thermal fatigue cracking and failure at an industrial facility many years ago when a cold stream and a hot stream were mixed just before entering the deaerator. Newer facilities either perform heat recovery and blend such streams in a tank before entering the deaerator or design the deaerator with separate spray headers for the two streams.

Figure 14 shows an example of a deaerator for a 1250 psig sawdust fired boiler at a pulp mill that has two separate pipe style spray headers. One header receives condensate and the other spray header receives demineralized makeup. The pipe style of spray headers is much sturdier than the water inlet chest design and inverted nozzles are not required for these spray headers. However, we have seen a discussion that suggested that the stainless steel pipes going through the water inlet chest may serve as a partial vent condenser. Thus, before changing the water inlet header design consult a deaerator manufacturer to determine if other changes may be required.

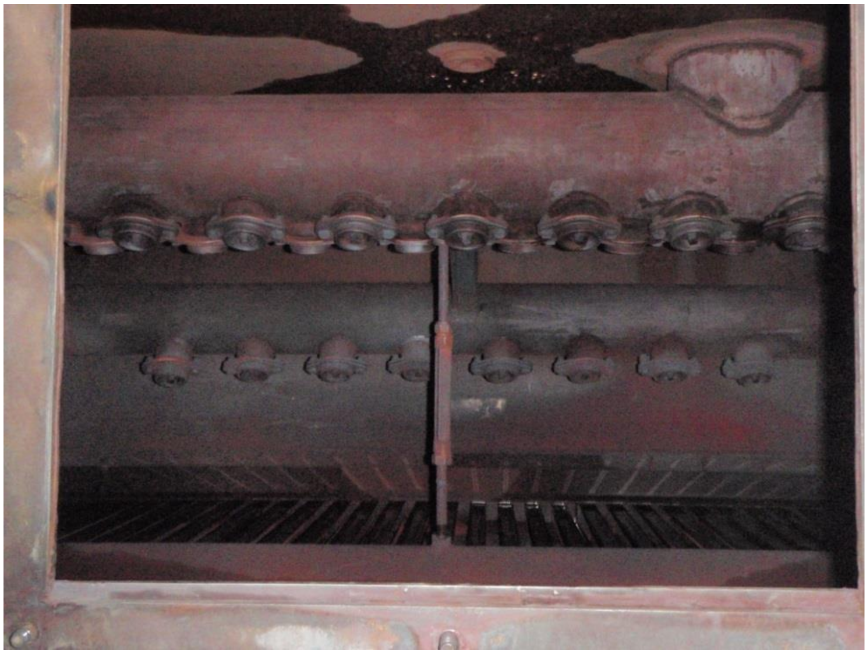

Figure 14: Dual Pipe Inlet Water Distributors

## FAILED TRAYS

Sudden trips of the unit can result in reverse flow in the deaerator. Depending on the deaerator design, this can cause the trays to lift and pull out of their supports, damage the traybox, and warp the water inlet chamber.

some of the deaerators installed in the 1950s, had tracks on the sides of the traybox and long, narrow trays were fed into the tracks. These had systemic problems of tray failures. Figure 15 shows an example of one of these 40-year old deaerators with numerous failed trays.

Figure 15: Failed Single Trays

In modern deaerator designs, the trays are usually either in riveted bundles or much bigger and more firmly supported. In the power industry, the trays usually consist of bundles of small stainless steel trays. These are fairly sturdy, but top trays within the bundles can snap off (Figure 16) as a result of large personnel working in the tray section to effect repairs on spray nozzles. If it is just a couple of trays within one bundle, it is not expected to have a significant effect or require immediate repair. In this case, it is my recollection that the welder attempted to temporarily tack-weld the riveted trays in place. However, this is thin wall stainless and replacement of the affected tray bundle is more expeditious.  These modern tray bundles are usually very well supported and a significant failure of the trays is rare. In modern spray/tray designs, there are usually vertical stays and horizontal hold-down braces on top and steel grating under the trays.

Figure 16: Snapped Top Trays.

Routine maintenance for trays typically just consists of basically ensuring all of this hardware is in place. Standard hardware includes the horizontal holddown braces (shown on top of the trays in Figure 16) and vertical stays that are used to align the tray bundles (not shown). When not fully in place the tray bundles can lift and become misaligned.

There have been a few cases where a partial collapse occurred and removal and realignment and partial replacement of a number of bundles was required – as shown in Figure 17. More important than the fact that two separate bundles had slipped down off the supports, all of the tray bundles in Figure 17 were upside down. The concave side was facing down rather than up. Standard designs have the trays installed such that they retain water to maximize the time for deaeration in the tray zone.


Figure 17: Complete Bundle Removal Required

There are other types of fill used in industrial deaerators. Basically the deaerator is a packed tower and the process industry will sometimes use stainless steel fill rather than actual trays in the deaerator.

## FAC AND EROSION OF DEAERATOR FLOOR

A common problem in high-pressure, all-steel power boiler cycles relying on ammonia for feedwater pH control is flow accelerated corrosion (FAC) of the floor. In some cases the erosive forces are great enough that erosion rather than FAC occurs. Figure 18 shows an example of erosion of a deaerator floor and Figure 19 shows an example of FAC of the deaerator floor. The chemistry program was subsequently changed to raise the ammonia and pH and to change from a reducing program to a slightly oxidizing treatment program to reduce FAC, in the unit. While the changes reduced FAC in the storage tank and other areas it did not seem to result in passivation of this area. The deaerator manufacturer installed baffles on the sides of the equalization lines to raise the water level on the floor. This had no effect on the attack. Allowing the door on the traybox to swing freely and operating at lower load (due to lower power demand) appeared to correspond with reduced erosion and FAC. In some subsequent outages, the steam erosion appeared to have nearly ceased, only to be noted again in a subsequent outage. Thus, it is expected that the erosion in this deaerator was related more to load than to any other factor.

Figure 18: Erosion of Deaerator Floor

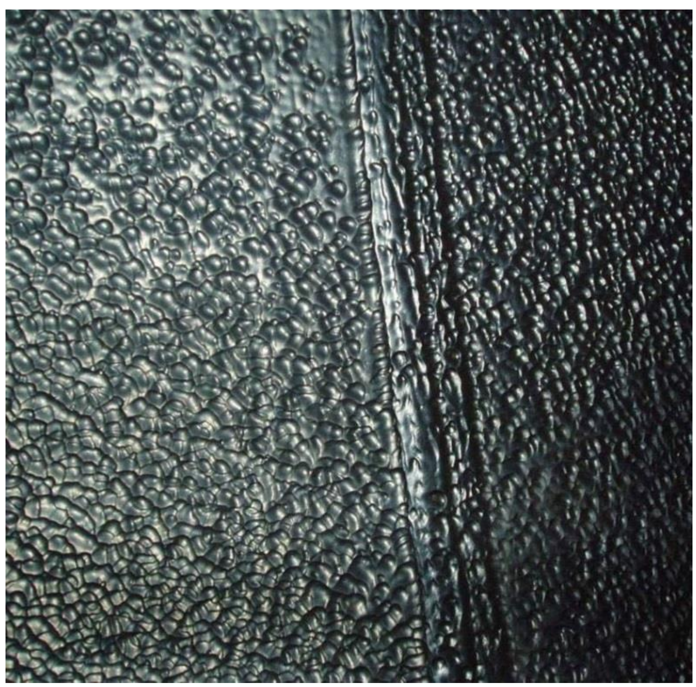

Figure 19: FAC of Same Deaerator Floor Beyond Eroded Area

The same mechanism that causes FAC of the floor can thin the carbon steel grating that supports the trays.  In some cases, the grating has been thinned to a knife edge, causing failure of parts of the tray support system.  At least periodically, beneath the traybox should be inspected for damage to the grating and support structure. Replacement grating should be P22 or stainless steel to minimize subsequent damage from FAC.

## LEAKING MANWAY DOOR

A number of years ago, the writer visited a pulp and paper mill that was experiencing a leak on one of the manways on the deaerator storage tank. During that period of operation, higher than usual consumption of reducing agents was experienced. Therefore, it is recommended to inspect and fix any leaks out of a deaerator or deaerator storage tank. While water may be leaking from the component, air can diffuse in the opposite direction into the component.

## CONTAMINATED STEAM

In industrial and some older style power plant designs, steam from a blowdown flash tank is routed to the deaerator. While this provides an opportunity for heat recovery, it also introduces a potential source of feedwater contamination if carryover is experienced in the flash tanks. There have been quite a few level control failures in blowdown flash tanks that have led to boiler water contamination of the steam entering the deaerator. This feedwater contamination has caused subsequent steam contamination where the feedwater is used for desuperheating. In such facilities it is suggested to inspect the steam inlet line for signs of white salt deposits. Also, the blowdown flash tank should be routinely inspected for signs of carryover.

## SUMMARY

This paper provided an introduction to deaerators and some common problems found in deaerators. While most of this paper focused on common problems found during the writer’s past equipment inspections, problems with venting during operation also were described.

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