



9707 Key West Avenue, Suite 100
Rockville, MD 20850
Phone: 301-740-1421
Fax: 301-990-9771
E-Mail: awt@awt.org

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Operation of Deaerators to Increase Boiler System Reliability

BY THOMAS WOLFE, WOLFE WATER TREATMENT SERVICES, LLC

Background

Those who are directly or indirectly involved in the water treatment aspects of operating steam boiler systems know the many obstacles to successful boiler operations. Table 1 lists 15 fairly common boiler system operational problems that are water-related. Insufficient deaeration represents 40 percent of the causes for these common problems. Oxygen and carbon dioxide corrosion, shown in Figure 1, are two examples of the corrosion problems eliminated with successful deaeration. A major difference between insufficient deaeration of feedwater problems, and other problems listed in Table 1, is that insufficient deaeration is not detected by standard daily monitoring procedures. Dissolved oxygen is seldom monitored, except in boiler systems that are operated above 600 psig. On the other hand, boiler feedwater hardness, pH and conductivity are widely used test and control parameters for most boiler operations at all operating pressures.

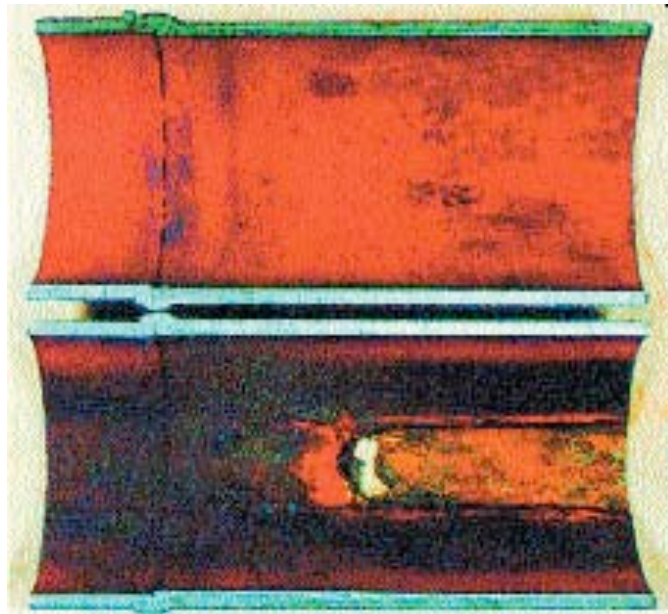


Figure 1: Condensate Line Corrosion

Mechanical Deaeration

The boiler feedwater deaerator shown in Figure 2 is an essential piece of equipment for the operation of modern steam boilers. Deaerators mechanically remove non-condensable gases (e.g., argon, carbon dioxide, nitrogen, neutralizing amines, oxygen) from water (e.g., boiler feedwater, steam condensate). Deaerators operate at pressures that range from a few inches of mercury absolute pressure (i.e., vacuum) to 60 psig or higher,

depending on the design of the deaerator and plant requirements. Other benefits of deaeration are that the deaerator:

- Provides a reserve quantity of hot water for the boiler in the event of power failure, production surges, as well as startups (Deaerated Water Storage Tank as depicted in Figure 2).
- Reduces repair and replacement costs caused by oxygen and carbon dioxide corrosion in condensate and feedwater systems.

Reduces chemical cleaning costs by reducing the quantity of iron, as well as copper in the boiler feedwater.

- Reduces steam trap and receiver pump maintenance.

Provides a surge tank for sudden increases in feedwater demand, as well as surges of condensate returns.

- Reduces chemical costs by lowering the need for chemical oxygen scavengers and neutralizing amines.
- Improves boiler system efficiency by using low-pressure steam such as feedwater turbine pump exhaust steam, as well as flash steam from blowdown recovery systems, to heat and deaerate the boiler feedwater.

Table 1. Common Boiler System Water-Related Problems

Common Cause of Problem		Classification of Problem
1	Failure of Pretreatment	Loss of boiler efficiency due to adhesion of hardness and silica scale
2	Failure of Pretreatment	Expansion or bursting of boiler tubes due to heavy scale adhesion
3	Failure of Pretreatment	Leakage of hardness, as well as silica from softener or demineralizer
4	Failure of Pretreatment/Failure of Boiler Water Chemistry Control	Reduction of turbine efficiency by silica and other salts
5	Insufficient Deaeration of Feedwater	Corrosion damage of feedwater and condensate piping due to oxygen, as well as carbon dioxide
6	Insufficient Deaeration of Feedwater	Corrosion damage of evaporation tube under deposition of metal oxides
7	Insufficient Deaeration of Feedwater	Reduction of steam purity
8	Failure of Boiler Water Chemistry Control	Reduction of turbine efficiency by silica scale
9	Insufficient Deaeration of Feedwater	Deterioration of product quality treated with the steam
10	Failure of Lay Up Procedure	Oxygen incoming to boiler during the idle time
11	Plant Operations	Rapid fluctuation of boiler operation load
12	Failure of Boiler Water Chemistry Control	Excess concentration of boiler water
13	Failure of Pretreatment	Boiler water contamination with organic matters
14	Insufficient Deaeration of Feedwater	Iron contamination of feedwater from condensate line
15	Insufficient Deaeration of Feedwater	Reduction of boiler water or condensate pH

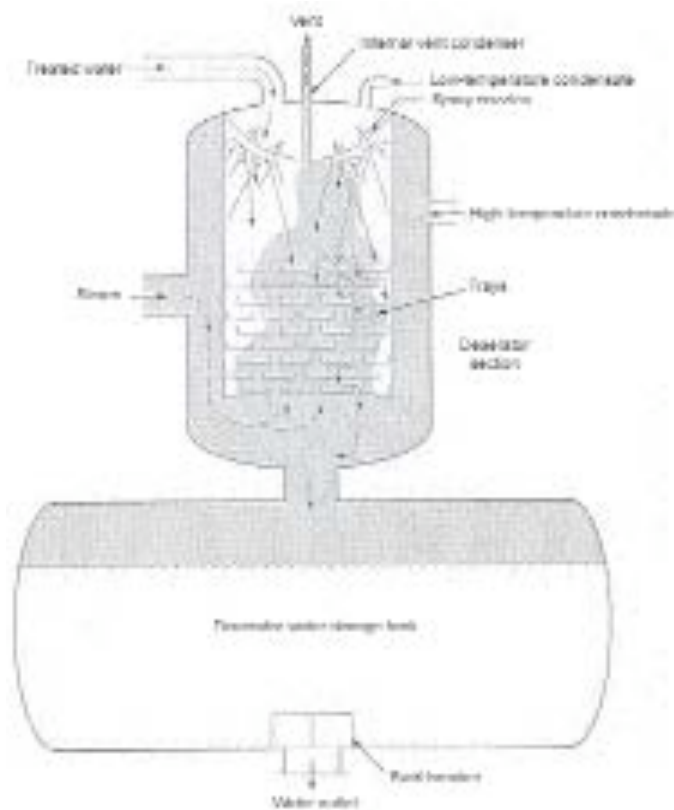


Figure 2: Spray/Tray Deaerator

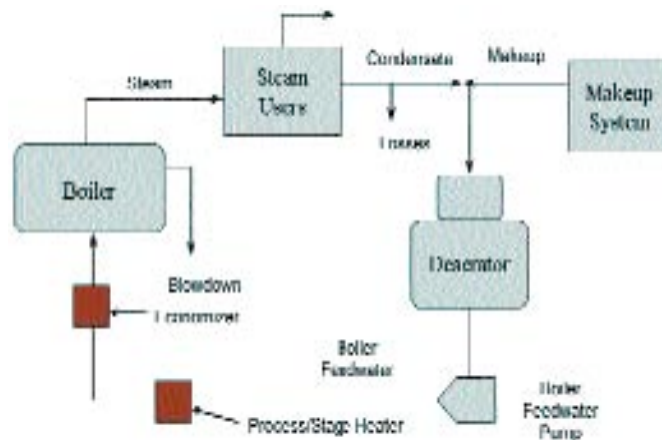


Figure 3: Boiler Feedwater Loop

The objective of this article is to provide a review of the methods by which the deaerator mechanically removes air from the water, and a summary of the more common chemicals used for deaeration (i.e., oxygen scavengers). The goal of this article is to provide a

concise primer on deaerators to help personnel, who work with deaerators on an operational level, manage and control oxygen and carbon dioxide corrosion-related problems.

The removal of air from the boiler feedwater is a primary concern. As you look at the boiler feedwater loop shown in Figure 3 the deaerator performance has an impact on every piece of equipment that uses water and steam in the system. Therefore, every consumer of the steam has an interest in the completeness of deaeration of the boiler feedwater. Water treatment personnel are especially interested in the extent of removal of dissolved oxygen and carbon dioxide from the boiler feedwater because both gases are corrosive to the metallurgies that transport water and steam throughout the boiler feedwater loop. The combination of oxygen and carbon dioxide is much more corrosive than the corrosion caused by either carbon dioxide or oxygen.

Dalton's and Henry's Laws provide the theoretical basis for the understanding of how gases can be mechanically removed from water. Dalton's Law states that the total pressure of a mixture of gases is equal to the sum of the partial pressure of each of the gases. In addition, Henry's Law states that the concentration of a dissolved gas in a solution is directly proportional to the pressure of that gas in the free space above the liquid (i.e., oxygen in water). It follows that a deaerator must be vented to a lower pressure than the gases above the solution in the deaerator in order to reduce the concentration of the gases in the solution.

The exception to Henry's Law is when a gas chemically reacts with the solvent (water). A common example of this exception is the reaction of carbon dioxide, ammonia and neutralizing amines with water to form carbonic acid, ammonium hydroxide and the hydroxide of the neutralizing amine. The pH of the water influences the quantity of ammonia, neutralizing amines and carbon dioxide removed by the deaerator. Most of the free ammonia, free neutralizing amines and free carbon dioxide are removed by deaeration at normal operating pH values. On the other hand, the pH of the water has to be changed significantly to remove the combined (e.g., the portion that has reacted with water) ammonia, combined neutralizing amine and combined carbon dioxide.

The combined ammonia and combined neutralizing amine are increasingly removed as the pH increases to pH values greater than pH 10. Likewise, the combined carbon dioxide is increasingly removed from the water as the pH values decrease to pH values less than six.

As with many compounds, oxygen will dissolve in water up to a certain concentration, which is dependent upon a number of factors. The most important factors are the water temperature, the pressure of the oxygen-water vapor over the water and concentration of oxygen in the oxygen-water vapor environment. Oxygen has an inverse solubility with water temperature, which means that as the water temperature increases, the concentration of dissolved oxygen in the water decreases. Likewise, as the water

temperature decreases, the amount of oxygen that can dissolve in the water increases as shown in Figure 4. For example, a sample of water standing in the air with a temperature of 70 °F will dissolve approximately 8 mg/L of oxygen. If the temperature of the water is increased to 140 °F, the water will only be capable of dissolving 5 mg/L of oxygen. The other 3 mg/L of dissolved oxygen is driven out of the water into the above air. If the water is heated still further to 200 °F, it will dissolve less than 2 mg/L of oxygen.

Deaeration is defined for this article as "the removal of gases from the boiler feedwater before it enters the boiler." Deaeration can take place in condensate tanks, condenser air ejectors, boiler feedwater tanks, deaerating heaters, as well as deaerators. The amount of air removed, as well as added to the water varies, but the process by which air enters or leaves the water is essentially the same for the condensate tanks, condenser air ejectors, boiler feedwater tanks, as well as deaerators.

There are three common classes of air removal systems used in steam boiler operations. First, there is the open tank in which makeup water and steam condensate are combined to become boiler feedwater. The air concentration of the water in the tanks will be at the equilibrium concentration for the water temperature and atmospheric pressure for the open tank. The temperature of the water in these tanks may or may not be controlled so the oxygen content of the water may be highly variable. For example, water in an open tank at equilibrium with atmospheric air will contain 6.5 mg/L of oxygen if the water is 104 °F, and 2 mg/L if the water temperature is increased to 190 °F as shown in Figure 4. Secondly, there is the deaerating heater, which is defined as a vessel that is designed to reduce the oxygen content of water to 43 µg/L or ppb (i.e., parts per billion). Finally, there is the deaerator defined as a vessel designed to reduce the oxygen content of water to 7 µg/L. The operating temperature and pressure are site-specific for the operating conditions.

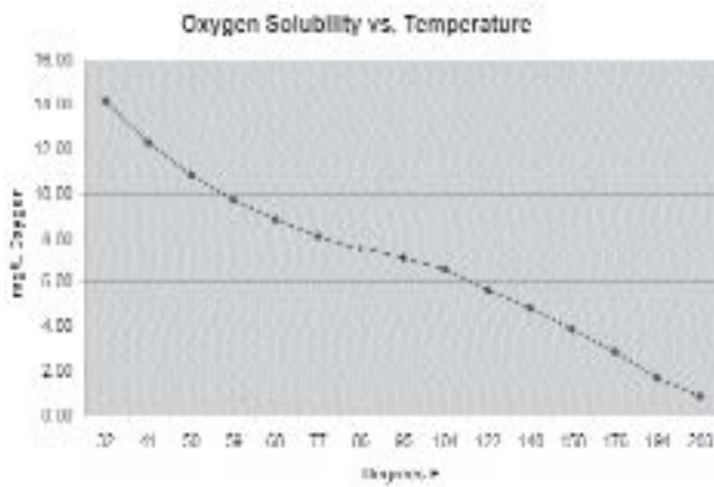


Figure 4: Oxygen Solubility in Water at 14.7 psia

As stated previously, the amount of dissolved oxygen in the water is the oxygen partial pressure in the water-oxygen environment. To illustrate this consider the sample of water that had the temperature of 70 °F. When exposed to 70 °F air at 1 atmosphere pressure, the water will dissolve 8 mg/L of oxygen. If this water sample were put under a vacuum of 16 inches of mercury, the water will only dissolve 4 mg/L of oxygen. In other words, 16 inches of mercury vacuum is equivalent to an 80 °F increase of the water temperature in a tank open to the atmosphere. If the water were taken out of the 16-inch vacuum and left in the air, it would redissolve more oxygen until the dissolved oxygen concentration in the water reached 8 mg/L. To summarize, if the water is heated, it will release oxygen into the environment surrounding the water sample and the concentration of oxygen in the water will decrease. If the oxygen, which has been liberated into the surrounding environment, is removed, additional oxygen can be removed from the water sample.

Three actions occur in a properly operating deaerator. First, the water is atomized into small droplets so that it can be heated quickly and efficiently. Second, the water is mixed with the purge steam to bring the feedwater to saturation temperature. Finally, oxygen is vented from the deaerator along with a controlled amount of the purge steam. These three actions must take place for proper deaeration to occur. If any of these items are not performed, the dissolved oxygen concentration in the boiler feed water will be higher than expected.

A common spray-tray deaerator is illustrated in Figure 2. The treated water (i.e., makeup water) is heated by the internal vent condenser and the low temperature condensate. This is an important step for efficient heat recovery in the deaerator. The treated water and low temperature condensate are atomized in the spring-loaded spray nozzles, and the trays, so that the water has a high surface to mass ratio. The high surface to mass ratio helps heat the water faster and provides more surface area for oxygen to disengage from the water droplet. The water is brought to saturation conditions by the counter-current movement of steam through the atomized water. This is important because the increase in water temperature causes the dissolved oxygen to be liberated from all of the water.

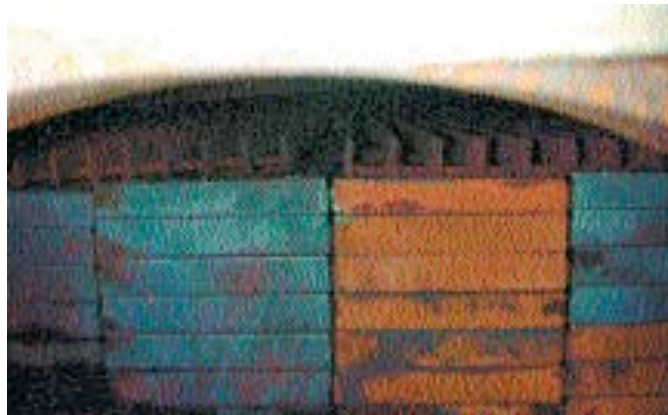


Figure 5 - Deaerator Trays

Table 2: Saturated Steam-Water Table

PSIG	Temperature °F
1	215.3
2	218.5
3	221.5
4	224.4
5	227.1
6	229.8
7	232.3
8	234.7
9	237.1
10	239.4
15	249.7
20	258.7
25	266.5

The last requirement for deaeration is venting the oxygen scrubbed from the water. As the dissolved oxygen is liberated from the water, it must be removed from the deaerator. The liberated oxygen is removed by venting the oxygen with the purging steam through the deaerator vent pipe. A properly operating deaerator has a continuous 18- to 24-inch plume of vented steam and noncondensable gases. It should be noted that this deaerator is designed so that all the treated water and low-pressure condensate is contacted by all of the inlet steam. The high temperature condensate enters the side of the deaerator because it is assumed this water contains no oxygen, or other corrosive gases, so it can bypass the deaeration zone and go directly to the deaerated water storage tank. This assumption, however, is not always correct. Therefore, troubleshooting deaerator oxygen problems should always include a search for "unknown" sources of air-laden water in the deaerator storage tank.

The amount of steam required for the deaerator is dependent upon a number of factors, including makeup water temperature, deaerator operating pressure and feedwater flow. The temperature of the steam in the deaerator is dependent upon the pressure at which the deaerator is operating, not the pressure of the steam supply to the deaerator. For example a deaerator operating at 15 psig will produce a deaerated water temperature equal to the saturation temperature of 15 psig steam (i.e. 249.7 °F). Table 2 contains the saturation temperature of steam at pressures above “standard atmosphere”. If the temperature in the deaerator storage varies more than plus or minus 3 °F from steam saturation temperature, there may be a problem with the temperature, pressure measurements, as well as the deaerator.

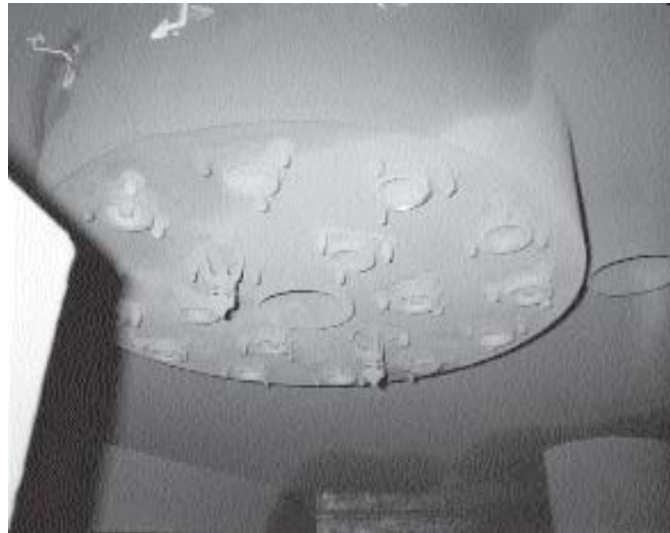


Figure 6: Deaerator Sprays

There are three main types of deaerator: the tray deaerator shown in Figure 5, spray deaerator shown in Figure 6 and the combination spray/tray deaerator shown in figure 2. The tray deaerator is probably the most common of all deaerators. It is important to keep the trays free of debris; and the trays must maintain correct stacking for satisfactory deaeration to be achieved. The spray deaerator utilizes a system of spring-loaded spray nozzles to atomize the incoming water into the scrubbing steam. Periodic maintenance of the spray nozzle springs' tension in the spray deaerator is required. The spray/tray deaerator uses a combination of sprays and trays to atomize the water, so occasional cleaning and restacking of the trays and adjustment of the sprays is required.

Oxygen Scavengers

After mechanical deaeration, the solubility of oxygen in boiler feedwater is very low. The oxygen content of water in a heated feedwater tank is usually variable and at a higher oxygen content. Therefore, a chemical oxygen scavenger is used to complete the oxygen removal process from a heated water tank. Water, which is heated in an open tank, requires a considerable quantity of oxygen scavenger. Much lower quantities of oxygen scavengers are required for water that has been mechanically deaerated to 10 µg/L or less.

In current water treatment procedures, it is common to refer to compounds, such as sodium sulfite, as oxygen scavengers because they only react with oxygen. Chemicals, such as hydrazine, carbohydrazide and diethylhydroxylamine (DEHA) are referred to as passivators, as well as volatile oxygen scavengers (VOS). In many ways, the passivation properties of the VOS chemicals are arguably more important than the oxygen scavenging properties of these chemicals.

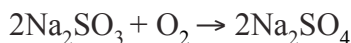
The scope of this article is more or less restricted to boiler systems operating at or below 600 psig. The boiler systems that operate at less than 200 psig may or may not have a deaerator; but boiler systems that operate at greater than 200 psig typically have an operating mechanical deaerator to achieve oxygen removal from boiler feedwater to less than 7 µg/L. Both oxygen scavengers and volatile oxygen scavengers will be discussed. Some of the important positive and negative aspects of each to atomize the incoming water into the scrubbing steam. Periodic maintenance of the spray nozzle springs' tension in the spray deaerator is required. The spray/tray deaerator uses a combination of sprays and trays to atomize the water, so occasional cleaning and restacking of trays and adjustment of the sprays is required. chemical are presented to help the reader in selecting the best oxygen control chemical for a specific boiler feedwater system. The oxygen scavenger discussions are classified as nonvolatile and volatile

Nonvolatile Oxygen Scavengers

Sodium Sulfit

Across all boiler feedwater systems that operate at or below 600 psig, the most commonly used oxygen scavenger, or reducing agent, in boiler feedwater systems is either sodium sulfite or the bisulfite analogue of sodium sulfite. Sodium sulfite has been a reliable oxygen scavenger in boiler feedwater for approximately 60 years. This compound is characterized as having fast reaction times, low use-cost, years of proven performance, availability in concentrated liquid or powder forms and FDA and USDA approvals. There are also catalyzed versions of sodium sulfite that use cobalt salts to increase reaction rates at lower temperatures. Sodium sulfite is nonvolatile so it does not provide any oxygen scavenging function in the steam and steam condensate areas. A disadvantage to the use of sodium sulfite in boiler water treatment is that it is not a passivator of ferrous metals in the boiler feedwater loop. The sodium sulfite and its reaction product, sodium sulfate, add to the dissolved solids content of the boiler water and steam. However, this characteristic of sodium sulfite is not a major concern unless the boiler feedwater uses demineralized water or other low-solids water for the makeup water source. There may be some carry over of acidic sulfur dioxide with the steam from 600 psig boilers. The formation of the acidic sulfur dioxide has been used beneficially to online clean alkaline deposits from steam turbines. The use of boiler feedwater for steam atemperature, as well as desuperheating of high-pressure steam precludes the use of sodium sulfite in some plants.

Sodium sulfite reacts with oxygen as follows:



From this equation, it can be calculated that 8.0 mg/L of a 100 percent powdered sodium sulfite product will remove 1 mg/L of dissolved oxygen. Because industrial-grade sodium sulfite is seldom 100 percent pure and because most proprietary sulfite products contain

catalysts, 10 mg/L of a blended powdered sulfite product is normally used to remove 1 mg/L of oxygen. Liquid bisulfite solutions will require 25-30 mg/L of product, because most liquid bisulfite products are plus or minus 35 percent active.

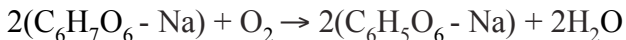
Sodium sulfite is normally controlled by maintaining a sulfite residual in the boiler water. A sulfite minimum residual of 10-15 mg/L is common in higher pressure boilers, but higher residuals are maintained in lower pressure boilers.

Erythorbate

Erythorbate is another nonvolatile reducing agent. Erythorbate is provided in the sodium, ammonium and neutralizing amine-erythorbate salts. Erythorbate salts have some desirable characteristics. This compound has oxygen reaction times similar to sodium sulfite and is effective as a metal passivator. Erythorbate is USDA and FDA approved and is a "Generally Regarded as Safe (G.R.A.S)" compound for food additives.

A shortcoming of erythorbate is that it is not volatile so it will not passivate or protect steam and condensate piping from oxygen corrosion. It is also more expensive than inorganic sulfites. The fact that erythorbate is not readily soluble creates shipping and handling problems for the product.

Erythorbate reacts with oxygen as follows:



All erythorbate scavengers are maintained at low levels in the feedwater. Normally, 20-100 µg/L of erythorbate is recommended as a control range for boiler feedwater.

Volatile Oxygen Scavengers

Hydrazine

Hydrazine has been a widely-used volatile reducing agent for many years. It reacts with oxygen according to the following equation:



Because the products of this reaction are nitrogen and water, no dissolved solids are added to the water. This reaction shows that one pound of 100 percent pure hydrazine is required for each pound of oxygen. Commercial hydrazine used in water treatment is most often supplied as a 15 or 35 percent solution because of the toxicity and low flash point of the 100 percent material. At any strength, hydrazine is less expensive than all other volatile reducing agents.

In addition to reacting with oxygen, hydrazine will reduce certain metal oxides to their more protective states for the base metal (i.e., passivate). This helps reduce corrosion in the steam system by forming protective metallic films by the following reactions:



When excess hydrazine is present in the boiler water, it will decompose. The decomposition products of hydrazine are ammonia and nitrogen:

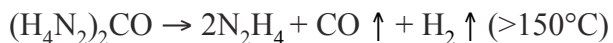


The ammonia is alkaline and will not attack steel, but if enough ammonia and oxygen are present together, they will attack copper and copper alloys that may be present in condensate systems. With proper application, the danger of ammonia evolution and copper corrosion caused by hydrazine may be minimized.

There are significant problems in using hydrazine. For example, hydrazine has a relatively slow reaction rate with oxygen. Furthermore, there are special considerations for the storage and handling of hydrazine. There are no FDA or USDA approvals for hydrazine. This compound is classified as a suspected carcinogen by both the American Conference of Governmental Industrial Hygienists (ACGIH) and the National Institute for Occupational Safety and Health (NIOSH). In addition to these restrictions, hydrazine must be reported on all "Community Right to Know" lists and must appear on the Environmental Protection Agency (EPA) Toxic Substance Control Act (TSCA) inventory. While enclosed feed systems exist to minimize feeding and storage problems, many companies refuse to stock the material on-site because of the reporting requirements

Carbohydrazide

Carbohydrazide has many of the same properties as hydrazine. Because it is a hydrazine molecule, it must still be reported on the EPA TSCA inventory. The thermal decomposition of carbohydrazide into hydrazine is shown in the following reaction:



Once the hydrazine molecules are generated, carbohydrazide reacts like ordinary hydrazine. Of course, the reaction times for oxygen scavenging, as well as metal passivation are slower because of the extra time needed to form hydrazine in situ. The major advantage of carbohydrazide is that the release of hydrazine vapors during storage is greatly diminished. However, skin toxicity is not significantly reduced. At the present time, carbohydrazide is not subject to NIOSH, Occupational Safety and Health Administration (OSHA), or ACGIH restrictions and is not classified as a carcinogen. Further restrictions are likely once the ACGIH and other agencies perform additional studies.

Diethylhydroxylamine

Diethylhydroxylamine (DEHA) is a volatile reducing agent and metal passivator. Like hydrazine, DEHA scavenges oxygen and passivates metal in steam and condensate

systems. The generally accepted reaction chemistry of DEHA with oxygen is shown below:

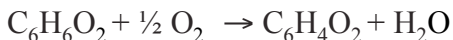


The theoretical combining ratio of DEHA and oxygen is 1.25:1 (1.25 mg/L of DEHA to 1 mg/L of oxygen). Because of slower reaction times, excess DEHA must be fed to increase reaction speed. In practice, 2 to 3 mg/L or less of DEHA is fed for every 1 mg/L of oxygen, or DEHA is fed at the theoretical oxygen demand (1.25 mg/L) plus 25 to 200 µg/L excess DEHA. DEHA is an excellent metal passivator in both feedwater and condensate systems and is an effective oxygen scavenger in condensate systems. This compound has no unusual handling or significant regulatory restrictions. On the other hand, some dissolved solids are produced in the feedwater. As with all of the VOS, DEHA has no USDA or FDA approval.

Hydroquinone

Hydroquinone is used as both a volatile reducing agent and a catalyst for other reducing agents. Hydroquinone is also available with neutralizing amines as a patented, proprietary application to prevent condensate system corrosion.

Hydroquinone reacts with oxygen in the following manner to form 1, 4-benzoquinone and water:



Eventually, benzoquinone reacts with additional oxygen to produce carbon dioxide gas. Hydroquinone is occasionally used where a low-solids feedwater oxygen scavenger suitable for atemperating and desuperheating applications is required.

Under most feedwater conditions, the reaction between oxygen and hydroquinone occurs rapidly at elevated feedwater temperatures. Hydroquinone is the fastest acting of all volatile reducing agents, which also accounts for its use as a catalyst. As with DEHA, the use of hydroquinone in high-pressure systems is not fully understood or well documented. Hydroquinone-containing products are stable in the acid form

However, blending hydroquinone with certain alkaline amines results in the formation of dark brown to black precipitates in the product storage container.

Summary

Boiler feedwater deaeration is an important process for operating a boiler feedwater loop free from unnecessary maintenance and replacement costs. The mechanical deaerator is a simple, but crucial operation in steam boiler systems. The deaerator requires very few day-to-day adjustments except to assure there is enough steam to maintain saturation condition in the deaerator, and to provide sufficient steam venting to completely purge all

gases from the deaerator. Periodic inspections and maintenance for the deaerator are necessary. Occasional replacement and repair of trays, as well as sprays, and repair of any defects in the deaerator that result in short-circuiting of the water, as well as steam through the deaerator, are necessary. Furthermore, the selection and application of an oxygen scavenger, as well as a passivator is a simple matter. The chemical that meets the performance requirements for the system should be selected.

The best advice for the end user of deaerators, as well as oxygen scavengers is to recognize that no oxygen scavenger can overcome inadequate mechanical deaeration. It is possible to delay an oxygen corrosion problem that results from a defective deaerator, but the deaerator should be repaired as soon as possible.

Suggested Reading

The Chemical Treatment of Boiler Water, James W. McCoy, Chemical Publishing Co., New York, NY.

Technical Reference and Training Manual, Association of Water Technologies, Inc. Industrial Water Treatment Practice, edited by P. Hammer, J. Jackson, E. F. Thurston, Butterworths in association with ImperialChemical Industries Limited.

Oxygen Scavengers in Steam Generating Systems and in Oil Production, NACE International Task Group T-3A-6 on Evaluation of Oxygen Scavengers in Oil Production Facilities and Boilers.

Betz Handbook of Industrial Water Conditioning, Library of Congress Catalogue Card Number: 62-21097.

The Corrosion Handbook, edited by Herbert H. Uhlig, PH.D., John Wiley & Sons, Inc. New York.

About the Author

Thomas W. Wolfe is president of Wolfe Water Treatment Services, LLC. He can be contacted at Wolfe Water Treatment Services, LLC, P.O. Box 40765, Baton Rouge, LA 70835, by phone at 225.296.5777, or email at twolfe40@earthlink.net .
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Technical Article Review Quiz
Operation of Deaerators to Increase Boiler System Reliability

The Questions for the exam may be answered by reading and understanding the **Fall 2005** Analyst Article titled "**Operation of Deaerators to Increase Boiler System Reliability**" by **Thomas Wolfe**. The correct answers are derived from that article and any disputed answers will be referred back to that article for justification.

1. Deaerators operate at pressures that range from a few inches of mercury absolute pressure (i.e. vacuum) to _____.
 - a. 60 psig or higher.
 - b. 2 psig.
 - c. 5 psig.
 - d. 7psig.

2. After mechanical deaeration the solubility of oxygen in boiler feedwater is _____.
 - a. slightly higher than city water.
 - b. the same as before deaeration.
 - c. very high
 - d. very low.

3. Waters that have been mechanically deaerated to 10 ug/L or less _____ oxygen scavengers
 - a. do not require any
 - b. require the same quantities of
 - c. require much lower quantities of
 - d. require much higher quantities of

4. Sodium Sulfite is characterized as having _____.
 - a. slow reaction times
 - b. high use cost
 - c. fast reaction times.
 - d. no impact on the dissolved solids content of the boiler water.

5. Erythorbate has oxygen reaction times similar to sodium sulfite _____.
 - a. and is effective as a metal passivator.
 - b. and is volatile so it can protect the condensate system as well.
 - c. and is less expensive than sodium sulfite
 - d. but is not USDA and FDA approved.

6. DEHA (diethylhydroxylamine) is _____>
 - a. not volatile.
 - b. not a reducing agent.
 - c. USDA approved.
 - d. a metal passivator.

7. The corrosion caused by the combination of oxygen and carbon dioxide _____ the corrosion caused by either carbon dioxide or oxygen alone.
- is much less than
 - is much more than
 - is the same as
 - in deaerators is similar as
8. A properly operating deaerator has a continuous “_____” plume of vented steam and noncondensable gases.
- 1-2 inch
 - 3-4 inch
 - 18-24 inch
 - 3-4 foot
9. A properly operating deaerator will -----
- reduce the amount of oxygen scavenger required
 - increase the amount of neutralizing amine required
 - increase steam trap maintenance
 - reduces boiler system efficiency
10. As water temperature increases, the concentration of dissolved oxygen in the water ____.
- changes only if the deaerator is functioning properly.
 - stays the same.
 - increases.
 - decreases.