DEAERATION

A White Paper of the Deaerator Manufacturers Group of the American Boiler Manufacturers Association

> "**Deaeration**: *the process of removing air and gases from boiler feedwater prior to its introduction to a boiler*." [1]

The necessity for deaerating boiler feedwater has been proven over time. Mechanical deaeration reduces the life-cycle costs of operating the steam system. Mechanical deaeration provides

- longer equipment life
- reduced pipeline replacement costs
- lower overall maintenance
- lower operating costs
- reduced system downtime

The initial cost of a deaerator is a small price to pay for the peace of mind provided in more reliable operation and lower total plant costs.

The question as to why one should deaerate can be answered by detailing the five primary reasons for including a deaerator as a part of the boiler/steam/condensate cycle. They are:

1) Oxygen removal
2) Carbon dioxide removal
3) Basis for improved operation
4) Improved heat transfer
5) Energy savings

Oxygen Removal

Oxygen removal is the primary reason for deaerating water and can be most economically accomplished by mechanical means. Removal of oxygen by use of chemicals (sodium sulfite or hydrazine) is expensive and often incomplete.

It has been determined that dissolved oxygen is up to ten times more corrosive than carbon dioxide, especially at higher temperatures. For example, water is 2½ times more corrosive at 195° F than it is at 140° F.

Oxygen corrosion is demonstrated by the following chemical equations. On contact with water, iron dissolves, forming the soluble compound ferrous hydroxide:

$$Fe + 2H_2O = Fe(OH)_2 + 2H^+$$

Iron + Water = Ferrous Hydroxide + Hydrogen

This reaction continues to equilibrium; once balanced, it ceases, assuming that the water is oxygen-free.

However, if dissolved oxygen is present in the system, it will combine with the ferrous hydroxide to form the insoluble compound ferric hydroxide (rust):

$$4Fe(OH)_2 + O_2 + H_2O = 4Fe(OH)_3$$

Ferrous Hydroxide + Oxygen = Ferric Hydroxide

Cycling dissolved oxygen prevents equilibrium by continuously removing the ferrous hydroxide from the solution. The reaction will continue until either the oxygen is entirely removed from the water (deaerated) or the metal has been totally dissolved.

One of the most serious aspects of oxygen corrosion is that it generally occurs as pitting so that the attack is concentrated in a small area of the total metal surface. With this type of corrosion, failures can occur even though only a relatively small portion of the metal has been lost. In addition, carbon dioxide increases the corrosion problem.

Carbon Dioxide Removal

If carbon dioxide is present with oxygen, the two gases acting simultaneously may be considered to be up to forty percent more corrosive than would be expected for the same quantities of the two gases acting individually. Ferrous hydroxide is an alkaline compound, and its rate of solution depends on the pH of the water with which it is in contact. The lower the pH of the water, the more rapidly the ferrous hydroxide goes into solution. Condensate may contain carbon dioxide in solution, forming carbonic acid:

$$CO_2 + H_2O = H_2CO_3$$

Carbon dioxide is the usual cause of specific steam and return line corrosion, characterized by a general thinning of the pipe wall or grooving along the bottom of the pipe.

The chief source of carbon dioxide is the bicarbonate and carbonate alkalinity of the makeup water to the boilers. The bicarbonate and carbonate alkalinity, when subjected to boiler temperature, undergoes thermal decomposition and liberates carbon dioxide, which becomes entrained with the steam:

$$2(HCO_3) + Heat = (CO_3) + CO_2 + H_2O$$

The other possible and usually minor source of carbon dioxide is the free, gaseous carbon dioxide that is dissolved in most natural water. Free carbon dioxide, because it is almost completely eliminated initially by efficient feedwater deaeration, is not a major factor. It is extremely important, however, that the carbon dioxide liberated by thermal decomposition in the boiler be deaerated immediately and not allowed to recycle or concentrate in the steam condensate cycle.

Improved Operation

In addition to removing the free oxygen and carbon dioxide, a deaerator also provides the advantage of heating the boiler feedwater. Adding hot feedwater to the boiler greatly reduces the chance of thermal shock caused by the expansion and contraction of heating surfaces.

There are two different methods of feeding water to the boiler(s).

- On-off pumping – This is the simplest and least expensive method, and has been proven over the years to operate satisfactorily when serving boilers that are resistant to thermal shock and have a relatively large water volume content.
- Modulated feedwater pumping – This is more sophisticated and therefore more expensive than on-off pumping, but can possibly save the boiler owner some expensive repair bills. This type of system is highly recommended for boiler types that may be susceptible to temperature fluctuations, and the attendant thermally induced stress cycling causing fatigue failure of the boiler structural components (commonly referred to as thermal shock).

Modulating feedwater systems are also very useful when serving boilers that have low water volume content, in which pressure and temperature fluctuations can aggravate water level control and hence cause nuisance shutdowns due to low water level.

A modulating deaerator system is also required if an economizer is used. Non-deaerated water will literally dissolve an economizer. In addition, modulated feedwater is also necessary since economizers seldom hold more than thirty seconds of feedwater at full load.

Always secure the recommendations of your boiler manufacturer regarding the type of deaerator best suited to your particular installation.

Improved Heat Transfer

Dissolved gases decrease heat transfer in heating and process equipment.

Air is an excellent insulator. When air is allowed to concentrate in process heat transfer equipment it impairs heat transfer. Since air is not kinetic in its desire to give up heat, it tends to plate out on the heating surfaces.

Of course, while it is vitally important to rid the steam processing equipment of unwanted non-condensable gases, it is equally important to see that these gases are not allowed to enter the system in the first place or to be recycled. These gases must be eliminated from the system as quickly as possible.

Energy Savings

The potential saving in energy that can be recovered by a deaerator is another benefit. The deaerator can act as the hub of the plant heat balance.

High-pressure returns, normally, trapped to atmosphere can now be trapped directly to the deaerator. The flash steam recovered by the deaerator from a high-pressure trapped system can amount to as much as 20 percent of the fuel required to provide heat for that process. Making low pressure systems trapless and pumping the condensate directly into the deaerator can save up to 6 percent in fuel. Exhaust steam and flash steam, formerly lost to atmosphere, can be used by the deaerator to preheat makeup water.

Another excellent source of potential energy savings may be realized with an effective blowdown heat recovery system. Up to 3 percent fuel savings are possible with a payback often realized in a matter of months. Continuous blowdown heat recovery can easily be incorporated into the deaerator cycle with a minimum of installation expense, and the boiler system need not be shut down during installation. As with boilers and economizers, many new deaerators today incorporate the continuous blowdown heat recovery system as part of the overall package.

Deaeration Requirements

Chemical charts and principles such as Henry's Law and Dalton's Law form the basis for theories involved in removing dissolved gases from a liquid. When the vapor pressure of the water and the solution pressure of the dissolved gases exceed the pressure imposed on the system, all gases become insoluble. Water cannot contain dissolved gases at saturation temperatures such as 212° F at atmospheric pressure or 250° F at 15 psig (assuming sea level conditions).

However, saturation temperature alone does not assure complete gas removal.

This leads to the requirements for good mechanical deaeration:

- Temperature – Heating to full saturation temperature as described above.
- Turbulence – A complete agitation or mixing is required to shake out all the dissolved gases. This scrubbing action is required so that the water overcomes the surface tension and viscosity that retain the dissolved gases.
- Thin film – A thin film must be created so that the distance the dissolved gases must travel is reduced. This also enhances the heating process.
- Time – The more time allowed for the first three activities, the more effective is the deaeration.
- Venting – It is critical to the entire deaerating process that the liberated gases are given an opportunity to escape from the cycle.
- Steady State– If the deaeration process is to proceed effectively; the system must maintain constant steam pressure in the system. If the system experiences large load surges, generally caused by on-off condensate returns, the controls will not be able to maintain adequate steam flow to insure complete deaeration. If the deaerator experiences large load swings, it will cease to function properly.

The foregoing process can be demonstrated by a simple experiment:

Fill a fairly large pan, preferably Pyrex, with cold water from the tap and put it on the stove at its highest setting. As the water heats, you will observe small bubbles accumulating on the side and the bottom. It might seem that these are steam bubbles. The bubbles are air coming out of solution. As the temperature nears boiling, more and more bubbles will form until, at just a few degrees before boiling, literally thousands of bubbles will be visible. When the water starts boiling vigorously, (saturation temperature) the air bubbles will disappear by virtue of the <u>turbulence</u> of the liquid.

If you had used a frying pan and just put in a <u>thin film</u> of water, the reaction would occur much more rapidly and of course the longer you let the water boil, the lower the oxygen content.

Bear in mind that ground water can have up to 20 ppm of dissolved oxygen and a deaerator must reduce this to a level of 7 ppb in a matter of seconds - a total reduction of nearly 3000 times.

<u>Supplemental Chemical Treatment</u>

A good chemical treatment program should also be instituted to assure optimum boiler water quality. This program normally includes the use of oxygen scavengers, mainly Sodium Sulfite or Hydrazine, to remove the last traces of oxygen in the boiler feedwater. However, as previously stated, removal of oxygen by use of chemicals alone is expensive and often incomplete.

Sodium Sulfite is most often used as the oxygen scavenger because of low cost and ease of handling. The end product of the reaction of Sodium Sulfite with oxygen is Sodium Sulfate. Boiler water Sulfite residual is typically maintained at 30-60 ppm A downside affect of using Sulfite, however, is that both Sulfite, and the product of its reaction Sulfate, act to increased boiler water TDS, which may effect increased blowdown rates.

Hydrazine is sometime used instead of Sodium Sulfite. It has the advantages that it volatilizes and does not contribute to boiler water solids. Boiler water Hydrazine residual is typically maintained at 0.1 – 0.5 ppm. Hydrazine will also act to neutralize acidity of the condensate return system. It suffers the disadvantages of being both more expensive and more hazardous to handle than Sulfite, as well as being more difficult to control. In addition, if fed in excess, Hydrazine can form Ammonia which will attach alloys containing copper. Be aware that there may be permissible exposure limits for these chemicals as well as serious toxicity and safety issues. Discussion of these concerns is beyond the scope of this white paper, but they should be taken into account in connection with any use of these or other chemicals.

Please note that local jurisdictions may regulate the type and use of certain chemical compounds in any application. Competent, qualified and/or, where mandated by local jurisdictions, Licensed Water Quality Service Provider(s) may be required to perform such services and/or maintenance procedures, as deemed necessary, to assure the proper and safe commissioning, operation, care and continued maintenance of equipment and storage and handling of chemical compounds associated with project specific water quality program(s).

Conclusion

Unless we can reverse the laws of nature, all the functions described in this paper will occur in one manner or another. The non-condensable gasses must be removed mechanically or the user will experience excessive operating costs.

[1] Handbook of Power, Utility and Boiler Terms and Phrases, Sixth Edition, Edited by the American Boiler Manufacturers Association, ©1992

The American Boiler Manufacturers Association is the national, nonprofit trade association representing the manufacturers of commercial-institutional, industrial, cogenerating, heat recovery steam generator and power-generating equipment, related fuel-burning equipment, the providers of products and services used by the boiler industry and users of boiler equipment. In short, ABMA represents the companies that design and build the systems that combust the fuels that generate the steam and hot water that powers and comforts America and the world.

Readers should also consult the ABMA Online Bookstore at www.abma.com for additional material on this and other technical questions, and the ABMA Online Buyers Guide for those ABMA member companies involved in deaeration and deaerating systems.

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