# Deaerator White Paper for use with Industrial/Commercial and Institutional Boilers

*ABMA …. representing the best of the boiler industry*

# Deaerator White Paper for use with Industrial/Commercial and Institutional Boilers

2011



**American Boiler Manufacturers Association**
**8221 Old Courthouse Road, Suite 380**
**Vienna, Virginia 22182**
**http://www.abma.com**

## Definition of Deaeration

Deaeration is the removal of dissolved or entrained gases from water to be used as boiler feed or for other processes. The gases of concern to steam plant operators are usually oxygen and carbon dioxide which are present in water due to natural cases. Oxygen and carbon dioxide present in untreated water cause corrosion of the usual boiler and steam plant materials. The rate of the corrosive action is proportional to the amount of the gas present in the feedwater and is accelerated by high temperature.

The primary purpose of deaeration is to remove the dissolved oxygen and carbon dioxide from water to such low levels that their corrosive potential with regard to carbon and low alloy steel is eliminated under the temperature and pressure conditions prevailing in steam generation and transport equipment. The economic value of being able to use steel, rather than higher alloy, materials for construction of steam plant equipment is easily recognized.

## Methods of Deaeration

Deaeration of water can be achieved by chemical and/or mechanical means.

Various chemicals are available which react with the oxygen in water to produce chemical forms that are not harmful to the steam system. Likewise, there are chemicals that can be added to the water to react with carbon dioxide and transform it into neutral forms of the substance.

Non-chemical (mechanical) methods of deaeration remove, rather than transform, the oxygen and carbon dioxide present in the water supply. Mechanical deaeration devices function by reversing the mechanism by which the gases initially go into solution with water.

Mechanical $O_2$ removal:
Removal of dissolved oxygen to very low limits, not exceeding 7 ppb, is possible by mechanical deaeration only. According to common boiler standards, lower concentrations than 7 ppb are usually not relevant for operation.

Mechanical $CO_2$ removal:
In general, mechanical deaeration can remove all free $CO_2$ to a non-detectable level. Dependent on actual pH value of the condensate, chemically bound $CO_2$, which cannot be completely removed by mechanical deaeration, may be present in the water. However, since the level of $CO_2$ present in treated water seldom exceeds 5 ppm, no further discussion of $CO_2$ removal will be addressed in this bulletin and the remainder of this paper will address only oxygen removal via the deaerator technology.

**Theory of Mechanical Oxygen Removal**

Oxygen is soluble in water in proportion to the partial pressure of the gas that is acting when it contacts the water (Henry's Law). The normal source of oxygen in water is the atmosphere which is 21% oxygen and contributes about 3 psi to the normal atmospheric pressure of 14.7 psi. At 60ºF, water in contact with the atmosphere will pick up about 10 ppm of $O_2$.

The solubility of oxygen in water decreases as the water temperature increases. As the water temperature increases, the amount of water vapor present in the atmosphere above the liquid also increases. This double effect means that less $O_2$ can be held by water as its temperature is increased, theoretically being 'zero' when the water it reaches its boiling point (saturation).

As a consequence of these physical characteristics, oxygen can be removed from water (or better, the amount of $O_2$ that the water can hold can be reduced) by raising the temperature and reducing the concentration of $O_2$ in the atmosphere above the water.

**Deaerator Configurations**

A complete 'deaerator' installation usually includes not only the actual deaeration devices but also provisions for holding a quantity of deaerated water in reserve to accommodate situations where extra feed may be required by the boiler. As a rule, 10 minutes worth of water storage has proven to be adequate to meet the needs of the majority of installations but this amount can range from less than 5 minutes to 30 minutes depending on the steam plant design and mode of operation.

The deaeration devices and storage can be provided within a single vessel or in a two-tank design. In the 'two-tank' or 'double shell' arrangements, the deaeration devices are housed in a smaller vessel or dome that is separate from the storage vessel, mounted on top. When the two-tank arrangement is used, the storage vessel is practically always a horizontal vessel. The top tank is a vertical or a horizontal deaeration tank. In such an arrangement the deaerator is supported directly on the storage tank and the two vessels are connected by means of downcomers and balancing lines to act as a single vessel during operation.

In the majority of cases, the deaerator (no matter if it is a one- or a two-tank design) is installed as a single, separate parcel that receives steam via piping connected to reduced pressure supplies from the boiler main, low pressure headers, or turbine extraction/exhaust points.

**Cardinal Principles of Efficient Deaeration**

1) The water must be heated to full saturation temperature to create an environment of 'zero' gas solubility.

2) Intensive contact between the water and steam must be realized to allow the gases to be 'scrubbed out' in a reasonable amount of time.

3) Released gases must be diluted by sufficient steam to produce minimum partial pressure above the water surface.

4) The released gases must be vented from the deaerator. For the sake of efficiency, the vent steam loss should be kept at a minimum.

**Modern Deaerator Design Features**

All modern deaerators accomplish deaeration in at least two steps or ‘stages’.

*Deaeration Stage 1 –Partial Deaeration by Direct Contact Pre-Heating Spray Devices*

Spraying cool water into an atmosphere of steam is a very effective method of obtaining high efficiency heat transfer and almost all modern deaerators use this technique as a first stage in the gas removal process. This spraying action causes the water to be heated almost instantaneously to a temperature that is within a few degrees of saturation as the steam is condensed by direct contact with the cooler water. A beneficial consequence of ‘preheating’ the water in this way is that a large part of the $O_2$ present in the water is released from solution as the water is heated.

Typically, the spraying devices used in deaerators are spray nozzles, which automatically adjust to the load placed upon them (e.g. by a spring system). The advantage of the ‘self-adjusting’ feature in these valves is that their opening varies in proportion to the load on the deaerator and high efficiency in the first stage is easier to maintain over a wide range of water flows. In contrast, there are spray devices that are not designed to vary their openings in response to load. These ‘fixed orifice’ spray nozzles produce progressively weaker spray action as the load is reduced below design flow, becoming less effective in heating and gas release performance. Therefore, most modern deaerators use ‘variable’ rather than ‘fixed orifice’ spray devices.
While effective at reducing the dissolved gas concentration to a large extent, a single stage of spray heating will not be enough to produce the extremely low level of $O_2$ needed to prevent corrosion of steel at boiler temperatures. Therefore, the spray-heating process must be supplemented to achieve complete deaeration.

*Stage 2 –Final Deaeration by Water/Steam Contact Scrubbing*

To finish off the oxygen removal, the water from the spraying stage is directed into another stage where surface area and additional time of water-steam contact can be provided to allow the water temperature to come closer to saturation and the residual traces of oxygen to leave the water. Surface and time in this step are interdependent. The more surface is provided, the faster the process can be completed. When a deaerator design provides the correct amount of water surface and time, the $O_2$ in the water will be reduced to not more than 7 ppb before leaving the deaerator.
Several techniques can be used by manufacturers to achieve this aim.

Tray Cascades

One method used to create a large surface area for steam-water contact is to provide a stack of baffles, called trays, with opening to allow controlled water and steam passage. The ‘tray stack’ is located between the spray devices and water level. The pre-heated and partially deaerated water from the spraying devices is distributed over the trays and flows down through the tray stack where it comes into contact with the steam flow which scrubs the oxygen from the water.
In this design, the spray devices and tray stack are usually located in separate “deaerator” vessel that is mounted above a second vessel that serves to hold an inventory of deaerated water. However, where an application allows a relatively small amount of deaerated water storage, tray deaerators can be supplied in a single tank arrangement.

Under-Water Steam Injection

In this set-up, the second stage of deaeration is established by injecting steam near the bottom of the storage tank, below the water level, using a steam charging device. While the steam drives through the water to reach its surface, the steam scrubs out the residual amounts of $O_2$

Scrubbing and Atomizing Devices

The second stage of deaeration may be accomplished by dividing the pre-heated water flow into small pieces (droplets, strings) by mixing it intimately with the incoming steam flow. To accomplish this task, there are fixed orifice designs, termed ‘scrubbers’ and variable orifice designs, referred to as ‘atomizers’. In essence both types cause the water to be atomized by the steam flow. Both types are well adapted to single tank deaerator arrangements.

**Effectiveness and Efficiency of Deaerators**

The technical efficiency and effectiveness of a deaerator is measured upon:

1. Technical effectiveness of a deaerator is measured by the amount of oxygen in the feedwater at the outlet of the storage tank, compared to the amount at the inlet, showing the ability to remove dissolved oxygen. Obviously, a 7 ppb design is more effective than a 20 ppb unit.

2. Thermal efficiency of a deaerator can be measured by the amount of vent steam loss. All modern deaerators are highly thermally efficient with the only heat loss being that which leaves the vent with the non-condensable gases and losses through the insulation, the latter not being a function of the deaerator design. With regard to the vent, the heat loss may represent a large number of heat units (Btus, kcals) but is usually a small portion of the heat input. The cost of the vent heat loss can be seen as an incremental operating cost.

3. Economic efficiency. Additionally, the economic efficiency of a deaerator must be evaluated considering the operating and replacement costs. This is a function of maintenance cost and frequency, equipment lifetime and initial equipment price. A component of the operating costs is the cost of chemicals needed to reach the desired performance. The economic impact of ineffective mechanical deaeration can be evaluated as the incremental operating cost associated with the additional chemical feed requirements.

**Deaerator Operating Pressure**

A deaerator can be designed to operate at any pressure above the ice point of water provided that a means of venting the removed non-condensable gases is available so that operation at saturation temperature is achieved. The conceivable operating pressure range would therefore be from almost full vacuum to critical pressure and units have been installed to operate from high vacuum to about 400 psig. Units operating at high vacuum necessarily operate at low temperature and variables like increased viscosity, oxygen solubility, and primarily high steam volumes to handle because of the low-pressure environment require larger equipment than would be needed at higher temperature.

Operation of the deaerator at positive pressure ensures that the unit can be positively vented at all times and is the preferred and usual mode of operation. The minimum operating pressure to ensure positive venting is 3 psig. Operation at 0-3 psig is possible, but incurs a risk of losing the vent action and introduction of air into the deaerator. These risks require special attention in a vacuum design to prevent a negative effect on the gas removal performance.

When operation at vacuum pressures is desirable (e.g., to improve efficiency of the plant), some form of device (e.g. vacuum pump or venting line to the condenser) must be connected to the deaerator vents for effective venting.

The deaerator operating pressures seen in industry vary with the plant design. It is generally recommended to use the lowest cost steam available to run the deaerator. Steam plants using reduced steam from the boiler main to supply the deaerator generally operate at 5-10 psig. Plants utilizing turbo-generators to co-generate power and process steam (e.g., paper mills) operate the deaerator at the pressures available from the turbine exhausts, 15-60 psig. Central station generating plants operate their deaerators on turbine extraction steam in the 130-200 psig range. Deaerators on HRSG applications generally operate at 5 psig to effect recovery of the low grade steam produced at the cool end of the generator.

## Integral deaerators for usage with HRSGs

With the increased use of combustion turbines as a power and heat source for steam generation, it is sometimes an advantage to install the deaerator unit in a manner that will allow it to serve as an add-on component to a steam drum of a heat recovery steam generator (HRSG), and this arrangement has become referred to as an “integral” deaerator. The combination with the steam drum can either be achieved by implementing a separate vessel or dome on top of the steam drum or by adding specially designed deaerating internals inside of the drum.

In the first approach, application in principle does not differ from a conventional two-tank deaerator arrangement, only the storage tank is replaced by the steam drum. The produced drum steam is delivered directly to the top-tank deaerator section, which is connected via a short pipe. Compared to the conventional deaerator, special design considerations for the separation baffling devices and method of transporting steam to the deaerator section as well as the deaerated water to the drum are needed to ensure problem-free operation.

In the second case, the internal drum solution, a deaerating device is installed directly into the steam drum, without the need of a top tank. In such a case, a special internal casing, a small carbon steel deaeration box, is installed around a high-performance condensate spraying device inside the drum.

From a construction standpoint, both options of “integral” deaerators are built in accordance with the boiler codes rather than as pressure vessels.

## Deaerator Construction Safety Features

Unless otherwise mandated by local law, comprehensive deaerator inspection should be done annually in accordance with authorities having jurisdiction. Pressure vessel construction of the deaerator is commonly covered by ASME Boiler and Pressure Vessel Code, commonly Section VIII, Division I.

## Final Remarks

The challenge for the deaerator designer is how to accomplish efficient deaeration in the smallest possible space. Deaeration performance should be stated for all relevant operating situations such as maximum load, minimum load, at varying pressure and temperature, condensate bypass situations of pre-heaters, etc. Many more pages of discussion would be necessary to give a full treatment of all the variations and details of deaerator design and application. Future white papers may focus on some of the finer points of deaerator selection and operation.