Does Your Deaerator Really Work?

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ABSTRACT: All deaerators are not created equal; with some designs, operating costs can exceed purchase price in a few years. Internal design can greatly affect the extent to which oxygen can be removed at minimum cost.
Design should encompass the coldest water conditions to be encountered throughout the year, not some idealized parameters.
Proper initial selection can eliminate the need to make design corrections in the field.

INTRODUCTION

Deaeration is one of the most commonly used unit operations in industry today. Virtually any facility using steam has at least one deaerator removing oxygen from the boiler feed water. Many of these units are taken for granted and not really tested to see how well they actually achieve the standard industry effluent quality of 7 ppb O2.

How does one go about testing their deaerator to determine how well it is operating? The simplest technique is to compare the temperature of the water in the storage tank to the saturation temperature at the steam pressure indicated in the upper scrubber section (measured in the steam atmosphere or space). This presumes of course the pressure and temperature gages or measuring elements are calibrated periodically (every 6 months or so) and provide factual and reliable information.

HEATING

Industrial units and steam supply lines should be designed for 100% cold water at the lowest possible temperature encountered during the year. Heat recovery equipment can fail and be left out of service for long periods. Utility deaerators normally encounter the same steady state conditions throughout their operating life.

A successfully operating deaerator should heat the water to within a degree or two Fahrenheit of the saturation temperature at the steam pressure within the unit. If you don't properly heat the water you do not deaerate the water, as this is the primary and most important step for good deaeration. At the boiling point of water the solubility of O2 is essentially zero **(Fig 1)**. Anything short of boiling means there is some O2 still left in solution. Once the water is heated to saturation temperature, the second step, that of mechanical scrubbing and the third step, venting, must be accomplished to insure the O2 gas can break free of the water and be carried out of the unit to the outside environment with minimum steam loss. If you are not properly heating the water, how well steps 2 and 3 are accomplished is immaterial.

So take a look at properly operating pressure and temperature measuring elements to see if your unit has a chance to meet the guaranteed oxygen effluent.

DISSOLVED OXYGEN TESTING

Once the effectiveness of heating is determined you must resort to chemistry to measure the O2 content of the deaerator scrubber effluent and see how effectively steps 2 and 3 are being conducted.
Note, I said the scrubber effluent, not the deaerator storage tank effluent. A well-designed deaerator

system (deaerator scrubber and storage tank) will always have a sample connection between the scrubber section **(fig 21)** and the storage vessel, unless of course both sections are combined into one pressure vessel.

If in an effort to economize, your unit does not have a properly placed sample connection, you can shut off the chemical oxygen scavenger feed to the storage tank and wait until the storage is purged of the scavenger before commencing the O2 testing.

Naturally these testing procedures should be conducted when your deaerator system is started up for the first time. In this way you will know if your particular design ever did work properly under your actual inlet conditions of operation (rather than some idealized dynamic conditions dreamed up in the initial engineering design stages).

Determination of dissolved oxygen in boiler water or feed water can be carried out by titration methods (ASTM D888-03), or by on-line instrumental techniques (ASTM D5462-93).

For both methods the sample must be cooled to ambient temperature, and the sample must be handled so as to exclude contamination by contact with the air. Precautions must be taken to insure that air cannot enter the sample in the sample lines, coolers, valves, etc.

In the titrimetric method a sealed ampoule is immersed into an overflowing stream of cooled sample. The ampoule is equilibrated for several minutes, and is then broken. Since the ampoule is sealed under partial vacuum, when broken a water sample enters the ampoule. Liquid is quickly mixed and read in a visual comparator. The color intensity is matched to a scale. Test ampoules come in a variety of ranges from low part-per-billion to high part-per-million levels.

Instrumental methods utilize a semi-permeable membrane arrangement with an electrochemical sensor, much like a pH probe. This probe is typically inserted in-line in the sample panel, but can be immersed in an overflowing vessel. A very large dynamic range is available, measuring dissolved oxygen levels from low ppb to high ppm all with the same probe.

Instrumental methods require frequent membrane maintenance and calibration.

VENTING AND TROUBLESHOOTING

Many problem conditions are observable from the outside of an on-line deaerator system, which can indicate whether your unit is not operating correctly, or as economically as possible.

These are: (Fig 2)

HIGH OXYGEN IN EFFLUENT
EXCESS CHEMICAL SCAVENGER USE
EXCESS VENT STEAM (Too High a Plume)
EXCESS NOISE AND/OR VIBRATION
WATER OUT OF THE VENT
INSUFFICIENT HEATING
UNSTABLE FLOW & LEVEL CONTROL
SIGNS OF INTERNAL CORROSION (Steam Leaks)

Some of these may crop up as a function of aging and normal wear and tear. Others may be indicative of poor equipment selection or design initially. This latter situation is particularly true if the unit was incapable of producing 7 ppb at startup or was very slow (a matter of days) in developing design effluent quality. A change in the inlet operating conditions from those outlined in the original design specifications can also produce these operating problems, particularly with equipment of marginal design parameters.

Standard industry warranties normally define the inlet water temperature conditions as 60 Deg F **or higher**, yet changes in plant operations (changes from well to surface supplies, loss of condensate returns, or boiler blowdown heat recovery) often cause higher raw water makeup requirements. Winter to summer temperature variations can drop inlet water temperatures to 40-50 Deg F or less. It is not uncommon to find systems unable to meet the 7 ppb design effluent guarantee during the winter months. Such a problem has been observed as far south as Houston TX. Naturally, a drastic increase in the cost for chemicals for O2 scavenging can result. If you have a new deaerator, that does not produce design quality effluent, substantially higher operating costs both for scavenger chemicals and higher than normal vent steam losses can result.

Design Modifications

Deaerating Systems can be modified to eliminate many of these operating system problems. After equipment examinations by qualified designers and troubleshooting specialists, numerous changes can be incorporated into the system designs both internally and externally. Among these are:

a) Improved inlet water distribution configuration

b) Improved spray nozzle systems

c) Increased residence time in the scrubber section

d) Alternative tray designs

e) Addition of internal support elements, such as hold-downs etc.

e) Relocation of system instrumentation and controls

f) Addition of system monitoring and control equipment

g) Addition of parallel scrubber sections

Many operating difficulties could have been avoided if proper selection of the type of deaerator had been made at the time of equipment procurement.

Types Of Deaerators

Modern deaerator scrubbers can be divided into two types, tray and atomizer (scrubber). Each of these can be divided further into two types:

Tray units **(Fig 3 - 11)** can be Co-counter-flow (often referred to as Co-flow or parallel down) or counterflow. These units usually require a minimum of 10 to 20 degree Fahrenheit temperature difference between the inlet water temperature and the operating temperature of the unit, depending on the type selected.

Atomizer units **(Fig 12 - 14)** can be variable or fixed orifice (scrubber). These units can require a 50 degree Fahrenheit temperature difference between the inlet water temperature and the operating temperature of the unit.

Co-counter flow or (Co-flow or parallel flow) tray scrubbing units and variable orifice spray designs (up to a point) are the most flexible and forgiving of changes in the inlet design conditions particularly those of temperature. If you want a unit capable handling a variety of inlet conditions, relocation or emergency conditions at your plant, then these would be your selection.

It is easy to see why this is the case, just by examining the water and steam flow patterns and velocity in the scrubbers with changing inlet temperature conditions.

Most of the deaeration (95-99% depending on type selected) is accomplished in the preheater or water spray (upper) section of the deaerator.

This is why the design of the spray nozzles and inlet distribution equipment is so important. This primary treatment section is common to both tray and atomizer deaerators. The secondary section or the polishing scrubber zone can be either a tray or steam atomizer section.

It is the job of the secondary scrubber to reduce the oxygen level to the standard industrial guarantee of 7-ppb O2 by weight. Either type (tray or steam atomizing) must divide the water flow into small enough particles to accomplish the final heating to nearly the saturation temperature at the set operating pressure. It must also minimize the distance the residual oxygen must travel to escape the water and enter the scrubbing steam atmosphere, thus enabling the steam leaving the vent connection to carry the oxygen to the external atmosphere.

A tray unit accomplishes this objective by continuously breaking up the water into new droplets as it progresses downward through the successive courses (layers) of trays (or packing).

An atomizing scrubber uses the kinetic energy of the steam, which is introduced into the water through either a fixed or variable orifice steam valve. The steam blasts the water into fine droplets allowing proper heating and oxygen diffusion into the scrubbing steam.

In a counterflow tray scrubber design **(Fig 3 - Fig 8)**, the steam passes opposite to the water so that reduced inlet temperature or increased water flow will cause the steam to produce greater resistance to water flow. It can, in marginal designs or those limited to a fixed inlet temperature, cause hold-up, driving the water to the sides of tray box (the umbrella effect). This channeling interferes with heat and mass transfer. In order to compensate for this problem, counterflow deaerators must be made larger in diameter (thus adding to the cost). Thirty two (32”) inches of tray height is required for the most common counterflow design.

Steam rising across the entire area of, and through the counterflow trays contacts only a single water sheet, a less dense water volume before reaching the vent off take connection, because it is collected across the entire area of the tray box. This condition results in 1) less condensation of the steam exiting the unit and 2) in higher vent rates. These

As the inlet water flow increases or temperature drops in a Co-counterflow (Co-flow or parallel) tray scrubber design **(Fig 9 – Fig 11)**, more steam flow is demanded to supply the additional heat required to maintain the preset temperature conditions. Both the steam and water pass downflow through the tray compartment. Steam distributes and drives the water through the trays, thus minimizing channeling, creating higher internal velocities and turbulence. In this way both heat and mass transfer are improved by reducing the film coefficients, on both the water and steam sides. Steam then reverses direction as it leaves the trays, passing upward in the annular space between the tray compartment and the pressure vessel to the inlet water spray section and out the vent connection. This design does not increase in diameter as steam loads increase. The designer must however, check steam velocities for the supply line and deaerator steam connection which may increase in size.

It is in the inlet water spray section where the steam must pass lower and horizontally through the two sheets of water formed by the centrally located hollow cone spray nozzles, where the majority of the improved heating and oxygen removal is accomplished, to a greater degree than is possible in the counterflow unit.

The more closed design of the Co-flow (parallel down) trays **(Fig 10 – Fig 11)** also is superior and more efficient than the open design of the counterflow system. It is responsible for the higher velocities, more intimate contact, better distribution and turbulence achieved in the Co-flow design. Only twenty four (24”) inches of tray height is required for the Co-flow system.

A variable orifice type **(Fig 12)** scrubber utilizes a spring loaded internal steam valve to introduce the steam into the water in the deaerator section, thus blasting the water into very fine droplets. The fact that the kinetic energy (velocity) the steam imparts to the water can remain high and relatively constant with changing inlet water flow rate and temperature, improves the effectiveness and range of the variable type of scrubber over the fixed orifice type. Small fine water particle formation is maintained with a variable orifice design. The bad side to this design is the requirement for additional moving parts and springs to moderate the steam flow, which can result in breakage and increased maintenance.

A fixed orifice type scrubber **(Fig 13 – Fig 14)** works well only over a very limited flow range, because the kinetic energy (velocity) of the steam through the orifices quickly drops off as the water flow falls (due to reduced steam flow) increasing the size of the water droplets formed.

When different or changing inlet operating conditions cause poor oxygen removal, it is sometimes possible to change the inlet distribution systems, spray valves (better efficiency), trays, or atomizing scrubbers to improve the operations of existing units. Often an examination of the external piping reveals engineering or installation errors which cause unstable operating conditions that interfere with successful system operation.

Troubleshooting Tips

Steam pressure in the deaerator should be sensed as close to the deaerating section as possible, preferably directly on the deaerating unit shell.

Steam pressure control valves should be located directly adjacent to the unit shell. Both these locations avoid introducing a lag between sensing a change in conditions and a response, which can cause hunting in operating steam pressure. Steam pressure in a deaerator must be very constant not continually changing, or system control is upset and operating results suffer. As the pressure in the deaerator section drops the enthalpy in the stored and deaerated water causes it to boil, rendering level sensing instruments inoperable and flow control is lost. This explosion of steam from the storage tank up into the deaerator section can destroy the trays and internals in the upper section.

Often the problems are not with the deaeration equipment, but with the piping, valving or instrumentation added to the unit by the original engineering or construction personnel. A design requirement as basic as insuring sufficient npsh for the boiler feed pumps at the operating flow and temperature can be overlooked.

Operating system problems can be avoided by eliminating the use of open-close solenoid valves for makeup control and use of more consistent controls, such as a 4-20 signal or float valves for continuous control of makeup water. This arrangement will also allow pretreatment and steam control equipment to operate more efficiently, with a more consistent flow.

Always install check valves as close to the unit as possible for all piping returns or feeds to the deaerator, in order to reduce flashing, vibrations and hammering in pipelines.

A deaerator can appear to be operating correctly because sufficient oxygen scavenger is being fed to the storage tank, but the area above the water line in the storage section can be experiencing gradual or even rapid corrosion due to any of the aforementioned problems. If the upper storage tank **(Fig 15 - Fig 21)** is experiencing corrosion the deaerating section will likewise experience corrosion. Sometimes the only warning of difficulty is excessive chemical scavenger use or equipment failure.

The most overlooked operating parameter and the most expensive of all, is the quantity of steam being lost to the environment. This is most easily determined through the placement of successively sized orifice plates in the vent line, while monitoring the oxygen content. Take care not to exceed the critical conditions. Once the oxygen drops below 7ppb the proper vent size and the minimum amount of vent steam has been determined. Control of the vent losses can be limited by automating the vent valve and controlling the position proportional to the effluent oxygen content. Vent loses can also be limited by characterizing the opening of a manual valve as outlined in various articles on pressure drop and fluid flow.

A 300 #/hr difference in the vent rate between two different deaerator designs is valued at $13,000 per year (assuming steam value at $5.00/1000#). Such a difference is quite common even in units in the 200,000#/hr. size range or smaller. **<u>You could purchase a deaerator you could not afford in the long run, even if the supplier gave it to you free.</u>**