

Boiler Water Quality Requirements and Associated Steam Quality for ICI Boilers



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Boiler Water Quality Requirements and Associated Steam Quality for ICI Boilers

2012

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INTRODUCTION

The purpose of this publication is to acquaint engineers, purchasers and operators of industrial, commercial and institutional (ICI) boilers with ABMA's judgment as to the relationship between boiler water quality, boiler operation, and boiler performance. This document is published for general guidance as a supplement to detailed operating manuals supplied by the equipment manufacturers. It should also be noted that the information presented is directed to steel boiler designs, as opposed to cast iron sectional or copper finned tube boilers. Furthermore Utility Boilers and Combined Cycle Boilers, which require extremely close control of water quality and steam purity, are not the topic of this document.

This new document combines two previous ABMA Guideline documents, namely “Boiler Water Requirements and Associated Steam Purity for Commercial Boilers” (1998), and “Boiler Water Limits and Achievable Steam Purity for Watertube Boilers”, (1995).

The document discusses the effect of various feedwater and condensate systems on the boiler operation. It also provides information on boiler water and steam testing as well as system care and maintenance.

It is recognized that specific boiler usage and water treatment will vary and may require values different from these recommendations. Boiler users therefore, need to define limits, equipment and operating parameters for their particular application.

These recommendations are for information only. Everyone is free to accept or reject the conclusions of these suggestions as their own judgment warrants in all aspects of the conduct of their business.

The ABMA does not represent or warrant that any level of steam purity depicted will be achieved by any particular boiler or boilers.

BACKGROUND

The American Boiler Manufacturers Association (ABMA) was established in 1888 as an association of commercial, industrial and utility boiler manufacturers and manufacturers of fuel burning systems.

In 1939, recognizing the need for information on boiler water and steam conditions, the association published boiler water conditions and steam purity recommendations. This work was reaffirmed and published in 1942, 1947 and 1954. A major revision was published in 1958 and reaffirmed in 1964. Since that time, there has been significant improvement in water treatment and the analytical techniques for measuring water and steam purity. In addition newer and more sophisticated plant designs require improved water and steam purity. Due to these developments and the fact that many users were unacquainted with the earlier work, the association recognized the need to update and republish these recommendations in 1982. That version represented significant change and was intended to reflect the current state of the art for steam generator water requirements. The Watertube version was further updated in 1995 to reflect more rigorous steam purity requirements for modern turbines and other applications requiring exceptionally high steam purity. The most recent version of the commercial boiler document was published in 1998. The 2005 combined version of the two water quality documents represents an updating to reflect current requirements for steam purity and water quality, particularly in view of the current interest in combined heat and power systems. The 2012 version updated the various types of feedwater treatment techniques commonly used and provided more depth into techniques and equipment functionality. The various product and technical groups within ABMA reviewed and revised the document prior to its 2012 republishing.

SAFETY PRECAUTIONS AND WARNINGS

1. Before commencing operations, follow the Boiler Manufacturers Installation and Start-Up Checklist, or if this is not available, the Installation and Start-up Checklist on page 34.
2. Neat feed of liquid chemicals is the recommended and safest practice because direct handling of chemicals is not required. However, when dissolving chemicals is required, the following should be observed:
 - (a) Use of suitable face mask, goggles, protective gloves and garments is required when handling or mixing caustic chemicals.
 - (b) Do not permit the dry chemicals or solution to come in contact with skin or clothing.
 - (c) Always follow the safety precautions on the container's labeling.
 - (d) Warm (80 to 100°F) water should be put into a suitable container.
 - (e) Slowly introduce dry chemical into water, stirring at all times until the chemical is completely dissolved.
 - (f) The chemical must be added slowly and in small amounts to prevent excessive heat and turbulence.
3. Boil out under pressure is not recommended for the class of boilers covered by this document. If units must be boiled out under pressure competent supervision must be provided.
4. If the boiler is not to be operated within 24 hours after boil out see the requirements of Chapter 7 on Lay-Up.
5. In existing systems the gradual introduction of filming amines is recommended to avoid the rapid removal of corrosion products. Fast removal of rust will cause plugging of traps and strainers (see page 18).
6. Boilers laid up dry shall be tagged with information to indicate the unit must not be operated until moisture-absorbing chemicals are removed and the boiler refilled (see also Chapter 7).
7. The use of nitrogen for blanketing is recommended in many of the lay-up procedures. Nitrogen will not support life; therefore, it is essential that proper precautions be taken before such equipment is entered for inspection or other purposes. These precautions shall include disconnecting of the nitrogen supply line, thorough purging and venting of the equipment with air and testing for oxygen levels inside the equipment. Appropriate caution signs shall be posted around the equipment to alert all personnel that nitrogen blanketing is in use.
8. Obtain **MATERIAL SAFETY DATA SHEETS** from the supplier for **ALL CHEMICALS USED** for water conditioning, cleaning and/or lay-up. Read and follow the recommended handling procedures and precautions. Be aware of any potential health hazards from the chemicals being used.

CHAPTER 1

FEEDWATER AND BOILER WATER

Feedwater supplied to boilers usually contains some amount of sediment, dissolved solids, and dissolved gasses. This can include everything from easily filtered dirt and sand, to harder to remove impurities such as iron, calcium, silica, sodium and chlorides, to gasses such as oxygen and carbon dioxide. When such contaminants are present in the feedwater and/or boiler water, it can have an adverse effect on boiler performance and life. Hence, it is of utmost importance to supply feedwater with the appropriate quality to the boiler and to maintain the quality of the boiler water within the boiler to prevent:

- Scale Forming Deposits
- Corrosion
- Poor Steam Quality

When this water is evaporated (or boiled) it leaves the system as a vapor, but the sediment and dissolved solids are left behind in a lesser amount of water. This results with the original dissolved solids and sediment present at higher concentrations within the boiler water. As the concentrations of these dissolved solids increases, the propensity to precipitate (form a solid) out of a solution increases. As these dissolved solids concentrate and begin to precipitate, they form scale on any available surfaces (primarily, the heating surfaces in the boiler). This scale acts as an inhibitor to heat transfer and the boiler will begin to operate below capacity and at lower efficiencies and may eventually fail.

Carbon dioxide is a major cause of corrosion in boiler systems. This is because it dissolves in the water formed when condensation occurs, producing carbonic acid. Most corrosion caused by carbonic acid occurs in the boiler condensate system; when inside the boiler, corrosion caused by carbonic acid will occur below the water level, and it can be identified by the channeling or grooving of the metal wall.

Oxygen can also cause corrosion in condensate systems. However, it is not as common as carbon dioxide corrosion because oxygen can be removed from the feedwater by several treatment techniques. Oxygen corrosion occurs wherever moisture is present, so it will be found both above and below the level of water in the piping. In the boiler, oxygen corrosion is usually found on the top side of boiler tubes.

Carryover is a relative term which is used to describe entrainment of boiler water in the steam. This entrained boiler water will have a direct impact on the quality of the steam produced by the boiler. Since it is impossible to completely separate boiler water from steam, carryover will occur in any boiler.

Therefore, to ensure optimal boiler operation, it is best to eliminate these unwanted contaminants from the feedwater before they cause problems. A reliable water treatment consultant should be contracted to analyze the water and recommend a proper water chemistry program as this is the best assurance to ensure that the feedwater supplied to the boiler is of appropriate quality. However, in the absence of manufacturer's instructions or those of a water treatment consultant, the following ASME recommendations for quality limits can be used as a reference.

FEEDWATER

The quality of recommended feedwater varies with the operating pressure of the boiler and the boiler design. The location of the water and heat source inside the boiler (i.e., inside the tubes or outside the tubes) dictates the type of boiler one is dealing with. Fire-tube boilers pass fire and hot combustion gas through the interior of the boiler tubes. The recommended feedwater limits for these types of boilers are listed in Table 1. Water-tube boilers pass water through the interior of the boiler tubes. The recommended feedwater limits for these types of boilers are listed in Table 2.

TABLE 1

RECOMMENDED FEEDWATER LIMITS FOR FIRE-TUBE BOILERS

Drum Pressure (psig)	Dissolved Oxygen (ppm)	Total Iron (ppm)	Total Copper (ppm)	Total Hardness (ppm)	pH	Nonvolatile TOC (ppm)	Oily Matter (ppm)
0 – 15	< 0.03	≤ 0.1	≤ 0.05	≤ 1.0	8.3 – 10.5	< 10	< 1
16 – 300	< 0.007	≤ 0.1	≤ 0.05	≤ 1.0	8.3 – 10.5	< 10	< 1

TABLE 2

RECOMMENDED FEEDWATER LIMITS FOR INDUSTRIAL WATER-TUBE BOILERS

Drum Pressure (psig)	Dissolved Oxygen (ppm)	Total Iron (ppm)	Total Copper (ppm)	Total Hardness (ppm)	pH	Nonvolatile TOC (ppm)	Oily Matter (ppm)
0 – 300	< 0.007	≤ 0.1	≤ 0.05	≤ 0.3	8.3 – 10.0	< 1	< 1
301 – 450	< 0.007	≤ 0.05	≤ 0.025	≤ 0.3	8.3 – 10.0	< 1	< 1
451 – 600	< 0.007	≤ 0.03	≤ 0.02	≤ 0.2	8.3 – 10.0	< 0.5	< 0.5
601 – 750	< 0.007	≤ 0.025	≤ 0.02	≤ 0.2	8.3 – 10.0	< 0.5	< 0.5
751 – 900	< 0.007	≤ 0.02	≤ 0.015	≤ 0.1	8.3 – 10.0	< 0.5	< 0.5
901 – 1000	< 0.007	≤ 0.02	≤ 0.01	≤ 0.05	8.8 – 9.6	< 0.2	< 0.2
1001 – 1500	< 0.007	≤ 0.01	≤ 0.01	≤ 0.05	8.8 – 9.6	< 0.2	< 0.2
1501 – 2000	< 0.007	≤ 0.01	≤ 0.01	≤ 0.05	8.8 – 9.6	< 0.2	< 0.2

A Compounding Effect: The concentration at which a dissolved solid will scale decreases as pressure increases. Thus this indicates an increasing water purity requirement with increasing boiler pressures. This is the reason for more stringent feed water quality requirements for higher pressure boilers, as shown in the Figure 1 below:

ABMA Boiler Drum Water
Recommendations

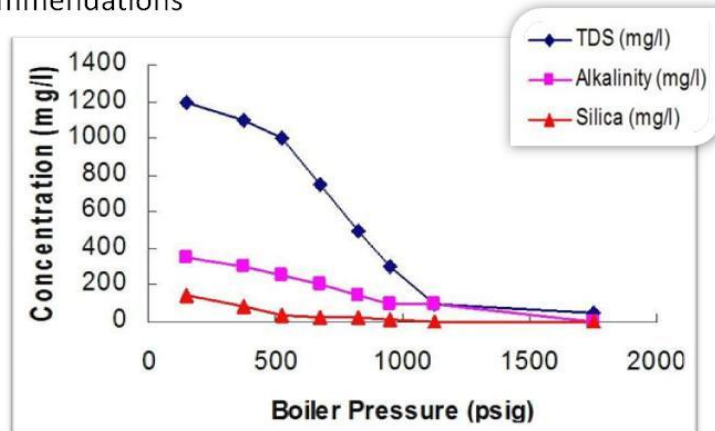


FIGURE 1

It should be noted that some systems, such as steam turbines and superheaters, would require higher purity feedwater than referenced in this document. In the case of steam turbines, the manufacturer of the turbine to be used should define the steam quality requirement needed from the boiler. It should further be noted that steam quality requirements could differ between the various turbine manufacturers. Thus it is important that the various selected equipment manufacturers (boiler, turbine, water treatment, etc.) communicate with the system owners at an early stage in the project regarding steam quality and feedwater quality requirements, in order to avoid later problems.

BOILER WATER

The quality of recommended boiler water varies with the operating pressure of the boiler. Table 3 lists recommended boiler water limits that were developed by considering the following:

- Type of feedwater generally available.
- Type of boiler water treatment normally utilized for the specific pressure.
- Effect of the dissolved solids in the steam on the boiler and other plant components.
- The general performance of steam drum internals. At the higher pressures, the lower boiler water limits reflect the increased difficulty of steam/water separation and the increased volatility of soluble compounds.

e. Boiler water alkalinity limits. Below 1000 psig alkalinity concentrations were selected as 1/5 of boiler water total solids to reduce the potential for excessive foaming. Above 1000 psig, the high purity (low solids) feedwater normally used eliminates the significance of any alkalinity limits. This is also true where high purity feedwater is used below 1000 psig.

f. Vaporous carryover of sodium becomes significant in the pressure range of 2601 to 2900 psig.

g. For a once-through boiler, the steam purity is essentially equal to feedwater purity. The recommended TDS and alkalinity limits assume no operating practice to achieve the associated values of steam purity. It may be possible to operate with higher values and still achieve satisfactory steam purity depending on the feedwater constituents and plant operating conditions.

TABLE 3
RECOMMENDED BOILER WATER LIMITS
AND ESTIMATES OF CARRYOVER LIMITS THAT CAN BE ACHIEVED

CONDITIONS FOR WHICH "FCO" IS VALID					
Drum Pressure psig	Maximum Boiler Water Solids ppm	Steam TDS Corresponding to Max. BW TDS ppm	Maximum Total Alkalinity ppm as CaCO ₃	Maximum Suspended Solids ppm	Maximum FCO, Fractional Carryover ²
0 - 300	3500	1.0	(1)	15	0.0003
301 - 450	3000	1.0	"	10	0.0003
451 - 600	2500	1.0	"	8	0.0004
601 - 750	1000	0.5	"	3	0.0005
751 - 900	750	0.5	"	2	0.0006
901 - 1000	625	0.5	"	1	0.0007
1001 - 1800	100	0.1	N/A	1	0.001
1801 - 2350	50	0.1	N/A	1	0.002
2351 - 2600	25	0.05	N/A	1	0.002
2601 - 2900	15	0.05	N/A	1	0.003

NOTES:

(1) 20% of Actual Boiler Water Solids. For TDS ≤ 100 ppm, the total alkalinity is dictated by the boiler water treatment.

(2) Does not include vaporous silica carryover

The fractional carryover (FCO) values listed in Table 4 can be used to estimate maximum boiler water (BW) concentration limits consistent with required steam dissolved solids (TDS) and sodium limits down to 0.050 ppm TDS and down to 0.005 ppm sodium.

$$\text{BW sodium} \times \text{FCO} = \text{Steam Sodium}$$

$$\text{BW TDS} \times \text{FCO} = \text{Steam TDS}$$

This formula does not apply to silica or other species subject to exceptional vaporous carryover, which is undiminished by devices installed to remove moisture from the steam.

It must be realized that the highest boiler water total dissolved solids limit for any of the pressure ranges in boilers operating below 1000 psig is based on present day practice and is consistent with softened feedwater. If a value lower than the maximum solids concentration in the boiler water is dictated by steam purity needs, improved feedwater purity (demineralization) and/or increased boiler water blowdown may be required.

Above the 1000 psig pressure range with the reduced total solids in the boiler water, foaming is not a consideration. Alkalinity will be dependent on the type of boiler water treatment employed. The feedwater required for these boiler pressure ranges is of demineralized quality.

Example: The desired purity of steam will be chosen as required for turbine protection, superheater protection, or process requirements. The table and formula are then used to estimate achievable carryover and the required boiler water purity. For example, if a boiler with a drum pressure of 500 psig is to provide steam containing less than 0.5 ppm dissolved solids, then the maximum recommended solids in the boiler water is 1250 ppm.

$$\text{BW TDS (ppm)} \times \text{FCO} = \text{Steam TDS (ppm)}$$

$$\text{BW TDS (ppm)} = \text{Steam TDS (ppm)} / \text{FCO} = 0.5 \text{ ppm} / 0.0004 = 1250 \text{ ppm}$$

Table 4 lists recommended maximum concentrations that may be obtained in the absence of other factors that may have to be considered in achieving the desired steam quality.

TABLE 4

RECOMMENDED BOILER WATER CONCENTRATION FOR FIRE-TUBE BOILERS

Boiler Pressure psig	Total Dissolved Solids ppm	Total Alkalinity ppm as CaCO ₃	Suspended Solids ² max. ppm	Silica ¹ ppm	Total Iron ¹ max. (Fe) ppm
0 – 250	5000 - 3500	1200 - 900	100	150 - 100	10
251 – 350	4000 – 3000	900 - 700	25	120 – 100	8
351 - 500	3000 - 2500	800 - 600	10	80 - 50	5

NOTES:

- (1) Maximum values may not be achievable due to plant operating conditions or feedwater characteristics
- (2) Critically affected by operating conditions and year of boiler manufacture

CARRYOVER

Since the degree of carryover or entrained boiler water, which can be tolerated, will vary with process requirements or operating conditions, it may be more accurate to simply define the steam quality which may be required for trouble free operation.

Saturated steam is normally generated in commercial installations. Barring unusual requirements, saturated steam quality for commercial installations is usually less stringent than that required for superheated steam which is commonly required in industrial processes. This greater latitude can be used to an advantage when considering commercial steam boiler system operation.

BOILER SERVICE

The type of system or steam use will largely determine the required steam quality. With saturated steam, the percent moisture may be of greater concern than the actual dissolved solids concentration. However, solids are more easily measured than percent moisture, so solids will be referred to as target values.

Boilers are typically designed, and tested, to deliver to system saturated steam not less than 98% steam quality. Stringent steady state control of operating parameters are employed by manufacturers when factory testing for boiler overall efficiency and performance. Many factors affect boiler steam quality performance in any system in which a boiler is commissioned. To name but a few, operating pressure, critical load, firing rate, water quality, boiler lead design, system design, operation, preventive maintenance and ancillary support system operation and maintenance are all contributing factors in yielding satisfactory steam quality performance.

Where saturated steam is used in cogeneration or turbine driven auxiliaries, lower moisture content should be considered. This is because impingement of water droplets on the turbine blades will cause erosion, and this may eventually cause considerable damage. However, such steam use can still tolerate above average total dissolved solids. For such

systems, steam solids should be restricted below a maximum of 3 ppm, corresponding to approximately 0.1 percent moisture.

Humidification steam quality requirements are not critical in most applications. The usual concern is over the presence of odors in the steam, which may be imparted into the humidified air. However, there are processes where very high standards must be met. In most of these cases, the quantity of steam required is small. The use of a separate steam source is often the best solution.

PRESSURE

The specific volume of steam increases as the pressure decreases. In other words, a steam bubble at low pressure will occupy a larger volume than one of equal weight at high pressure. This can have an important influence on steam quality, because the steam release space in low pressure boilers should be greater than that provided in a higher pressure boiler with the same generating capacity.

This space is important because it is one of the factors that control the separation of moisture or water droplets from steam. Operating conditions that affect this, such as high water level, will promote mechanical entrainment of boiler water in the steam.

Load changes, which cause sudden pressure drops, will also have an adverse effect on steam quality. The pressure drop will cause flashing of boiler water into steam because of the reduction in boiling point. The sudden demand for additional steam will add to the turbulence in the steam release space, and this combination will cause excessive moisture to be entrained in the steam.

CHAPTER 2

FEEDWATER PRETREATMENT SYSTEMS

A properly engineered and designed feedwater pretreatment system will save a tremendous amount of money and extend the lifespan of high value critical components in a plant such as the boilers, cooling towers and turbines. A relatively small investment spent on water treatment provides great insurance for properly operating equipment throughout the plant.

A feedwater pretreatment system may include one or several components working together to provide a method of introducing treated feedwater into a boiler. The treatment steps that will be required will depend on the source of the feedwater, its constituents and steam quality requirements as discussed in Chapter 1.

CARTRIDGE FILTERS

Cartridge filters have a wide variety of uses within a feedwater pretreatment system. Typical filters have pore sizes that range from 0.5 μm up to 250 μm and are available in many different materials of construction such as nylon and polypropylene. They are often used as final safety filters to protect membranes, pumps, and other equipment from suspended particles. For such an application, a pore size of 5 μm absolute is recommended. If there is a risk of fouling with colloidal silica or with metal silicates, cartridge filtration with 1 to 3 μm absolute pore size is recommended. The filter should be sized on a flow rate according to the manufacturer's recommendation and replaced before the pressure drop has increased to the permitted limit, but at least every 3 months.

Backflushable media filters as final safety filters are generally not recommended because of their risk of breakthrough in case of a malfunction of their backflush mechanism, their lower efficiency and the higher biofouling risk. Backflushable fine filters may be used upstream of the cartridge filters to protect them. They are however, no substitute for disposable cartridges. The cartridge filter housing should be equipped with a pressure gauge to indicate the differential pressure, thereby indicating the extent of its fouling. Regular inspections of used cartridges provide useful information regarding fouling risks and cleaning requirements.

If the differential pressure across the filter increases rapidly, it is an indication of possible problems in the raw water supply or in the pretreatment process. Replacing cartridge filters more often than every 1 to 3 months also usually indicates a problem with the pretreatment. The cartridge filter, however, is not meant to be a major component for the removal of high amounts of filterable solids. This would not only be an inefficient use of rather expensive filters, but would probably lead to premature failure of downstream equipment due to the high probability that some of the unwanted material will break through. An alternative approach would be to use a second cartridge with larger pore size upstream.

CHEMICAL TREATMENT EQUIPMENT

Chemical treatment equipment is used to introduce any chemical treatment, which may be necessary for good water chemistry. The type of equipment required will depend upon the condition of the raw water.

Types of chemicals that are typically used:

Biocides

See Disinfectants.

Coagulants

See Coagulants/Flocculants on page 20.

Disinfectants

Disinfectants kill unwanted microorganisms in water and are used in various applications.

Chlorine and Chlorine dioxide are used principally as a disinfectant for surface waters. They are an effective biocide at concentrations as low as 0.1 ppm and over a wide pH range. Chlorine dioxide disinfects according to the same principle as chlorine, however, as opposed to chlorine, chlorine dioxide has no harmful effects on human health.

Filming Amines

Unlike neutralizing amines, filming amines do not neutralize acidity or raise pH. Rather, they form a non-wettable barrier, which repels the corrosive environment of the condensate. Filming amines can handle severe oxygen corrosion problems more effectively than neutralizing amines.

The properties of filming amines also vary, particularly with respect to the corrosion resistance of the water repellent film. Combinations of filming and neutralizing amines are often employed.

CAUTION: In existing systems the gradual introduction of filming amines is recommended to avoid the rapid removal of corrosion products. Fast removal of rust will cause plugging of traps and strainers.

Flocculants

See Coagulants/Flocculants on page 20.

Neutralizing Amines

These are organic compounds, which are used to neutralize the acidity of the condensate. The corrosivity is greatly reduced by maintaining the condensate pH in an alkaline range. A pH somewhere between 8.5 and 9.3 is usually recommended. The severity of oxygen corrosion is also reduced at this high pH.

The properties of neutralizing amines vary with respect to their neutralizing ability and also the manner in which they are distributed throughout the steam distribution system. Accordingly, they may be used alone or in combination to achieve the desired results. Cyclohexylamine, diethylaminoethanol and morpholine are the most commonly used neutralizing amines. This is primarily because they are approved for use in plants, which are regulated, by the Federal Drug Administration (FDA) and U.S. Department of Agriculture (USDA).

Neutralizing Agents

Neutralizing agents are commonly used to neutralize acidic and basic feedwater or boiler water. A sodium hydroxide solution (NaOH) is commonly used to increase pH levels. A diluted sulphuric acid (H₂SO₄) or a diluted hydrochloric acid (HCl) solution is commonly used to decrease pH levels. In order to prevent corrosion within the boiler system, it is very important to monitor the pH level. The concentration of neutralizing agents that are added to the system depends upon the pH of the feedwater or boiler water.

Organic Oxygen Scavengers

Volatile or organic oxygen scavengers are employed as supplementary treatments, particularly where oxygen is causing a corrosion problem. Organic oxygen scavengers have the ability to establish and maintain a corrosion resistant film on the metal surfaces when the pH is maintained above 8.5. This is usually called passivation. In condensate treatment, these materials are not usually used to completely remove oxygen from the condensate.

Scale Inhibitors

Scale inhibitors are surface-active negatively charged polymers. When the solubility limit of compounds such as calcium carbonate or calcium sulfate is exceeded, the polymers become attached to the compounds. The structure for crystallization is disrupted and the formation of scale is inhibited. The smaller particles of scale that actually form, combine with the inhibitor will then be dispersed and remain in solution. A few examples of scale inhibitors are phosphate esters, phosphoric acid, and solutions of low molecular weight polyacrylic acid.

Types of chemical feed equipment available are:

- Intermittent-shot feeders
- Proportioning feeders
- Injection pump systems which may include storage tank and agitator

It is critical that the appropriate chemicals are introduced in the appropriate amounts and in the appropriate locations in the feedwater pretreatment system. Therefore, equipment selection, chemical selection and the location of injection point(s) of the chemicals should be made by a qualified chemical treatment firm.

COAGULANTS / FLOCCULANTS

The efficiency of media filtration to reduce the SDI value can be markedly improved if the colloids in the raw water are coagulated and/or flocculated prior to filtration. In-line filtration can be applied to raw waters with an SDI only slightly above 5. The optimization of the method is also called in-line coagulation or in-line coagulation-flocculation. A coagulant is injected into the raw water stream, effectively mixed, and the formed microflocs are immediately removed by media filtration.

Ferric sulfate and ferric chloride are used to destabilize the negative surface charge of the colloids and to entrap them into the freshly formed ferric hydroxide microflocs. Aluminum coagulants are also effective, but not recommended for RO feed because of possible fouling problems with residual aluminum. Rapid dispersion and mixing of the coagulant is extremely important. An in-line static mixer or injection on the suction side of a booster pump is recommended. The optimum dosage is usually in the range of 10–30 mg/L, but should be determined case by case.

To strengthen the hydroxide microflocs and thereby improve their filterability, and/or to bridge the colloidal particles together, flocculants can be used in combination with coagulants or alone. Flocculants are soluble high molecular weight organic compounds (e.g., linear polyacrylamides). Through different active groups, they may be positively charged (cationic), negatively charged (anionic), or close to neutral (nonionic).

Coagulants and flocculants may interfere with an RO membrane indirectly or directly. Indirect interference occurs when the compound forms a precipitate that is deposited on the membrane. For example, channeling of the media filter may enable flocs to pass through and deposit on the membrane. A precipitate can also be formed when concentrating the treated feed water, such as when aluminum or ferric coagulants are added without subsequently lowering pH to avoid super saturation in the RO stage. Furthermore, reaction with a compound added after the media filter can cause a precipitate to form. This is most noticeable with antiscalants. Nearly all antiscalants are negatively charged and will react with cationic coagulants or flocculants present in the water. The membranes in several RO plants have been heavily fouled by a gel formed by reaction between cationic polyelectrolytes and antiscalants.

Direct interference occurs when the compound itself affects the membrane resulting in a flux loss. The ionic strength of the water may have an effect on the interference of the coagulant or flocculant with the membrane. If so, the result at brackish water conditions could be different from that at seawater conditions. To minimize the risk of direct or indirect interference with the RO membrane, anionic or nonionic flocculants are preferred rather than cationic flocculants. Overdosing must be avoided.

For raw waters containing high concentrations of suspended matter resulting in a high SDI, the classic coagulation-flocculation process is preferred. The hydroxide flocs are allowed to grow and settle in specifically designed reaction chambers. The hydroxide sludge is removed, and the supernatant water is further treated by media filtration.

CONDENSATE RECEIVER (HOT WELLS)

Condensate receivers are required in a system to provide a collection and storage point for returning condensate. Returning condensate has a high heat content and is basically distilled water which makes it ideal to be feed to a boiler. Depending on the quality, the condensate in the condensate receiver can be returned directly to the boiler, be returned to the deareator, or used as a source of heat for another process.

DEAERATORS

Corrosion of iron or steel is influenced by three fundamental factors:

1. Temperature
2. pH value
3. Oxygen content

Temperature and pH value control the activity or aggressiveness of corrosion (high temperatures and low pH values increase aggressiveness). The oxygen content is a large factor in determining the extent or amount of corrosion. Figure 2 illustrates the expected oxygen content of raw water at various temperatures.

Iron goes into solution in pure water to a slight extent, according to the formula $\text{Fe} + 2\text{H}_2\text{O} \rightarrow \text{Fe}(\text{OH})_2 + \text{H}_2$ but the ferrous hydrate $\text{Fe}(\text{OH})_2$ formed is alkaline and raises the pH value. At a definite pH value further dissolving of iron is stopped. However, if oxygen is present it immediately oxidizes the ferrous hydrate forming ferric hydrate $\text{Fe}(\text{OH})_3$, which is insoluble and precipitates, permitting more iron to go into solution and thus the reaction continues until all oxygen is dissipated.

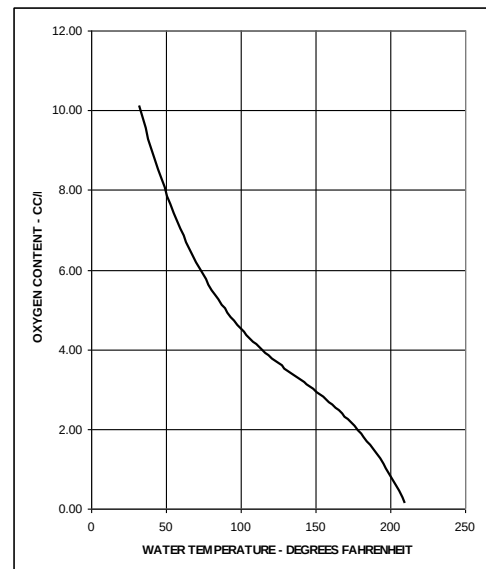


Figure 2

It is evident, therefore, that the removal of oxygen and carbon dioxide from solution is important and essential when conditioning water for industrial use. This is particularly true when boiler feed water and process water are used at elevated temperatures.

Deaeration is the mechanical removal of dissolved gases from a fluid. The process of deaeration is most frequently applied in boiler feed water heaters to protect piping, boilers and condensate equipment from corrosion. In other applications deaeration of cold water is necessary to protect pipe lines and equipment from corrosion, as well as to provide oxygen-free water required in some processes. Deaeration of service water for buildings and institutions is desirable in order to protect distribution systems.

The three cardinal principals that must be satisfied in any mechanical deaerator are:

Heating: Water must be heated to full saturation temperature (boiling point), corresponding to the steam pressure in the unit. Since, theoretically, the solubility of any gas is zero at the boiling point of the liquid, complete gas removal is not possible unless the liquid is kept at boiling temperature.

For operation at sub-atmospheric pressures, as is the case with cold water deaerators, evacuation or heating or both, must be applied to create this boiling condition.

Mechanical Agitation: The heated water must be mechanically agitated, by spraying, cascading over trays, or by atomization, to expose maximum surface contact to the scrubbing atmosphere, thus permitting complete release and removal of gases. When water is broken down into fine droplets for thin films, the distance that the gas bubble must travel for release is greatly decreased. Thorough agitation also overcomes tendencies of surface tension and viscosity to retain the gas bubbles and increases the rate of gas diffusion from the liquid to the surrounding atmosphere. The deaerating equipment, therefore, must provide the most efficient mechanical agitation possible to permit meeting modern requirements of gas removal. Since a normal warranty of “less than 0.005 cc per liter of oxygen” means less than 7 pounds in a billion pounds of water, the importance of effective agitation cannot be overstressed.

Complete Gas Removal: Adequate steam must be passed through the water to scrub out and carry away the gases after release.

Extremely low partial gas pressure must be maintained since Henry’s Law states that the amount of gas which will dissolve in a liquid is proportional to the partial gas pressure in the atmosphere contacting the liquid. It is mandatory that the volume of scrubbing steam be high to produce the low partial gas pressure, and it is equally mandatory that these conditions prevail throughout the deaerating section. The effect of partial gas pressure and heating is illustrated in Figure 3.

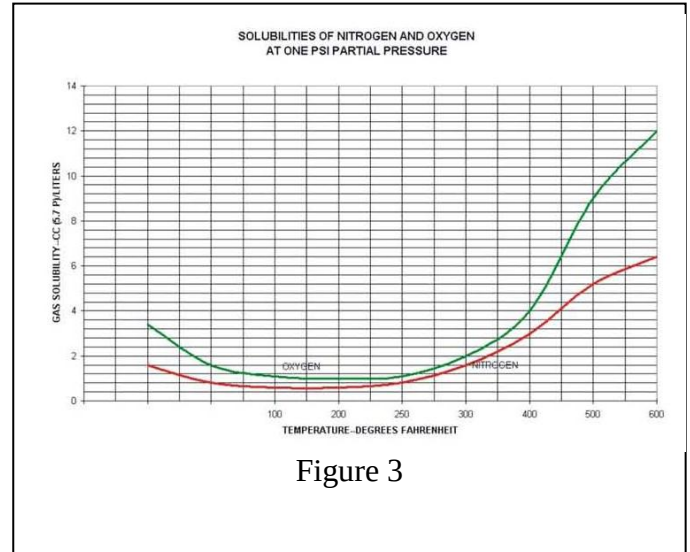


Figure 3

Deaerator Types

There are several types of deaerators that are commonly used: parallel flow tray, counter-flow tray, atomizing, spray scrubber, and cold water type. All designs employ the cardinal principles of deaeration outlined above.

Tray Deaerators

Tray type units are most widely used for deaerating boiler feedwater in industrial plants and central generating stations. Water is heated to full saturation temperature with minimum pressure drop and minimum vent, thereby assuring best thermal efficiency.

Deaeration is accomplished by spreading the water over multiple layers of trays designed to break the water into thin films and drops to promote intimate contact with the scrubbing steam. Tray type deaerators are manufactured in counter flow designs – steam and water flow counter-current to each other – and parallel flow designs – steam and water flow parallel to each other.

Spray Deaerators

This type of deaerator employs a high velocity steam jet to break up and scrub the water flow and create a turbulent mixture of steam and water for attaining final deaeration.

The breakup of water into fog-like particles increases surface area exposed to the steam and increases deaeration. Use in industrial plants occurs particularly where operating loads and pressures are stable.

Cold Water Deaerators

Cold Water deaerators are used primarily to eliminate corrosive gases from cooling water, demineralization systems and industrial water supplies without the addition of heat. The boiling condition is accomplished by pressure reduction with vacuum-producing equipment. Surface contact with scrubbing vapor is provided by a packing or Raschig rings.

The necessity for deaeration of boiler feed and process water has become so recognized that even small plants now achieve longer equipment life and reduced maintenance by employing some type of deaeration. Deaeration today is an important factor in the successful and economical operation of any modern boiler plant, regardless of its size.

DEALKALIZERS

Dealkalization is a process to reduce the boiler water alkalinity, as an aid in reducing the possibility of corrosion due to carbonic acid attacking the condensate system. The use of a dealkalizer usually requires the addition of a sodium hydroxide (caustic soda) injection system for pH adjustment.

Softened water is passed through a dealkalizer to reduce the bicarbonate and/or carbonate alkalinity and sulfate. These are replaced by an equivalent amount of chloride. The resulting water keeps boiler and process equipment clean and scale free, and also solves the problems of excessive boiler alkalinity and corrosive condensate. Savings can be obtained by lowering boiler blowdown requirement when the total alkalinity is the limiting factor and condensate line corrosion due to carbon dioxide can be minimized.

It is advisable to feed the dealkalizer with softened water. The hardness ions in the feed water can combine with the sulfate ions attracted to the anion resin and form an insoluble calcium sulfate precipitate. This scale will tend to foul the dealkalizer over time as it accumulates on the resin bed.

The advantages of dealkalizing with a strong base anion exchange resin are:

For regeneration, acid of not more than 105% of the stoichiometric value is needed. This minimizes operating costs and environmental impact.

The disadvantages are:

Residual hardness: If complete softening is required, a sodium exchange process with a strong acid cation exchange resin can be added, even in one vessel (layered bed). The overall consumption of regenerant chemicals via thoroughfare regeneration is still lower than softening with a strong acid cation exchange resin alone. Due to the higher investment costs, however, this combination will only be attractive for plants with high capacity. Another possibility to overcome this drawback of incomplete softening is to dose an antiscalant into the dealkalized water.

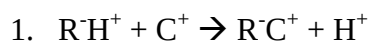
Variable pH: The pH of the dealkalized water ranges from 3.5–6.5 depending on the degree of exhaustion of the resin. This cyclic pH variation makes it difficult to control the salt rejection of the plant. At $\text{pH} < 4.2$, the passage of mineral acid may increase the effluent TDS content. It is therefore recommended that more than one dealkalizer be used in parallel and regenerated at different times to minimize the variability in pH. Other possibilities to avoid extremely low pH values are CO_2 removal or pH adjustment by NaOH afterwards.

DEMINERALIZER

Demineralization, or deionization as it is sometimes called, is the process of removing dissolved ionic impurities from water. These positively charged cations and negatively charged anions allow conductance of electricity and are called electrolytes. Electrical conductivity is thus a measure of water purity, with low conductivity corresponding to high purity. Weakly ionized contaminants such as silica contribute only slightly to the conductivity of water.

Demineralization by means of ion exchange is basically a two, step process involving treatment with both cation and anion exchange resins. This treatment can be in a series operation or in a common bed, depending on the process conditions and requirements.

In series operation, the water is usually first passed through a column of strong acid cation exchange resin which is in the hydrogen form (R^+H^+) to exchange the cations in solution for hydrogen ions.



(C represents common cations such as Ca^{++} , Mg^{++} , Na^+)

This effluent is then passed to a column of anion exchange resin in the hydroxide form (R^+OH^-) to exchange anions in solution with hydroxide ions: