**THE**
**NATIONAL**
**BOARD**
OF BOILER AND
PRESSURE VESSEL
INSPECTORS

# BOILER/FEEDWATER GUIDELINES



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## 1.0 GENERAL

The purpose of this document is to provide basic guidelines to the in-service boiler inspector for boiler/feedwater treatment and the recognition of normal/abnormal boiler/feedwater conditions for power boilers, steam heating boilers and hot water heating boilers.

## 2.0 ENVIRONMENTAL EFFECTS ON WATER

### 2.1 Earth's Hydrological Cycle

2.1.1 Water begins to evaporate as the sun heats up a body of water; this evaporated water gathers in the atmosphere and forms into clouds; when the water vapor in the clouds cools sufficiently to condense it begins to rain.

2.1.2 The rain is without impurities as it begins to fall; because it is pure or content neutral (pH7) it is "hungry rain," with a high affinity for oxygen and carbon dioxide in the atmosphere. The rain droplets absorb the oxygen and carbon dioxide as it passes through the atmosphere.

2.1.2.1 Some sources of carbon dioxide in the atmosphere are the combustion of fossil fuels, swamp fermentation, dairy farms (cattle flatulence), and respiration.

2.1.2.2 The carbon dioxide contributes to making the rain acidic (acid rain) and is the major source of carbon dioxide found in the boiler's condensate return system.

2.1.3 As the rain enters the ground, the acid condition helps the water dissolve limestone and it picks up other dissolved and suspended solids.

2.1.3.1 These underground minerals, found in feedwater, are the source of boiler scale.

### 2.2 Steam Boiler's Hydrological Cycle

2.2.1 A steam boiler's hydrological cycle is similar to that of the the earth's hydrological cycle. In a steam boiler system there are three potentially destructive elements; oxygen, carbon dioxide, and solids.

2.2.2 As the boiler water is heated and changes to steam free oxygen is released, carbon dioxide is released from the solids, and the solids drop out (precipitate).

2.2.3 As the steam is used it cools and turns to condensate in the steam system. The condensate like the rain droplets is "hungry condensate" with a high affinity for carbon dioxide and oxygen.  As the condensate cools, it becomes easier for gasses, such as carbon dioxide and oxygen to dissolve in the water.

2.2.3.1   Carbon dioxide is absorbed by the cooling condensate causing it to become acidic creating a similar condition as “acid rain” found in the earth’s hydrological cycle.  The acidic condition erodes iron pipes, creating a trench in the bottom of condensate piping and sometimes all the way through the pipe.

2.2.4   Free oxygen also joins with the cooling condensate.  Pits or holes in iron are caused by excessive oxygen in the boiler/feedwater.  These pits are called “tubercles.”

2.2.5   Iron, eaten away by “acid rain” and oxygen corrosion is transported to the boiler where it becomes an insulating deposit; it restricts heat transfer which can causes heat stress damage to the tubes and fuel waste.

2.2.5.1   If the iron laden condensate leaks out of the system enroute to the boiler it usually will form an orange stain on the floor or other equipment.  When observed this orange stain is an indication that water control practices should be reviewed.

## 3.0 WATER TREATMENT OBJECTIVES

### 3.1 External and Internal Water Treatment

3.1.1   Proper treatment of makeup and feedwater is necessary to prevent scale, other deposits and corrosion in pre-boiler, boiler, steam and condensate systems, and to provide the required steam purity.  Absence of adequate external and internal treatment can lead to operational upsets or unscheduled outages; it is also ill advised from the point of view of safety, economy, and reliability.  When given a choice the reduction or removal of objectionable constituents by pretreatment external to the boiler is always preferable to and more reliable than, management of these constituents within the boiler by internal chemical treatment.

### 3.2 Oxygen Corrosion

3.2.1   Oxygen in the presences of cool water, less than 212° F, can cause a seriously destructive activity called oxygen corrosion.  The oxygen is absorbed into water in proportion to temperature and pressure; see examples below:

70° F water at 0 psig can contain oxygen approximately equal to 8.6 ppm;
150° F water at 0 psig can contain oxygen approximately equal to 4.3 ppm; and
212° F water at 0 psig can contain oxygen approximately equal to 0.0 ppm.

3.2.2 During an internal inspection the in-service inspector should look closely for “rusty, crusty looking knobby projection” (tubercles) scattered throughout the boiler and boiler piping. These tubercles are the by-product of, and a protective housing for, oxidation corrosion. The size of the tubercle does not necessarily indicate the depth of damage; there may be a hole beneath a small tubercle and a pit beneath a larger one. If not removed, oxygen corrosion will continue until holes are formed. Even if the oxygen is removed from the wet side, once formed it will continue to eat a hole as a different activity called “concentration cell” corrosion. The only way to completely stop the corrosion at this site is to remove the tubercle and the concentration of solids under it.

3.2.3 Dissolved oxygen can be eliminated in a boiler system by utilizing a deaerator feed tank, heated feedwater or condensate tank. Introducing an oxygen scavenger into the feedwater system will also help eliminate any dissolved oxygen in the feedwater. The target for dissolved oxygen in the feedwater at the economizer inlet or, in the absence of an economizer, the boiler feedwater inlet is zero dissolved oxygen.

3.2.4 Most often oxygen corrosion is found in wet stored boilers and feed water tanks that have prolonged cool temperatures. To reduce the chance of corrosion in boilers and feedwater tanks the water should be thoroughly mixed with an adequate amount of oxygen scavenger and heated to boiling while being vented to drive off oxygen at the start of storage.

3.3 Acid Corrosion

3.3.1 Raw water, as received through the city mains or wells, contains impurities, including carbon dioxide. As condensate cools, it becomes easier for the carbon dioxide gas to dissolve in the water. Carbon dioxide combined with water can form carbonic acid with a range of pH from 6.9 down to a maximum of approximately equal to pH 4.4.

3.3.2 This acidic condition occurs in steam condensate piping systems; if the piping is carbon steel, it is likely that the pipe will be damaged. This damage can be general overall corrosion, localized pitting or cracking in stressed metal.

3.3.3 High temperatures accelerate the reaction and if uncorrected, serious pitting can result with possible rupture of boiler condensate piping or boiler tubes.

3.3.4 Rusty water in the boiler gage glass is a sure sign of acid corrosion in the boiler system or in the boiler itself.

3.3.5 Make-up water is the major source of carbon dioxide; the first priority is to control make-up water to the most practical minimum.

3.3.5.1 Logging make-up water readings can aide in determining the amount of make-up water being used. Repairing leaks on the boiler and boiler system will reduce the amount of make-up water used.

3.3.6 The second priority in reducing carbon dioxide is the utilizing mechanical methods (external pretreatment) before the water enters the boiler. Dealkalizing the make-up water will reduce solids that are one of the major sources of carbon dioxide.

3.3.6.1 External pretreatment methods include filtering, softening, and dealkalizing the water.

3.3.7 Utilization of chemical treatment is the third priority in reducing any remaining carbon dioxide that may be present.

3.3.7.1 The solids that remain after external pretreatment can be treated internally with a variety of treatment chemicals. The boiler water should be maintained at pH 11; this may require an addition of alkaline if the water is not soft. A chemical called a sludge conditioner can be added to treat the solids so that they drop out (precipitate). These treated solids then must be removed from the boiler by blowdown.

3.4 Scale Deposits

3.4.1 All raw water contains dissolved salts. Where the water is hard, these are mainly calcium and magnesium compounds. Under boiler operations these salts come out of solution and form scale deposits on the hot boiler metal. This is due to the decomposition of bicarbonates and to the decreased solubility of calcium salts at higher temperatures. As the water is evaporated, the solids are left behind and the scale deposits build up.

3.4.1 Scale forms an insulating barrier on the boiler tubes, resulting in heat losses and lower efficiency. Scale deposits can also cause overheating and failure of boiler metal.

3.4.2 Scale forms as either hard or soft scale.

3.4.2.1 Hard scale forms in steam boilers at the steam and water interface of a firetube boiler on the boiler shell and on the outside of the boiler tubes. In water tube boilers scale forms at the steam and water interface of the steam drum shell or flash chambers and on the inside of the boiler tubes. Hard scale has the appearance of a white or brown concrete and has a smooth texture.

3.4.2.2 Soft scale is usually found in hot water heating boilers and system. In has the appearance of thick, black or brown sludge and forms in the boiler tubes, on the boiler shell and throughout the heating system.

3.4.3 Scale can be removed by mechanical or chemical means. The boiler manufacturer's recommendations should be followed when removing scale from a boiler.

3.5 Solids

3.5.1 Solids cause many problems throughout the entire boiler system. External pretreatment include; filtering, softening, and dealkalizing. Those solids which remain after external pretreatment can be treated internally with a variety of treatment chemicals.

3.5.2 At least two conditions should be controlled with internal treatment. First, the boiler water should be maintained at pH 11; this may require an addition of alkali if the water is not soft. Secondly, a chemical called a sludge conditioner can be added to treat the solids so that they drop out (precipitate). Finally, these treated solids then must be removed from the boiler by blowdown.

3.5.3 Dissolved solids in the water are soluble and cannot be seen; dissolved solids are measured with a conductivity meter in micromhos/cm (µmhos/cm) or measured in Total Dissolved Solids (TDS) in ppm. The boiler manufacturer's recommendation for the specific conductance or TDS should be followed.

3.5.3.1 The following are examples of TDS in water:

Lake water has approximately 180 ppm of dissolved solids; 1,000,000 pounds of this water will contain approximately 180 pounds of solids; a 100 hp boiler vaporizing 3,450 pounds of this as make-up water would leave behind 0.62 pounds of solids.

Well water can have as high as 1,250 ppm of dissolved solids; 1,000,000 pounds of this water will have 1,250 pounds of solids; a 100 hp boiler vaporizing 3,450 pounds of this as make-up water could leave 4.3 pounds of solids behind.

3.5.4 Suspended solids are insoluble and are measured in Total Suspended Solids (TSS). Suspended solids refer to small solid particles which remain in suspension in the boiler water.

3.5.5 Blowdown and Blowoff

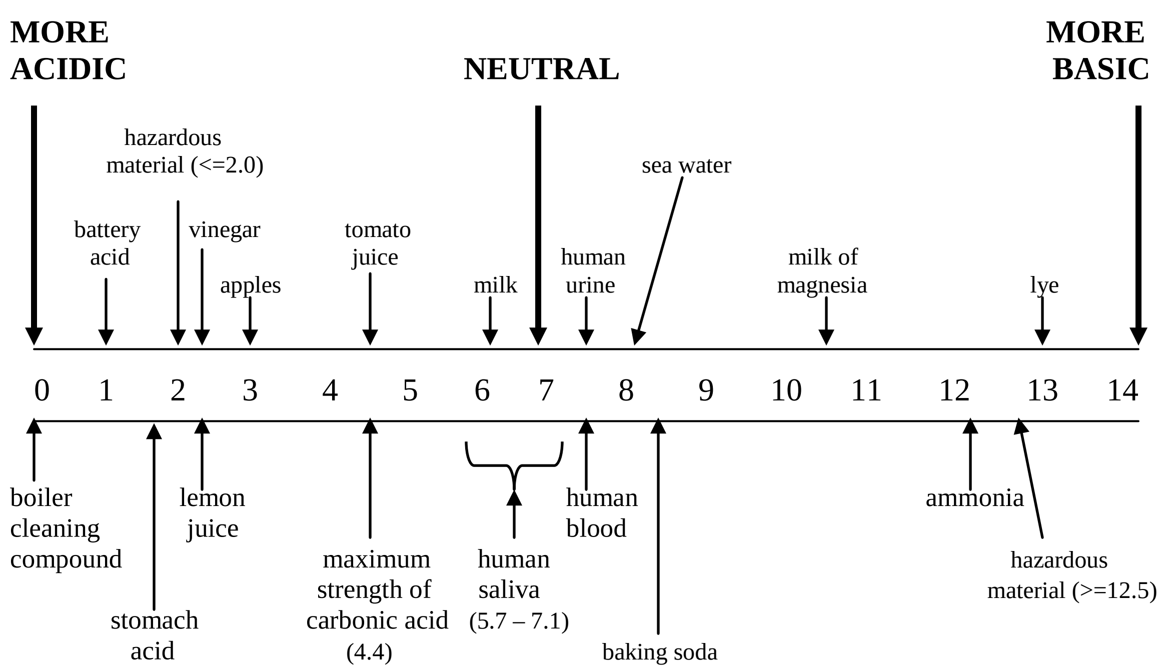
3.5.5.1 The purpose of blowdown and/or blowoff is to keep the amount of dissolve solids and sludge in the boiler water under control. As water is turned to steam, the solids remain behind and unless there is 100% condensate return, the solid content tends to build up. As a rule of thumb, about 1000 ppm can be considered a safe maximum. A hard water containing 200 ppm in the feedwater would tolerate five concentrations in the boiler (200 times 5 = 1000). On the other hand, a soft water with 25 ppm could be concentrated 40 times before reaching the critical point (40 times 25 = 1000).

3.5.5.1 Blowdown/blowoffs should be held to a minimum, since it involves heat losses and, if excessive, wastes treatment chemicals.

4.0 Boiler/Feedwater pH

pH 4.1 is an indication of the acidic or basic nature of water and other liquids. It can be indicated by taste, pH paper, or a temperature adjusted pH meter.

4.2 The following numerical scale depicts pH values of a variety of materials for comparison:



4.3 Boiler water should be maintained at pH 11, generally, the higher the pH (basic) the less soluble some solids are in the water. The lower the pH (acidic) the more soluble these solids are.

4.3.1 Hard scale is most often formed when dissolved solids are deposited directly on a heat transfer surface as water changes to steam. The preferred method of handling dissolved solids is to remove them out of the water before they adhere to the tubes. A method to do accomplish this is to raise the pH to 11 which makes the these solids less soluble.

4.3.2 As more feedwater is introduced to the pH 11 boiler water, the solids are not soluble and tend to drop out (precipitate) to form suspended solids.

4.4 Condensate should be maintained between pH 7.5 and 8.5. There is a natural tendency for condensate to be acidic (pH 6.9 – 4.4). Low pH can damage carbon steel piping systems. This low pH is caused by carbon dioxide gas (almost always present) joining the water forming carbonic acid (acid rain) as the steam condenses.

4.4.1 On-line chemical treatment should be utilized to raise the pH to between 7.5 and 8.5, in this range the carbonic acid is neutralized and damage is avoided.

## 5.0 Definitions

5.1 The following terms are common to boiler/feedwater and their treatment:

*Acid* - any chemical compound containing hydrogen that dissociates to produce hydrogen ions when dissolved in water. Capable of neutralizing hydroxides or bases to produce salts.

*Acidity* - the state of being acid; the degree of quantity of acid present.

*Alkali* - any chemical compound of a basic nature that dissociates to produce hydroxyl ions when dissolved in water. Capable of neutralizing acids to produce salts.

*Alkalinity* – the state of being alkaline; the degree or quantity of alkaline present. In water it represents the carbonates, bicarbonates, hydroxides, and occasionally the borates, silicates and phosphates as determined by titration with standard acid and generally expressed as calcium carbonate in parts per million.

*Amines* – a class of organic compounds that may be considered as derived from ammonia by replacing one or more of the hydrogen ions with organic radicals. They are basic in character and neutralize acids. Those used in water treatment are volatile and are used to maintain a suitable pH in steam and condensate lines.

*Base* – a compound that reacts with an acid to form a salt, as ammonia, calcium hydroxide, or certain nitrogen-containing organic compounds.

*Blowdown/Blowoff* – the water removed under pressure from the boiler through the drain to eliminate sediment and reduce total solids. Surface blowdowns remove solids from the boiler's surface while bottom blowoffs remove solids from the bottom of the boiler.

*Buffer* – a chemical that tends to stabilize the pH of a solution preventing any large change on the addition of moderate amounts of acid or alkalis.

*Catalyst* – a substance that by its presence accelerates a chemical reaction without itself entering into the reaction.

*Chelating* – the property of a chemical when dissolved in water that keeps the hard water salts in solution and thus prevents the formation of scale.

*Colloid* – a fine dispersion in water that does not settle out but that is not a true solution. Protective colloids have the ability of holding other finely divided particles in suspension.

*Condensate* – the water formed by the cooling and condensing of steam.

*Dispersant* – a substance added to water to prevent the precipitation and agglomeration (clustering) of solid scale; generally a protective colloid.

*Grains per gallon (gpg)* – a measure used to denote the quality of a substance present in water (1 gph = 17.1 ppm).

*Hydrazine* – a strong reducing agent used as an oxygen scavenger.

*Hydroxide* – a chemical compound containing the hydroxyl group. The hydroxides of metals are usually bases and those of nonmetals are usually acids; can be either organic or inorganic.

*Hydroxyl or Hydroxy* – a chemical prefix indicating OH group in an organic compound.

*Inhibitor* – a compound that slows down or stops an undesired chemical reaction such as corrosion or oxidation.

*Makeup* – water added from outside the boiler water system to the condensate.

*Muriatic acid* – commercial hydrochloric acid.

*Neutralize* – the counteraction of acidity with an alkali or of alkalinity with an acid to form salts.

*Orthophosphate* – a form of phosphate that that precipitates rather than sequesters (removes) hard water salts.

*Parts per million* – the most commonly used method of expressing the quantity of a substance present in water; more convenient to use than percent due to the relatively small quantities involved.

*pH* – a scale used to measure the quantity of acidity or alkalinity of a solution. The scale runs from 1 (strong acid) to 14 (strong alkali) with 7 (distilled water) as the neutral point.

*Phosphate* – a generic term for any compound containing a phosphate group.

*Polymerization* – the union of a considerable number of simple molecules, called monomers, to form a giant molecule, known as a polymer, having the same chemical composition.

*Polyphosphate* – a form of phosphate that sequesters (removes) rather than precipitates hard water salts.

*Precipitation* – the formation and settling out of solid particles in a solution.

*Sequestering* – the property of a chemical when dissolved in water that keeps the hard water salts in solution and thus prevents the formation of scale. Generally applied to inorganic compounds such as sodium tripolyphosphate or sodium hexmetaphoshate.

*Titration* – a method for determining volumetrically the concentration of a desired substance in solution and strength until the chemical reaction is completed as shown by a change in color of a suitable indicator.

*Zeolite* – originally a group of natural minerals capable of removing calcium and magnesium ions from water and replacing them with sodium. The term has been broaden to include synthetic resins that similarly soften water by ion exchange.