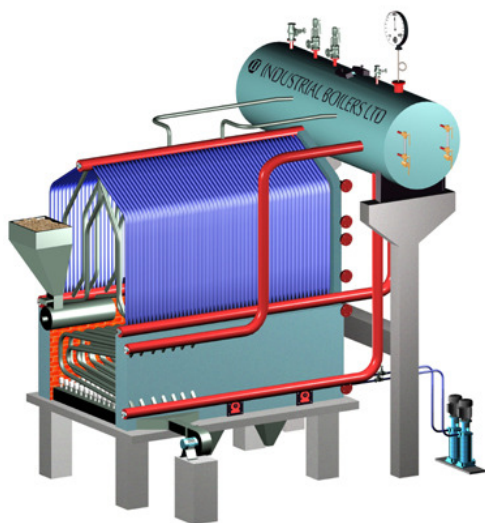




WATER TREATMENT IN BOILERS



1.0 INTRODUCTION

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For the past two decades, boiler designs have improved considerably. Modern packaged boilers have been designed to produce high purity steam with optimum capital investment. They are compact and require less manpower for their operation and maintenance. Old boilers of Lancashire type were just a pressure vessel accumulating suspended solids and they demanded very little attention for the boiler feed water treatment. No external treatment was practiced and only basic chemicals like phosphates and sulphites were periodically used for internal treatment. However, lack of good water treatment practice was evident from the amount of fouling and corrosion observed in the boiler internals. But it had no significance in those days.

Increased need for maximum operating efficiency and optimum fuel and water usage with modern boilers has given new dimensions to today's water treatment practices. The objective of this booklet is to outline the recommendations for water treatment practices to provide troublefree, efficient boiler operations with minimum risk of tube failures.

2.0. Boiler Classifications

Based on the pressure rating, boilers can be classified as high pressure, medium pressure and low pressure boilers. Generally, boilers operating above 22 Kg/cm^2 are considered as high pressure boilers. Those operating below 10 kg/cm^2 are considered as low pressure boilers. Medium pressure boilers are those operating between these values.



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3.0 Factors Influencing the Selection of Water Treatment Programme

- a) **Boiler pressure** : In general, the water quality requirements become increasingly stringent as the boiler pressure increases.
- b) **Furnace Tube Geometry** : Boilers having straight tubes can tolerate relatively more dissolved solids compared to bent tube boilers.
- c) **Super Heater** : Boilers operating with super heaters can tolerate lesser dissolved solids as compared to boilers operating without the same.
- d) **Steam Disengaging Area In the Drum** : A smaller steam disengaging area in the drum in relation to evaporation rate (as in modern package boilers) further dictates feed water quality to prevent priming and carryover in boilers.
- e) **Economiser** : A Boiler having an economiser needs special consideration with regard to carbonate hardness and dissolved oxygen in the water as compared to a boiler operating at the same pressure, but without economiser. Economiser in a boiler is most vulnerable to scale and corrosion.
- f) **Heat Flux** : The tolerance limit for dissolved solids is lower for having high heat flux compared to a boiler operating at the same pressure, but with lower heat flux.
- g) **Recovery of condensate** : When the percentage recovery of condensate is high (like as that) in a power plant, higher concentration of dissolved solids can be tolerated in make up water due to the very high dilution effect compared to industrial boilers having very low or sometimes almost no condensate recovery.
- h) **End Use of steam** : End use of steam is one important parameter in selecting water treatment programme. Some of the end uses dictating the water quality are :
 - i) Steam used for driving turbines.
 - ii) Steam used for direct heating in the process.

4.0 Boiler Conditioning Methods

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External Treatment (Pre-treatment) :

Treatment used for the removal or reduction of calcium, magnesium, silica and other impurities (with the use of plant treatment) before water reaches the boiler.

Internal Treatment (Post treatment) :

Treatment by which water treatment chemicals are added in the boiler feed water to prevent scaling, corrosion, priming and foaming in the boiler.

For modern boilers for their trouble free operation, a combination of both internal and external treatments have to be practised.

4.1 Objectives of External Treatment (Pretreatment) :

- a) Removal or reduction of some undesirable characteristics and addition of desirable characteristics to the water for end use.
- b) To prevent scale and deposit formation, corrosion and other water related problems.
- c) To make water some suitable and less troublesome for a proposed application before it is delivered to the point of use.

For a boiler cycle it is best to use pre-treatment procedures which reduce or remove calcium and magnesium salts from make up water. The extent to which this must be accomplished is related to boiler operating pressure and design. Most satisfactory operating conditions can be maintained regardless of boiler pressure when the pretreatment process employed reduces calcium and magnesium salts to the greatest extent. The presence of dissolved oxygen mainly accounts for boiler corrosion. Thus, pretreatment in a boiler cycle should include efficient deaeration.

Corrosion problems in steam condensate lines can be attributed to dissolved oxygen and carbon dioxide in condensate. The chief sources of carbon dioxide in steam is carbonate content of the make up water supply. Therefore, external treatment process which removes or reduces bicarbonate content of the make up water is beneficial in minimizing return line system corrosion problems.

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4.2. Clarification

Generally the first step in water processing involves coagulation and removal of suspended solids. Natural settling will remove only relatively coarse suspended solids. This process is generally speeded up by coagulation. Coagulation is the process by which finely divided materials combined by chemical means to produce larger particles capable of rapid settling. Typical coagulant chemicals used are alum and ferrous sulphate. The preliminary treatment sometimes includes aeration and chlorination. Aeration is used for removal of undesirable gases and volatile impurities (e.g. hydrogen sulphide, carbon dioxide, volatile organics) and iron and manganese if present are oxidised and precipitated for subsequent removal by coagulation and filtration.

Chlorine is used to remove organics matter.

4.3. Filtration

Following coagulation, settling and chlorination, the water is passed through filter. Filtration removes the finely divided suspended particles not removed in the settling tank. Activated carbon filters are employed when there is a need for removal of final traces of organics and excess chlorine.

4.4 Precipitation Softening Process

LIME SODA SOFTENING

Lime softening does not remove non-carbonate hardness. Soda ash is supplemented with the lime for the removal of non-carbonate hardness from water.

LIMITATIONS OF COLD LIME, LIME SODA PROCESS

- a) Reaction is slow.
- b) Both calcium carbonate and magnesium hydroxide are slightly soluble in reduced to value below 25 ppm.
- c) Sometimes after precipitation of calcium carbonate poses severe scaling problem in the pipelines.

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4.5 Ion Exchange Process

It involves removal of impurities by chemical reaction with lime with the following effects. Elaborate blending control is needed to adjust alkalinity and hardness in the treated water. Common salt and acid are used for regeneration of sodium and hydrogen cation units respectively.

This is the simplest ion exchange process wherein calcium and magnesium in the water are removed and replaced by sodium. Nothing else is changed so that the solids remain the same when the resin is exhausted it can be regenerated with the saturation solution of sodium chloride. Calcium and magnesium are discharged to waste.

DEALKALISATION

Dealkalisation uses a weak acid resin in hydrogen form. It is capable of exchanging alkaline hardness into the corresponding acid (carbonic acid). But it leaves the non-alkaline hardness practically undisturbed. The carbonic acid produced is blown out in a degassing tower and the water is then adjusted for alkalinity with a little caustic soda. In this process the total solids are thus reduced by the amount of alkaline hardness. The regeneration of the unit is carried out by sulfuric acid or hydrochloric acid.

SPLIT STEAM DEALKALISATION

In this process, we have a parallel arrangement of ion exchange resin in sodium and hydrogen form through which the water flows and combines again after treatment. The treatment water is practically soft and low in alkalinity.

DEMINERALISATION

This process uses two types of resins either in separate units or as mixture in a single unit. One resin removes all metal ions (calcium, magnesium and sodium etc.) and the other removes all the acid ions (sulphate, chloride, bicarbonate, silica etc.). The result is a water virtually free of dissolved solids.

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4.6 Other Treatment Processes

EVAPORATION

Where water available is very high in dissolved impurities such as brackish estuaries or sea water, the chemical pretreatment becomes uneconomical. In this case, evaporation is often employed. The distilled water is produced virtually free of all impurities.

REVERSE OSMOSIS

This is a more recent method which in effect means pumping the water at high pressure through a special membrane which allows only the water through trapping the dissolved solids. This process is very efficient and can also be used as treatment preceding ion exchange demineralisation. When used ahead of the demineraliser, the regeneration cost is substantially reduced and the resin life is extended.

DEAERATION

Dissolved oxygen in water produces corrosion and pitting in the boiler system. Oxygen removal is accomplished in deaerators which are of two types viz, pressure deaerators and vacuum deaerators.

Pressure deaerators break up water into spray or film then sweep the steam across and through it to force out the dissolved gases. In this process, oxygen content can be reduced to a level of 0.007 ppm. close to the limit of chemical detectability.

Vacuum deaerators use mechanical pumps to create required vacuum. The degree of vacuum depends on the water temperature. The oxygen residual from these deaerators is usually of the order of 0.2 ppm.

5.0 Internal Treatment (Post Treatment)

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5.1 Objectives of Internal Treatment

To chemically adjust or balance water inside the boiler to prevent scale formation, inhibit corrosion, steam contamination and embrittlement.

Even with sophisticated external treatment plants. Some impurities always enter the boiler either through feed or condensate. Therefore, there is a need for the internal treatment in some form to practically all boilers. The amount and type of chemicals used depends on plant operating conditions and the feed water analysis.

5.2 Conventional Treatment

Conventional treatment involved use of soda ash (carbonate cycle) or alkaline phosphate (phosphate cycle) to precipitate the calcium and magnesium and products such as tannin and lignin were used for the sludge conditioning. These treatment have enjoyed a relatively successful performance history in preventing boiler scale, resulting from free water hardness. But the trend towards higher heat transfer rates and smaller diameter tubes has led to very low tolerance for the sludge in today's boilers since the chance for its adherence to heat transfer surfaces has increased. Furthermore, calcium hydroxyapatite formed in the PO₄ cycle is susceptible to binding by oil. The increased amount of iron, copper and other metals currently found in the feed water also demand suitable conditioning. Presence of iron and high phosphate level can lead to possible formation of iron phosphate which causes sludge to agglomerate and adhere to the tube surfaces. Even a well controlled phosphate programme cannot prevent the formation of iron hydroxide deposit. An excessive phosphate deposits. Systems with low silica, low alkalinity and high magnesium to calcium ratio are particularly susceptible to magnesium phosphate related deposit problems.

5.3 Polymeric Conditioners

Search for improved water treatment programme resulted in the development of entirely new type of chemical supplements and sludge conditioners. These chemicals are polymeric in nature and their effectiveness is influenced by the properties like charge type, molecular weight and functionality. They also operate by non-stoichiometric antiscaling mechanism. These sludge conditioners

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supplement the phosphate and carbonate cycle treatment and keep the sludge fluid for easy removal through blow down. Some of the sludge conditioners effectively disperse heavy metals and their oxides together with residual hardness salts and provide clean heat transfer surfaces. The dispersants in the sludge conditioners like DEWTREAT-100/101/102/103/104 have been selected because they interact with iron oxide preventing it from accumulating as deposits, transport it through the boiler water permit its removal through normal blow down procedures.

Deposit prevention by nonstoichiometric antiscalants is improved in the modern treatment with the use of organics and instant oxygen scavengers. The incorporation of an effective sludge conditioner in the treatment programme conditions the nonionic contaminants such as silica and oil. Silica particles are physically coated by organics, preventing their agglomeration or adherence to boiler metal. Oil acts as a binder to suspended boiler solids and is a cause of carryover. Oil is absorbed in the boiler water and remains dispersed through the special sludge conditioners like DEWTREAT-100 range. The need for oil absorption sing an efficient product like DEWTREAT-100 range has become very important with increased recoveries in return condensate.

6.0 Corrosion

Corrosion can take place in the pre-boiler system (feed water heaters and piping), the boiler (boiler drums and tubes) and the post boiler system (steam-condensate equipment and piping).

The presence of oxygen in the boiler system may be due to

- a) Incomplete removal of oxygen from the feed water.
- b) Air leakage into the system.

Oxygen acts by accelerating the reaction of iron and water. It can react with iron hydroxide to form a hydrated ferric oxide or hematite. This action is generally localised and forms a pit in the metal. When the pit becomes progressively anodic, severe corrosion results. At the cathodic surface oxygen reacts with hydrogen and depolarises the surface permitting more iron to dissolve at the anode creating a pit.

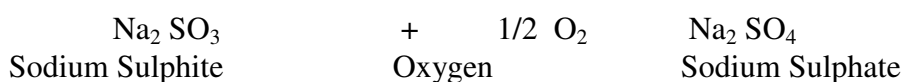
6.1 Instant Oxygen Scavengers

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Instant oxygen scavenger like DEWTREAT-200 range incorporate catalyst to enhance the reaction rate of sodium sulphite with oxygen. Comparative reaction rates are given in figure. For low pressure boilers, correct dosing of DEWTREAT-200 will effectively control oxygen Induced corrosion in both pre-boiler and the boiler section. But no protection is provided to the post boiler section since the product is non-volatile. An excess of 20 ppm to 40 ppm sodium sulphite is generally maintained in the boiler water while the boiler is in service. This excess will provide sufficient reserve of sulphite to take care of any fluctuations in the boiler feed water. Sodium sulphite reacts with oxygen to produce sodium sulfate which contributes to dissolved solids in boiler water.



6.2 Instant Volatile Oxygen Scavenger

Unlike sodium sulphite, oxygen-hydrazine reaction products do not induce mineral solids in the boiler water making it ideally suited for high pressure boilers. Hydrazine will react with dissolved oxygen to form nitrogen and water.



But this hydrazine reaction with oxygen is very sluggish. DEWTREAT-201 are instant volatile oxygen scavengers developed to speed up this reaction. The benefits of . DEWTREAT-201 accelerating the otherwise sluggish reaction of feed water oxygen removal. This reaction minimises preboiler corrosion products. DEWTREAT-201 volatilises from boiler at temperature about 110 degrees C and moves with steam into the post boiler section from oxygen corrosion.



Hydrazine reacts with iron oxide to form passive magnetite and reduces cupric oxide to passive cuprous oxide. Magnetite acts as barrier against further corrosion and metal pick up by the condensate is generally reduced. Demonstrates ability of catalysed hydrazine to reduce ferric to ferrous iron. In order to be effective the dosage of oxygen scavenger in the feed water must be such that it results in the recommended reserve of the chemical in the boiler water. This reserve of

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chemical provides safety against any accidental oxygen ingress into the boilers.

6.3 Neutralising Amines

Carbonic acid in the condensate causes corrosion in the past boiler section. For neutralising carbon dioxide in the condensate addition of alkaline salts such as caustic soda in the feed water does not help since the salt does not volatalise and go into steam phase.

For this purpose organic chemicals known as neutralising amines which can volatalise and go into the steam phase and can react with carbondioxide instantly when the condensate is formed are used.

Distribution Coefficient

Distribution Coefficient is the ratio of amine in the steam phase to that in the condensate. An amine having a distribution coefficient of less than 1 can protect only the nearest hot section, while one having distribution coefficient of greater than 1, can protect only farthest cold section in the condensate system. In order to offer the maximum protection to all parts of condensate system, it is essential to use products that have a broad spectrum distribution coefficient.

6.5 Filming Amines

Filming amines offer protection against both oxygen and carbon dioxide by forming a thin, protective water repellant on the metal surfaces in the condensate system.

6.6 Blends of Neutralising and Filming Amines

For large systems, it is economical to use a blend of neutralising and filming amines These products which are easy to handle liquids, offer excellent protection to the whole condensate system.

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7.0 Other Problems in the Boiler

7.1 Priming and Foaming

Either of these may contribute to carryover of boiler water into the system. This reduces efficiency, as water contains only sensible heat and will reduce the heat content of the system. Damage to the post boiler equipment, particularly turbines and damage to process may also result.

Priming is the ejection of boiler water into the steam take off and in general results from factors associated with boiler operation. There are several possible causes.

1. Operating the boiler water level too high.
2. Operating the boiler at below its design pressure.
3. Demanding more steam than the boiler is capable of supplying either momentarily or continuously.

Foaming is due to the chemical composition of the water. Pure water does not foam and in a boiler steam bubbles are large, rising quickly to the surface, and bursting quickly. In the presence of certain dissolved or suspended substances, the surface is altered and the steam bubbles remain small. Therefore, they do not rise quickly and in effect expand the water foam over into the steam off take. Common cases are :

- a) High suspended solids in the boiler water.
- b) High alkalinity in the boiler water.
- c) High dissolved solids in the boiler water.
- d) Contamination of the boiler water by a substance which can cause foam (detergent or saponifiable oil for example).

All the mechanical factors can be overcome by modifying the operating conditions. The degree to which each aspect of the water characteristics contribute to foaming is not fully known, but in general (contamination oart),

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suspended solids have more effect than alkalinity or dissolved solids. Onset of foaming will depend upon the boiler design and operation. Where a water is potentially foaming than any alteration in operation, such as sudden steam demand could aggravate the situation and so carryover is often unpredictable.

All these water conditions can be adjusted by blowdown or varying the addition of water treatment chemicals and it is usual to limit the dissolved solids in the boiler to a point where it is known that carryover will not occur. The maximum limit is stipulated by the boiler manufacturer but not be too low, as blow down represents loss of heat and chemicals.

7.1 Antifoams

The addition of certain organic compounds known as antifoams in very small amounts (0.1 - 0.5 in the water) affect the surface condition of the steam bubbles and causes them to coalesce again. By using these compounds, foaming can be prevented under conditions where it would usually occur and dissolved solids can be kept at the normal level without problems. Where the feed water characteristics are such that excessive blow down would be needed, the use of an antifoam will enable blow down to be greatly reduced.

7.2 Silica Carryover

At high temperature silica is volatile and will enter the steam in the vapour phase, forming deposits on turbine blades as it cools. This phenomenon commences at about 40 Kg/Sq.cm. g and becomes increasingly serious as the pressure increases. If the silica content of the steam is kept below 0.02 ppm, there is usually no problem and this is assured by limiting the boiler water silica content, the value depending on the pressure and alkalinity.

Upto 40 kg/Sq.cm.g., silica can usually be controlled by maintaining the level at not more than half the hydroxide alkalinity. Above this pressure, the silica content of the boiler water must be kept well under control ensuring that the feed water is pretreated, demineralisation being the usual way.

8.0 Water Quality Guidelines for Industrial Boilers

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Below table give the feed water and boiler water quality guidelines for industrial boilers. The practical limits above or below the tabulated values can be established in each case by careful purity which will be clearly achievable if other tabulated water quality values are maintained.:

1. External treatment in some form or other is essential to maintain boiler and feed water as per guidelines given.
2. Industrial water tube boiler and industrial fire tube boiler tolerate higher degree of total dissolved solids and hence base exchange softening will be adequate for this type of boilers. For industrial fire tube boilers, the treatment could be further relaxed to cold lime soda process since these boilers can tolerate higher suspended solids level.
3. Combination treatment depending on economics can be employed for other types of boilers.
 - a) Combination of cold lime soda with base exchange process will be ideal for the water tube boilers operating at 0 to 300 psig which can tolerate higher silica in the boiler water while hotlime soda followed by base exchange will be needed for the boilers operating at higher pressure for the same duty.
 - b) When alkalinity becomes the controlling parameter as dictated by the end use, dealkalisation base exchange combination can be economically employed.

9.0 Conclusion

Scaling and corrosion in boiler internal heat transfer surfaces are the major problems faced by the industry. With the result, conventional treatment accepted for boiler feed a decade ago can no more be applied for the modern boilers. Water is the blood line in every boiler. Water treatment specialists are the best doctors who can help in providing sound health to the boilers. Even those boilers operating trouble free and smoothly need annual check up by the water doctors. This will prevent boiler tube failures and sudden break-downs.

Needless to say long term troublefree operation demand, periodic control test on feed water, boiler water, steam and condensate return. Therefore, every effort should be made to scrutinise claims for cure all treatment and miraculous gadget before deciding on a treatment or making a change in the existing treatment.

ASME Table 1: Suggested Water Chemistry Limits

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Boiler type: Industrial watertube, high duty, primary fuel fired, drum type

Makeup water percentage: Up to 100% of feedwater

Conditions: Includes superheater, turbine drives, or process restriction on steam purity

Steam: superheated and/or turbine

Saturated steam purity target: See tabulated values below

Drum Operating Pressure (1) (11)	psig (MPa)	0-300 (0-2.07)	301-450 (2.08- 3.10)	541-600 (3.11- 4.14)	601-750 (4.15- 5.17)	751-900 (5.18- 6.21)	901-1000 (6.22- 6.89)	1001-1500 (6.90- 10.34)	1501-2000 (10.35- 13.79)
Feedwater (7)									
Dissolved oxygen ppm (mg/l) O ₂ measured before chemical oxygen scavenger addition (8)		<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007	<0.007
Total iron ppm (mg/l) Fe		≤0.1	≤0.05	≤0.03	≤0.025	≤0.02	≤0.02	≤0.01	≤0.01
Total copper ppm (mg/l) Cu		≤0.05	≤0.025	≤0.02	≤0.02	≤0.015	≤0.01	≤0.01	≤0.01
Total hardness ppm (mg/l) CaCO ₃		≤0.3	≤0.3	≤0.2	≤0.2	≤0.1	≤0.05	ND	ND
pH range @ 25°C		8.3-10	8.3-10	8.3-10	8.3-10	8.3-10	8.8-9.6	8.8-9.6	8.8-9.6
Chemicals for preboiler system protection		NS	NS	NS	NS	NS	VAM	VAM	VAM
Nonvolatile TOC ppm (mg/l) C (6)		<1	<1	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2
Oily matter ppm (mg/l)		<1	<1	<0.5	<0.5	<0.5	<0.2	<0.2	<0.2
Boiler Water									
Silica ppm (mg/l) SiO ₂		≤150	≤90	≤40	≤30	≤20	≤8	≤2	≤1
Total alkalinity ppm (mg/l) CaCO ₃		<700 (3)	<600 (3)	<500 (3)	<200 (3)	<150 (3)	<100 (3)	NS (4)	NS (4)
Free hydroxide ppm (mg/l) CaCO ₃ (2)		NS	NS	NS	NS	NS	NS	ND (4)	ND (4)
Unneutralized conductivity μmhos/cm (μS/cm) 25°C (12)		5400- 1100 (5)	4600- 900 (5)	3800- 800 (5)	1500- 300 (5)	1200- 200 (5)	1000- 200 (5)	≤150	≤80
Total Dissolved Solids in Steam (9)									
TDS (maximum) ppm (mg/l)		1.0-0.2	1.0-0.2	1.0-0.2	0.5-0.1	0.5-0.1	0.5-0.1	0.1	0.1

NS = Not specified

ND = Not detectable

VAM = Use only volatile alkaline materials upstream of attemperation water source (10)

NOTES TO TABLE

(1) With local heat fluxes $>1.5 \times 10^5$ Btu/hr/ft² (>473.2 kW/m²), use values for at least the next higher pressure range.

(2) Minimum hydroxide alkalinity concentrations in boilers below 900 psig (6.21 MPa) must be individually specified by a qualified water treatment consultant with regard to silica solubility and other components of internal treatment.

(3) Maximum total alkalinity consistent with acceptable steam purity. If necessary, should override conductance as blow-down control parameter. If makeup is demineralized quality water and boiler operates at less than 1000 psig (6.89

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MPa) drum pressure, the boiler water conductance should be that in table for 1001-1500 psig (6.9-10.34 MPa) range. In this case, the necessary continuous blowdown will usually keep these parameters below the tabulated maximum values. Alkalinity values in excess of 10% of specific conductance values may cause foaming.

(4) Not detectable in these cases refers to free sodium or potassium hydroxide alkalinity. Some small variable amount of total alkalinity will be present and measurable with the assumed congruent or co-ordinated phosphate-pH control or volatile treatment employed at these high pressure ranges.

(5) Maximum values are often not achievable without exceeding maximum total alkalinity values, especially in boilers below 900 psig (6.21 MPa) with >20% makeup of water whose total alkalinity is >20% of TDS naturally or after pre-treatment by lime-soda, or sodium cycle ion exchange softening. Actual permissible conductance values to achieve any desired steam purity must be established for each case by careful steam purity measurements. Relationship between conductance and steam purity is affected by too many variables to allow its reduction to a simple list of tabulated values.

(6) Nonvolatile TOC is that organic carbon not intentionally added as part of the water treatment regime.

(7) Boilers below 900 psig (6.21 MPa) with large furnaces, large steam release space, and internal chelant, polymer, and/or antifoam treatment can sometimes tolerate higher levels of feedwater impurities than those in the table and still achieve adequate deposition control and steam purity. Removal of these impurities by external pretreatment is always a more positive solution. Alternatives must be evaluated as to practicality and economics in each individual case.

(8) Values in the table assume existence of a deaerator.

(9) Achievable steam purity depends on many variables, including boiler water total alkalinity and specific conductance as well as design of boiler steam drum internals and operating conditions [(Note (5))]. Since boilers in this category require a relatively high degree of steam purity for protection of the superheaters and turbines, more stringent steam purity requirements such as process steam restrictions on individual chemical species or restrictions more stringent than 0.1 ppm (mg/l) TDS turbine steam purity must be addressed specifically.

(10) As a general rule, the requirements for attemperation spray water quality are the same as those for steam purity. In some cases boiler feedwater is suitable; however, frequently additional purification is required. In all cases the spray water should be obtained from a source that is free of deposit forming and corrosive chemicals such as sodium hydroxide, sodium sulfite, sodium phosphate, iron, and copper. The suggested limits for spray water quality are <30 ppb ($\mu\text{g/l}$) TDS maximum, <10 ppb ($\mu\text{g/l}$) Na maximum, <20 ppb ($\mu\text{g/l}$) SiO_2 maximum, and it should be essentially oxygen free.

(11) Low pressure boilers frequently use feedwater that is suitable for use in higher pressure boilers. In these cases the boiler water chemistry limits should be based on the pressure range that is most consistent with the feedwater quality.

(12) Conversion from ppm (mg/l) TDS values in the ABMA standards [12] used a factor of 0.65.

Refer to ASME Document "Consensus on Operating Practices for the Control of Feedwater and Boiler Water Chemistry in Modern Industrial Boilers" for other boiler types and conditions.